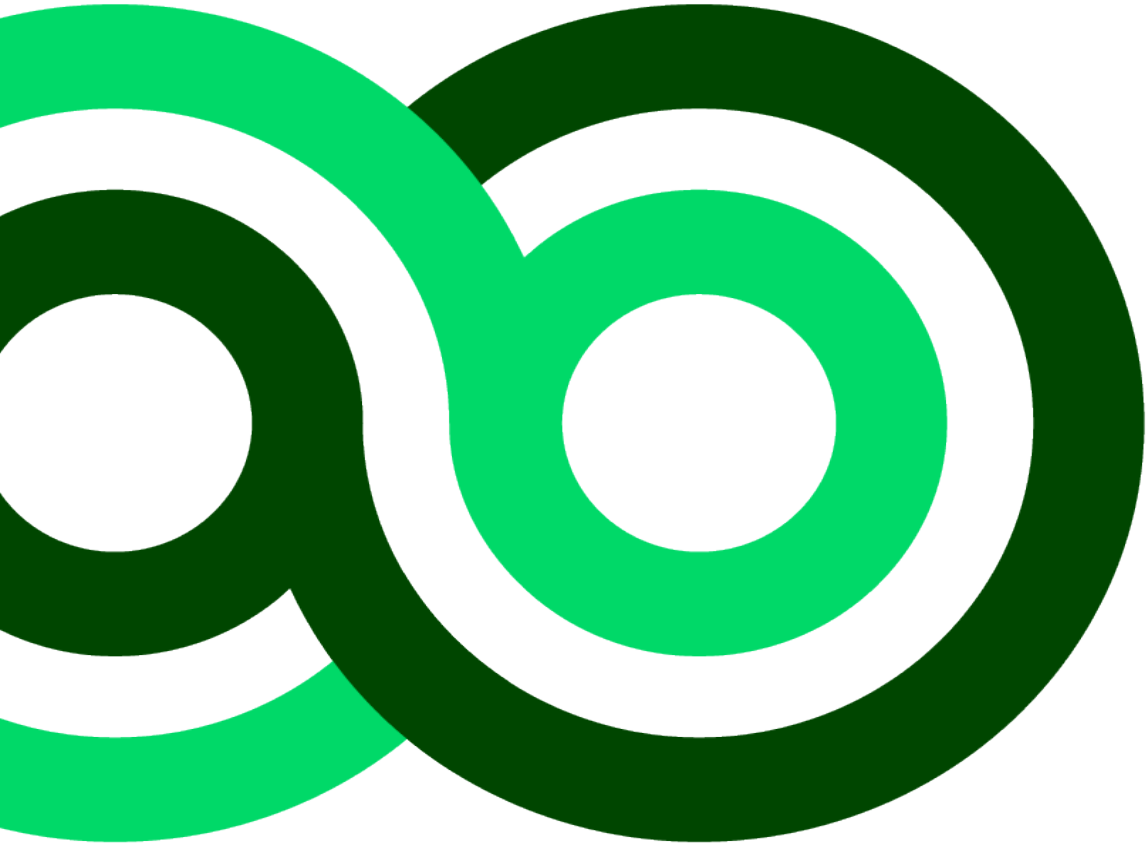
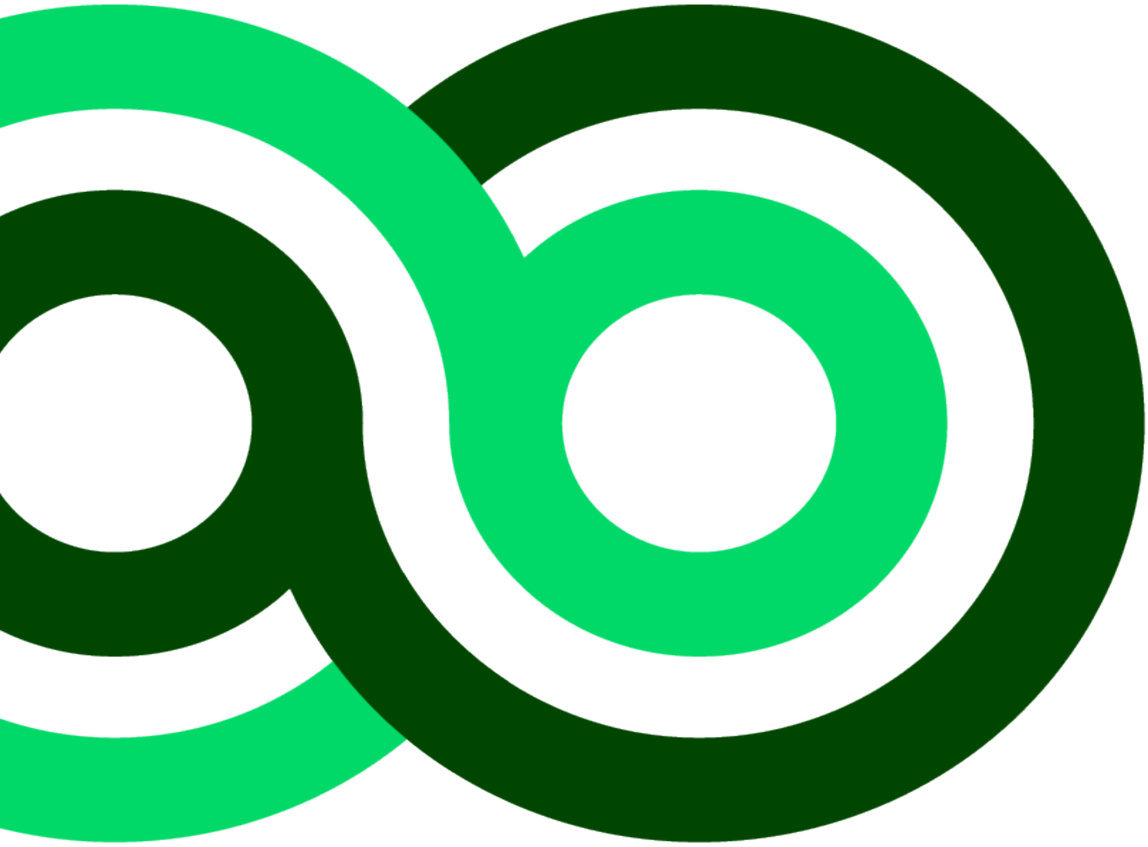


TEST PROCEDURE

WLTC+

(World - harmonised Light-duty vehicle Test Cycle custom tailored for Green NCAP)

Version 2.0.0 February 2021



Version 2.0.0 February 2021

ANNEX XXI

TYPE 1 EMISSIONS TEST PROCEDURES

1. Introduction

This Annex describes the procedure for determining the levels of emissions of gaseous compounds, particulate matter, particle number, CO_2 emissions, fuel consumption, electric energy consumption and electric range from light-duty vehicles.

2. [Reserved]

3. Definitions

See separate file GNT_Definitions_Accronyms_Symbols.xlsx.

4. Abbreviations

See separate file GNT_Definitions_Accronyms_Symbols.xlsx.

5. General requirements

5.0. [Reserved]

5.1. The vehicle and its components liable to affect the emissions of gaseous compounds, particulate matter and particle number shall be so designed, constructed and assembled as to enable the vehicle in normal use and under normal conditions of use such as humidity, rain, snow, heat, cold, sand, dirt, vibrations, wear, etc. to comply with the provisions of this Annex during its useful life. This shall include the security of all hoses, joints and connections used within the emission control systems.

5.2. The test vehicle shall be representative in terms of its emissions-related components and functionality of the intended production series to be covered by the approval. The laboratory and GNT shall agree which vehicle test model is representative.

5.3. Vehicle testing condition

5.3.1. The types and amounts of lubricants and coolant for emissions testing shall be on maximum level and of manufacturer approved quality. This includes all fluids in the car (engine oil, gearbox oil, suspension fluids, brake fluid, windscreen wiper fluids (front and rear), refrigerant, coolant, AdBlue and the fuel tank).

5.3.2. The type of fuel for emissions testing shall be as specified in Annex IX.

5.3.3. All emissions controlling systems shall be in working order.

5.3.4. The use of any defeat device is prohibited, according to the provisions of Article 5(2) of Regulation No 715/2007.

5.3.5. The engine shall be designed to avoid crankcase emissions.

5.3.6. The tyres used for emissions testing shall be as defined in paragraph 2.4.5. of Sub-Annex 6 to this Annex.

5.4. Petrol tank inlet orifices

5.4.1. Subject to paragraph 5.4.2., the inlet orifice of the petrol or ethanol tank shall be so designed as to prevent the tank from being filled from a fuel pump delivery nozzle that has an external diameter of 23.6 mm or greater.

5.4.2. Paragraph 5.4.1. shall not apply to a vehicle in respect of which both of the following conditions are satisfied:

(a) The vehicle is so designed and constructed that no device designed to control the emissions shall be adversely affected by leaded petrol; and

(b) The vehicle is conspicuously, legibly and indelibly marked with the symbol for unleaded petrol, specified in ISO 2575:2010 "Road vehicles -- Symbols for controls, indicators and tell-tales", in a position immediately visible to a person filling the petrol tank. Additional markings are permitted.

5.5. Provisions for electronic system security

The provisions for electronic system security shall be those specified in paragraph 2.3. of Annex I.

5.6. Interpolation family

5.6.1. [Reserved]

5.6.2. [Reserved]

5.6.3. [Reserved]

5.7 [Reserved]

5.8. [Reserved]

5.9. [Reserved]

6. Performance requirements

6.1. Limit values

Limit values for emissions shall be those specified in Table 2 of Annex I of Regulation (EC) No 715/2007.

6.2. Testing

Testing shall be performed according to:

(a) The WLTC Class 3b as described in Sub-Annex 1;

(b) The gear selection and shift point determination as described in Sub-Annex 2;

(c) The appropriate reference fuel as described in Annex IX of Regulation 2017/1151;

(d) The road load and dynamometer settings as described in Sub-Annex 4;

(e) The test equipment as described in Sub-Annex 5;

(f) The test procedures as described in Sub-Annexes 6 and 8;

(g) The methods of calculation as described in Sub-Annexes 7 and 8.

Sub-Annex 1

Worldwide light-duty test cycles (WLTC)

1. General requirements

The cycle to be driven is the WLTC 3b cycle.

2. Vehicle classifications

2.1. [Reserved]

2.2. [Reserved]

2.3. All vehicles tested by Green NCAP will be seen as Class 3 vehicles.

2.3.1. [Reserved]

2.3.1.1. [Reserved]

2.3.1.2. Class 3b vehicles with $v_{max} \geq 120$ km/h.

2.3.2. All vehicles tested in accordance with Sub-Annex 8 shall be considered to be Class 3 vehicles.

3. Test cycles

3.1. [Reserved]

3.1.1. [Reserved]

3.1.2. [Reserved]

3.1.3. [Reserved]

3.2. [Reserved]

3.2.1. [Reserved]

3.2.2. [Reserved]

3.2.3. [Reserved]

3.2.4. [Reserved]

3.2.5. [Reserved]

3.3. Class 3 cycle

3.3.1. [Reserved]

3.3.1.1. [Reserved]

3.3.1.2. [Reserved]

3.3.1.3. [Reserved]

3.3.1.4. [Reserved]

3.3.1.5. [Reserved]

3.3.2. Class 3b cycle

3.3.2.1. A complete cycle shall consist of a low phase (Low_3) phase, a medium phase ($Medium_{3b}$), a high phase ($High_{3b}$) and an extra high phase (Extra $High_3$).

3.3.2.2. The Low_3 phase is described in Figure A1/7 and Table A1/7.

3.3.2.3. The $Medium_{3b}$ phase is described in Figure A1/9 and Table A1/9.

3.3.2.4. The $High_{3b}$ phase is described in Figure A1/11 and Table A1/11.

3.3.2.5. The Extra $High_3$ phase is described in Figure A1/12 and Table A1/12.

3.4. Duration of all phases

3.4.1. All low speed phases last 589 seconds.

3.4.2. All medium speed phases last 433 seconds.

3.4.3. All high speed phases last 455 seconds.

3.4.4. All extra high speed phases last 323 seconds.

3.5. WLTC city cycles

OVC-HEVs and PEVs shall be tested using the appropriate Class 3b WLTC and WLTC city cycles (see Sub-Annex 8).

The WLTC city cycle consists of the low and medium speed phases only.

4. [Reserved]

5. [Reserved]

6. WLTC Class 3 cycle

Figure A1/7

WLTC, Class 3 cycle, phase Low$_3$

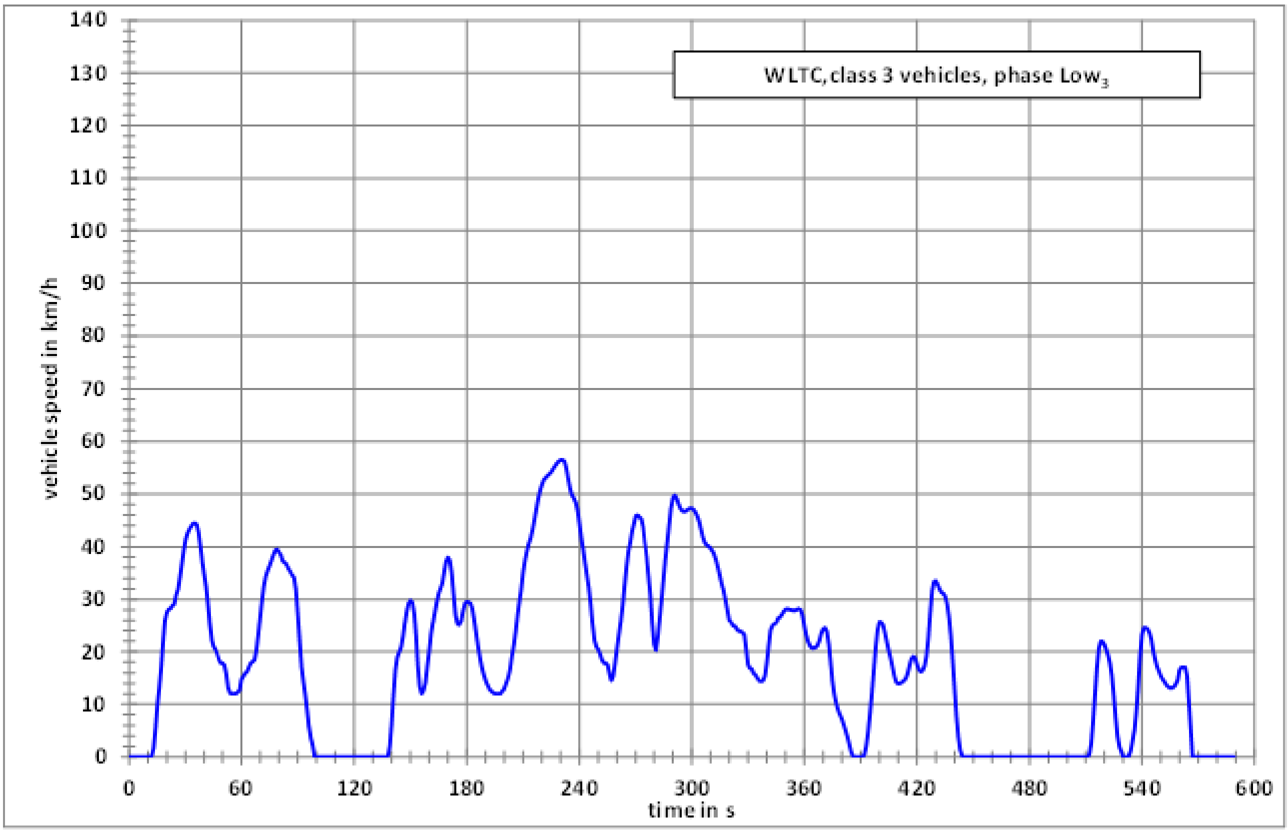


Figure A1/8

[Reserved]

Figure A1/9

WLTC, Class 3b cycle, phase Medium$_{3b}$

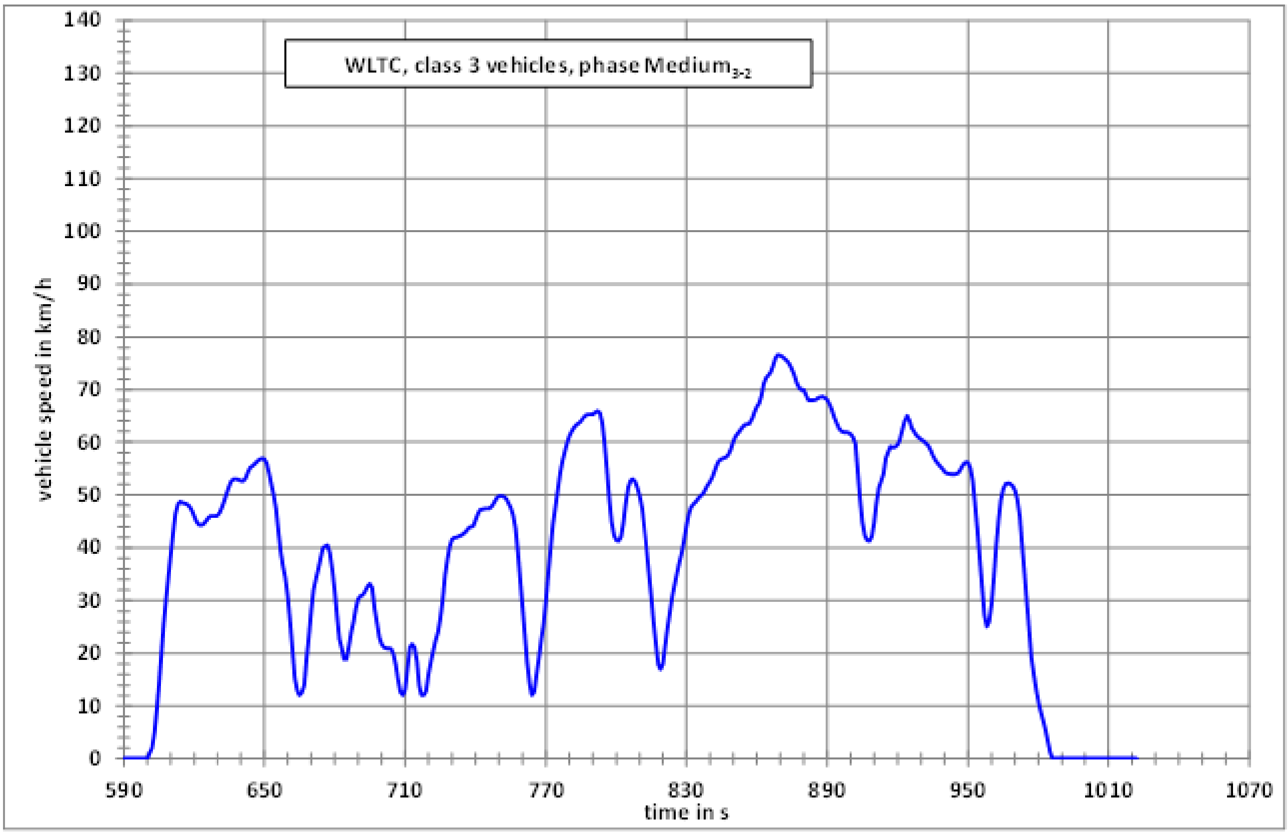


Figure A1/10

[Reserved]

Figure A1/11

WLTC, Class 3b cycle, phase $High_{3b}$

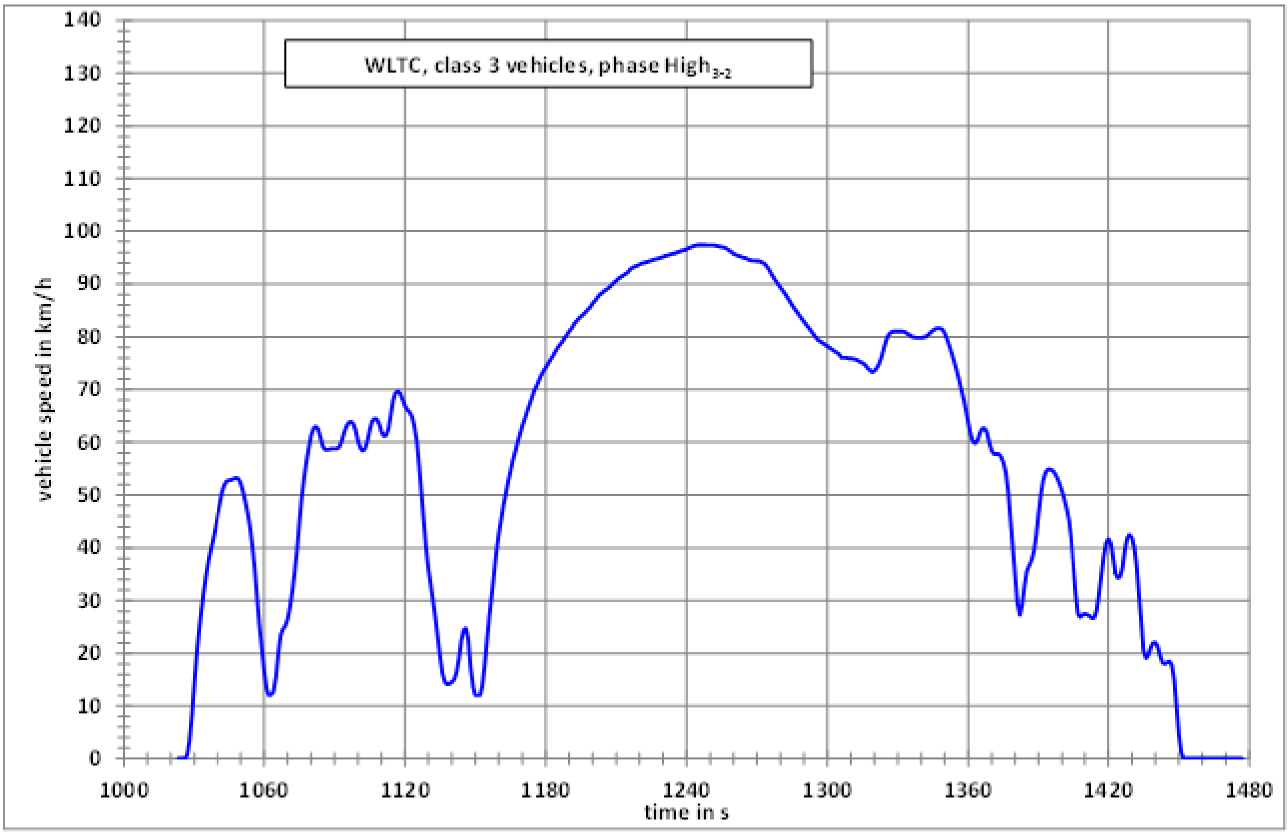


Figure A1/12

WLTC, Class 3 cycle, phase Extra High$_3$

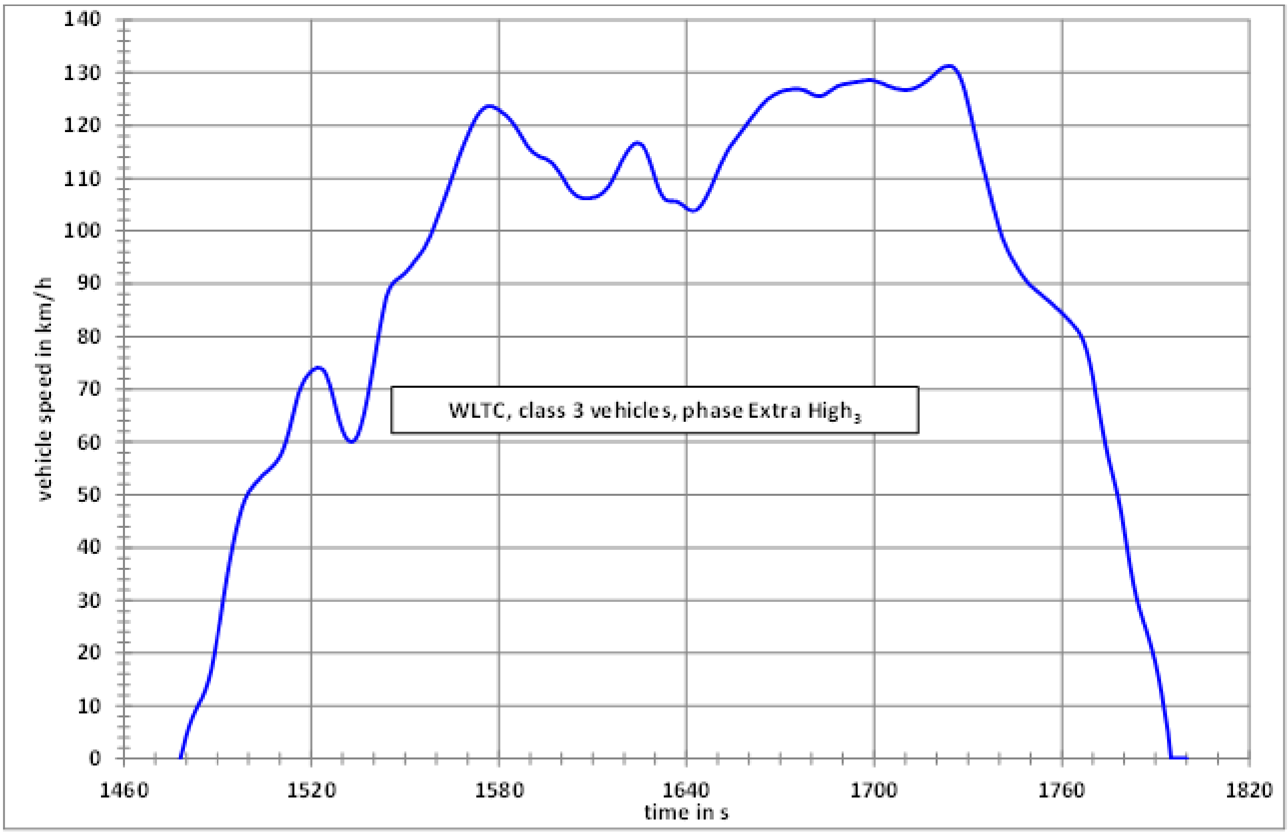


Table A1/7

WLTC, Class 3 cycle, phase Low$_3$

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
0	0.0	47	19.5	94	12.0	141	11.7
1	0.0	48	18.4	95	9.1	142	16.4
2	0.0	49	17.8	96	5.8	143	18.9
3	0.0	50	17.8	97	3.6	144	19.9
4	0.0	51	17.4	98	2.2	145	20.8
5	0.0	52	15.7	99	0.0	146	22.8
6	0.0	53	13.1	100	0.0	147	25.4
7	0.0	54	12.1	101	0.0	148	27.7
8	0.0	55	12.0	102	0.0	149	29.2
9	0.0	56	12.0	103	0.0	150	29.8
10	0.0	57	12.0	104	0.0	151	29.4
11	0.0	58	12.3	105	0.0	152	27.2
12	0.2	59	12.6	106	0.0	153	22.6
13	1.7	60	14.7	107	0.0	154	17.3
14	5.4	61	15.3	108	0.0	155	13.3
15	9.9	62	15.9	109	0.0	156	12.0
16	13.1	63	16.2	110	0.0	157	12.6
17	16.9	64	17.1	111	0.0	158	14.1
18	21.7	65	17.8	112	0.0	159	17.2
19	26.0	66	18.1	113	0.0	160	20.1
20	27.5	67	18.4	114	0.0	161	23.4
21	28.1	68	20.3	115	0.0	162	25.5
22	28.3	69	23.2	116	0.0	163	27.6
23	28.8	70	26.5	117	0.0	164	29.5
24	29.1	71	29.8	118	0.0	165	31.1
25	30.8	72	32.6	119	0.0	166	32.1
26	31.9	73	34.4	120	0.0	167	33.2
27	34.1	74	35.5	121	0.0	168	35.2
28	36.6	75	36.4	122	0.0	169	37.2
29	39.1	76	37.4	123	0.0	170	38.0
30	41.3	77	38.5	124	0.0	171	37.4
31	42.5	78	39.3	125	0.0	172	35.1
32	43.3	79	39.5	126	0.0	173	31.0
33	43.9	80	39.0	127	0.0	174	27.1
34	44.4	81	38.5	128	0.0	175	25.3
35	44.5	82	37.3	129	0.0	176	25.1
36	44.2	83	37.0	130	0.0	177	25.9

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
37	42.7	84	36.7	131	0.0	178	27.8
38	39.9	85	35.9	132	0.0	179	29.2
39	37.0	86	35.3	133	0.0	180	29.6
40	34.6	87	34.6	134	0.0	181	29.5
41	32.3	88	34.2	135	0.0	182	29.2
42	29.0	89	31.9	136	0.0	183	28.3
43	25.1	90	27.3	137	0.0	184	26.1
44	22.2	91	22.0	138	0.2	185	23.6
45	20.9	92	17.0	139	1.9	186	21.0
46	20.4	93	14.2	140	6.1	187	18.9
188	17.1	237	49.2	286	37.4	335	15.0
189	15.7	238	48.4	287	40.7	336	14.5
190	14.5	239	46.9	288	44.0	337	14.3
191	13.7	240	44.3	289	47.3	338	14.5
192	12.9	241	41.5	290	49.2	339	15.4
193	12.5	242	39.5	291	49.8	340	17.8
194	12.2	243	37.0	292	49.2	341	21.1
195	12.0	244	34.6	293	48.1	342	24.1
196	12.0	245	32.3	294	47.3	343	25.0
197	12.0	246	29.0	295	46.8	344	25.3
198	12.0	247	25.1	296	46.7	345	25.5
199	12.5	248	22.2	297	46.8	346	26.4
200	13.0	249	20.9	298	47.1	347	26.6
201	14.0	250	20.4	299	47.3	348	27.1
202	15.0	251	19.5	300	47.3	349	27.7
203	16.5	252	18.4	301	47.1	350	28.1
204	19.0	253	17.8	302	46.6	351	28.2
205	21.2	254	17.8	303	45.8	352	28.1
206	23.8	255	17.4	304	44.8	353	28.0
207	26.9	256	15.7	305	43.3	354	27.9
208	29.6	257	14.5	306	41.8	355	27.9
209	32.0	258	15.4	307	40.8	356	28.1
210	35.2	259	17.9	308	40.3	357	28.2
211	37.5	260	20.6	309	40.1	358	28.0
212	39.2	261	23.2	310	39.7	359	26.9
213	40.5	262	25.7	311	39.2	360	25.0
214	41.6	263	28.7	312	38.5	361	23.2
215	43.1	264	32.5	313	37.4	362	21.9
216	45.0	265	36.1	314	36.0	363	21.1
217	47.1	266	39.0	315	34.4	364	20.7
218	49.0	267	40.8	316	33.0	365	20.7

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
219	50.6	268	42.9	317	31.7	366	20.8
220	51.8	269	44.4	318	30.0	367	21.2
221	52.7	270	45.9	319	28.0	368	22.1
222	53.1	271	46.0	320	26.1	369	23.5
223	53.5	272	45.6	321	25.6	370	24.3
224	53.8	273	45.3	322	24.9	371	24.5
225	54.2	274	43.7	323	24.9	372	23.8
226	54.8	275	40.8	324	24.3	373	21.3
227	55.3	276	38.0	325	23.9	374	17.7
228	55.8	277	34.4	326	23.9	375	14.4
229	56.2	278	30.9	327	23.6	376	11.9
230	56.5	279	25.5	328	23.3	377	10.2
231	56.5	280	21.4	329	20.5	378	8.9
232	56.2	281	20.2	330	17.5	379	8.0
233	54.9	282	22.9	331	16.9	380	7.2
234	52.9	283	26.6	332	16.7	381	6.1
235	51.0	284	30.2	333	15.9	382	4.9
236	49.8	285	34.1	334	15.6	383	3.7
384	2.3	433	31.3	482	0.0	531	0.0
385	0.9	434	31.1	483	0.0	532	0.0
386	0.0	435	30.6	484	0.0	533	0.2
387	0.0	436	29.2	485	0.0	534	1.2
388	0.0	437	26.7	486	0.0	535	3.2
389	0.0	438	23.0	487	0.0	536	5.2
390	0.0	439	18.2	488	0.0	537	8.2
391	0.0	440	12.9	489	0.0	538	13
392	0.5	441	7.7	490	0.0	539	18.8
393	2.1	442	3.8	491	0.0	540	23.1
394	4.8	443	1.3	492	0.0	541	24.5
395	8.3	444	0.2	493	0.0	542	24.5
396	12.3	445	0.0	494	0.0	543	24.3
397	16.6	446	0.0	495	0.0	544	23.6
398	20.9	447	0.0	496	0.0	545	22.3
399	24.2	448	0.0	497	0.0	546	20.1
400	25.6	449	0.0	498	0.0	547	18.5
401	25.6	450	0.0	499	0.0	548	17.2
402	24.9	451	0.0	500	0.0	549	16.3
403	23.3	452	0.0	501	0.0	550	15.4
404	21.6	453	0.0	502	0.0	551	14.7
405	20.2	454	0.0	503	0.0	552	14.3
406	18.7	455	0.0	504	0.0	553	13.7

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
407	17.0	456	0.0	505	0.0	554	13.3
408	15.3	457	0.0	506	0.0	555	13.1
409	14.2	458	0.0	507	0.0	556	13.1
410	13.9	459	0.0	508	0.0	557	13.3
411	14.0	460	0.0	509	0.0	558	13.8
412	14.2	461	0.0	510	0.0	559	14.5
413	14.5	462	0.0	511	0.0	560	16.5
414	14.9	463	0.0	512	0.5	561	17.0
415	15.9	464	0.0	513	2.5	562	17.0
416	17.4	465	0.0	514	6.6	563	17.0
417	18.7	466	0.0	515	11.8	564	15.4
418	19.1	467	0.0	516	16.8	565	10.1
419	18.8	468	0.0	517	20.5	566	4.8
420	17.6	469	0.0	518	21.9	567	0.0
421	16.6	470	0.0	519	21.9	568	0.0
422	16.2	471	0.0	520	21.3	569	0.0
423	16.4	472	0.0	521	20.3	570	0.0
424	17.2	473	0.0	522	19.2	571	0.0
425	19.1	474	0.0	523	17.8	572	0.0
426	22.6	475	0.0	524	15.5	573	0.0
427	27.4	476	0.0	525	11.9	574	0.0
428	31.6	477	0.0	526	7.6	575	0.0
429	33.4	478	0.0	527	4.0	576	0.0
430	33.5	479	0.0	528	2.0	577	0.0
431	32.8	480	0.0	529	1.0	578	0.0
432	31.9	481	0.0	530	0.0	579	0.0
580	0.0						
581	0.0						
582	0.0						
583	0.0						
584	0.0						
585	0.0						
586	0.0						
587	0.0						
588	0.0						
589	0.0						

Table A1/8

[Reserved]

Table A1/9

WLTC, Class 3b cycle, phase Medium$_{3b}$

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
590	0.0	637	53.0	684	18.9	731	41.9
591	0.0	638	53.0	685	18.9	732	42.0
592	0.0	639	52.9	686	21.3	733	42.2
593	0.0	640	52.7	687	23.9	734	42.4
594	0.0	641	52.6	688	25.9	735	42.7
595	0.0	642	53.1	689	28.4	736	43.1
596	0.0	643	54.3	690	30.3	737	43.7
597	0.0	644	55.2	691	30.9	738	44.0
598	0.0	645	55.5	692	31.1	739	44.1
599	0.0	646	55.9	693	31.8	740	45.3
600	0.0	647	56.3	694	32.7	741	46.4
601	1.0	648	56.7	695	33.2	742	47.2
602	2.1	649	56.9	696	32.4	743	47.3
603	4.8	650	56.8	697	28.3	744	47.4
604	9.1	651	56.0	698	25.8	745	47.4
605	14.2	652	54.2	699	23.1	746	47.5
606	19.8	653	52.1	700	21.8	747	47.9
607	25.5	654	50.1	701	21.2	748	48.6
608	30.5	655	47.2	702	21.0	749	49.4
609	34.8	656	43.2	703	21.0	750	49.8
610	38.8	657	39.2	704	20.9	751	49.8
611	42.9	658	36.5	705	19.9	752	49.7
612	46.4	659	34.3	706	17.9	753	49.3
613	48.3	660	31.0	707	15.1	754	48.5
614	48.7	661	26.0	708	12.8	755	47.6
615	48.5	662	20.7	709	12.0	756	46.3
616	48.4	663	15.4	710	13.2	757	43.7
617	48.2	664	13.1	711	17.1	758	39.3
618	47.8	665	12.0	712	21.1	759	34.1
619	47.0	666	12.5	713	21.8	760	29.0
620	45.9	667	14.0	714	21.2	761	23.7
621	44.9	668	19.0	715	18.5	762	18.4

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
622	44.4	669	23.2	716	13.9	763	14.3
623	44.3	670	28.0	717	12.0	764	12.0
624	44.5	671	32.0	718	12.0	765	12.8
625	45.1	672	34.0	719	13.0	766	16.0
626	45.7	673	36.0	720	16.0	767	19.1
627	46.0	674	38.0	721	18.5	768	22.4
628	46.0	675	40.0	722	20.6	769	25.6
629	46.0	676	40.3	723	22.5	770	30.1
630	46.1	677	40.5	724	24.0	771	35.3
631	46.7	678	39.0	725	26.6	772	39.9
632	47.7	679	35.7	726	29.9	773	44.5
633	48.9	680	31.8	727	34.8	774	47.5
634	50.3	681	27.1	728	37.8	775	50.9
635	51.6	682	22.8	729	40.2	776	54.1
636	52.6	683	21.1	730	41.6	777	56.3
778	58.1	827	37.1	876	72.7	925	64.1
779	59.8	828	38.9	877	71.3	926	62.7
780	61.1	829	41.4	878	70.4	927	62.0
781	62.1	830	44.0	879	70.0	928	61.3
782	62.8	831	46.3	880	70.0	929	60.9
783	63.3	832	47.7	881	69.0	930	60.5
784	63.6	833	48.2	882	68.0	931	60.2
785	64.0	834	48.7	883	68.0	932	59.8
786	64.7	835	49.3	884	68.0	933	59.4
787	65.2	836	49.8	885	68.1	934	58.6
788	65.3	837	50.2	886	68.4	935	57.5
789	65.3	838	50.9	887	68.6	936	56.6
790	65.4	839	51.8	888	68.7	937	56.0
791	65.7	840	52.5	889	68.5	938	55.5
792	66.0	841	53.3	890	68.1	939	55.0
793	65.6	842	54.5	891	67.3	940	54.4
794	63.5	843	55.7	892	66.2	941	54.1
795	59.7	844	56.5	893	64.8	942	54.0
796	54.6	845	56.8	894	63.6	943	53.9
797	49.3	846	57.0	895	62.6	944	53.9
798	44.9	847	57.2	896	62.1	945	54.0
799	42.3	848	57.7	897	61.9	946	54.2
800	41.4	849	58.7	898	61.9	947	55.0
801	41.3	850	60.1	899	61.8	948	55.8
802	42.1	851	61.1	900	61.5	949	56.2
803	44.7	852	61.7	901	60.9	950	56.1

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
804	48.4	853	62.3	902	59.7	951	55.1
805	51.4	854	62.9	903	54.6	952	52.7
806	52.7	855	63.3	904	49.3	953	48.4
807	53.0	856	63.4	905	44.9	954	43.1
808	52.5	857	63.5	906	42.3	955	37.8
809	51.3	858	64.5	907	41.4	956	32.5
810	49.7	859	65.8	908	41.3	957	27.2
811	47.4	860	66.8	909	42.1	958	25.1
812	43.7	861	67.4	910	44.7	959	26.0
813	39.7	862	68.8	911	48.4	960	29.3
814	35.5	863	71.1	912	51.4	961	34.6
815	31.1	864	72.3	913	52.7	962	40.4
816	26.3	865	72.8	914	54.0	963	45.3
817	21.9	866	73.4	915	57.0	964	49.0
818	18.0	867	74.6	916	58.1	965	51.1
819	17.0	868	76.0	917	59.2	966	52.1
820	18.0	869	76.6	918	59.0	967	52.2
821	21.4	870	76.5	919	59.1	968	52.1
822	24.8	871	76.2	920	59.5	969	51.7
823	27.9	872	75.8	921	60.5	970	50.9
824	30.8	873	75.4	922	62.3	971	49.2
825	33.0	874	74.8	923	63.9	972	45.9
826	35.1	875	73.9	924	65.1	973	40.6
974	35.3						
975	30.0						
976	24.7						
977	19.3						
978	16.0						
979	13.2						
980	10.7						
981	8.8						
982	7.2						
983	5.5						
984	3.2						
985	1.1						
986	0.0						
987	0.0						
988	0.0						
989	0.0						
990	0.0						
991	0.0						

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
992	0.0						
993	0.0						
994	0.0						
995	0.0						
996	0.0						
997	0.0						
998	0.0						
999	0.0						
1000	0.0						
1001	0.0						
1002	0.0						
1003	0.0						
1004	0.0						
1005	0.0						
1006	0.0						
1007	0.0						
1008	0.0						
1009	0.0						
1010	0.0						
1011	0.0						
1012	0.0						
1013	0.0						
1014	0.0						
1015	0.0						
1016	0.0						
1017	0.0						
1018	0.0						
1019	0.0						
1020	0.0						
1021	0.0						
1022	0.0						

Table A1/10

[Reserved]

Table A1/11

WLTC, Class 3b cycle, phase High$_{3b}$

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
1023	0.0	1070	26.4	1117	69.7	1164	52.6
1024	0.0	1071	28.8	1118	69.3	1165	54.5
1025	0.0	1072	31.8	1119	68.1	1166	56.6
1026	0.0	1073	35.3	1120	66.9	1167	58.3
1027	0.8	1074	39.5	1121	66.2	1168	60.0
1028	3.6	1075	44.5	1122	65.7	1169	61.5
1029	8.6	1076	49.3	1123	64.9	1170	63.1
1030	14.6	1077	53.3	1124	63.2	1171	64.3
1031	20.0	1078	56.4	1125	60.3	1172	65.7
1032	24.4	1079	58.9	1126	55.8	1173	67.1
1033	28.2	1080	61.2	1127	50.5	1174	68.3
1034	31.7	1081	62.6	1128	45.2	1175	69.7
1035	35.0	1082	63.0	1129	40.1	1176	70.6
1036	37.6	1083	62.5	1130	36.2	1177	71.6
1037	39.7	1084	60.9	1131	32.9	1178	72.6
1038	41.5	1085	59.3	1132	29.8	1179	73.5
1039	43.6	1086	58.6	1133	26.6	1180	74.2
1040	46.0	1087	58.6	1134	23.0	1181	74.9
1041	48.4	1088	58.7	1135	19.4	1182	75.6
1042	50.5	1089	58.8	1136	16.3	1183	76.3
1043	51.9	1090	58.8	1137	14.6	1184	77.1
1044	52.6	1091	58.8	1138	14.2	1185	77.9
1045	52.8	1092	59.1	1139	14.3	1186	78.5
1046	52.9	1093	60.1	1140	14.6	1187	79.0
1047	53.1	1094	61.7	1141	15.1	1188	79.7
1048	53.3	1095	63.0	1142	16.4	1189	80.3
1049	53.1	1096	63.7	1143	19.1	1190	81.0
1050	52.3	1097	63.9	1144	22.5	1191	81.6
1051	50.7	1098	63.5	1145	24.4	1192	82.4
1052	48.8	1099	62.3	1146	24.8	1193	82.9
1053	46.5	1100	60.3	1147	22.7	1194	83.4
1054	43.8	1101	58.9	1148	17.4	1195	83.8

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
1055	40.3	1102	58.4	1149	13.8	1196	84.2
1056	36.0	1103	58.8	1150	12.0	1197	84.7
1057	30.7	1104	60.2	1151	12.0	1198	85.2
1058	25.4	1105	62.3	1152	12.0	1199	85.6
1059	21.0	1106	63.9	1153	13.9	1200	86.3
1060	16.7	1107	64.5	1154	17.7	1201	86.8
1061	13.4	1108	64.4	1155	22.8	1202	87.4
1062	12.0	1109	63.5	1156	27.3	1203	88.0
1063	12.1	1110	62.0	1157	31.2	1204	88.3
1064	12.8	1111	61.2	1158	35.2	1205	88.7
1065	15.6	1112	61.3	1159	39.4	1206	89.0
1066	19.9	1113	62.6	1160	42.5	1207	89.3
1067	23.4	1114	65.3	1161	45.4	1208	89.8
1068	24.6	1115	68.0	1162	48.2	1209	90.2
1069	25.2	1116	69.4	1163	50.3	1210	90.6
1211	91.0	1260	95.7	1309	75.9	1358	68.2
1212	91.3	1261	95.5	1310	75.9	1359	66.1
1213	91.6	1262	95.3	1311	75.8	1360	63.8
1214	91.9	1263	95.2	1312	75.7	1361	61.6
1215	92.2	1264	95.0	1313	75.5	1362	60.2
1216	92.8	1265	94.9	1314	75.2	1363	59.8
1217	93.1	1266	94.7	1315	75.0	1364	60.4
1218	93.3	1267	94.5	1316	74.7	1365	61.8
1219	93.5	1268	94.4	1317	74.1	1366	62.6
1220	93.7	1269	94.4	1318	73.7	1367	62.7
1221	93.9	1270	94.3	1319	73.3	1368	61.9
1222	94.0	1271	94.3	1320	73.5	1369	60.0
1223	94.1	1272	94.1	1321	74.0	1370	58.4
1224	94.3	1273	93.9	1322	74.9	1371	57.8
1225	94.4	1274	93.4	1323	76.1	1372	57.8
1226	94.6	1275	92.8	1324	77.7	1373	57.8
1227	94.7	1276	92.0	1325	79.2	1374	57.3
1228	94.8	1277	91.3	1326	80.3	1375	56.2
1229	95.0	1278	90.6	1327	80.8	1376	54.3
1230	95.1	1279	90.0	1328	81.0	1377	50.8
1231	95.3	1280	89.3	1329	81.0	1378	45.5
1232	95.4	1281	88.7	1330	81.0	1379	40.2
1233	95.6	1282	88.1	1331	81.0	1380	34.9
1234	95.7	1283	87.4	1332	81.0	1381	29.6
1235	95.8	1284	86.7	1333	80.9	1382	27.3
1236	96.0	1285	86.0	1334	80.6	1383	29.3

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
1237	96.1	1286	85.3	1335	80.3	1384	32.9
1238	96.3	1287	84.7	1336	80.0	1385	35.6
1239	96.4	1288	84.1	1337	79.9	1386	36.7
1240	96.6	1289	83.5	1338	79.8	1387	37.6
1241	96.8	1290	82.9	1339	79.8	1388	39.4
1242	97.0	1291	82.3	1340	79.8	1389	42.5
1243	97.2	1292	81.7	1341	79.9	1390	46.5
1244	97.3	1293	81.1	1342	80.0	1391	50.2
1245	97.4	1294	80.5	1343	80.4	1392	52.8
1246	97.4	1295	79.9	1344	80.8	1393	54.3
1247	97.4	1296	79.4	1345	81.2	1394	54.9
1248	97.4	1297	79.1	1346	81.5	1395	54.9
1249	97.3	1298	78.8	1347	81.6	1396	54.7
1250	97.3	1299	78.5	1348	81.6	1397	54.1
1251	97.3	1300	78.2	1349	81.4	1398	53.2
1252	97.3	1301	77.9	1350	80.7	1399	52.1
1253	97.2	1302	77.6	1351	79.6	1400	50.7
1254	97.1	1303	77.3	1352	78.2	1401	49.1
1255	97.0	1304	77.0	1353	76.8	1402	47.4
1256	96.9	1305	76.7	1354	75.3	1403	45.2
1257	96.7	1306	76.0	1355	73.8	1404	41.8
1258	96.4	1307	76.0	1356	72.1	1405	36.5
1259	96.1	1308	76.0	1357	70.2	1406	31.2
1407	27.6	1456	0.0				
1408	26.9	1457	0.0				
1409	27.3	1458	0.0				
1410	27.5	1459	0.0				
1411	27.4	1460	0.0				
1412	27.1	1461	0.0				
1413	26.7	1462	0.0				
1414	26.8	1463	0.0				
1415	28.2	1464	0.0				
1416	31.1	1465	0.0				
1417	34.8	1466	0.0				
1418	38.4	1467	0.0				
1419	40.9	1468	0.0				
1420	41.7	1469	0.0				
1421	40.9	1470	0.0				
1422	38.3	1471	0.0				
1423	35.3	1472	0.0				
1424	34.3	1473	0.0				

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
1425	34.6	1474	0.0				
1426	36.3	1475	0.0				
1427	39.5	1476	0.0				
1428	41.8	1477	0.0				
1429	42.5						
1430	41.9						
1431	40.1						
1432	36.6						
1433	31.3						
1434	26.0						
1435	20.6						
1436	19.1						
1437	19.7						
1438	21.1						
1439	22.0						
1440	22.1						
1441	21.4						
1442	19.6						
1443	18.3						
1444	18.0						
1445	18.3						
1446	18.5						
1447	17.9						
1448	15.0						
1449	9.9						
1450	4.6						
1451	1.2						
1452	0.0						
1453	0.0						
1454	0.0						
1455	0.0						

Table A1/12

WLTC, Class 3 cycle, phase Extra High$_3$

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
1478	0.0	1525	72.5	1572	120.7	1619	113.0
1479	2.2	1526	70.8	1573	121.8	1620	114.1
1480	4.4	1527	68.6	1574	122.6	1621	115.1
1481	6.3	1528	66.2	1575	123.2	1622	115.9
1482	7.9	1529	64.0	1576	123.6	1623	116.5
1483	9.2	1530	62.2	1577	123.7	1624	116.7
1484	10.4	1531	60.9	1578	123.6	1625	116.6
1485	11.5	1532	60.2	1579	123.3	1626	116.2
1486	12.9	1533	60.0	1580	123.0	1627	115.2
1487	14.7	1534	60.4	1581	122.5	1628	113.8
1488	17.0	1535	61.4	1582	122.1	1629	112.0
1489	19.8	1536	63.2	1583	121.5	1630	110.1
1490	23.1	1537	65.6	1584	120.8	1631	108.3
1491	26.7	1538	68.4	1585	120.0	1632	107.0
1492	30.5	1539	71.6	1586	119.1	1633	106.1
1493	34.1	1540	74.9	1587	118.1	1634	105.8
1494	37.5	1541	78.4	1588	117.1	1635	105.7
1495	40.6	1542	81.8	1589	116.2	1636	105.7
1496	43.3	1543	84.9	1590	115.5	1637	105.6
1497	45.7	1544	87.4	1591	114.9	1638	105.3
1498	47.7	1545	89.0	1592	114.5	1639	104.9
1499	49.3	1546	90.0	1593	114.1	1640	104.4
1500	50.5	1547	90.6	1594	113.9	1641	104.0
1501	51.3	1548	91.0	1595	113.7	1642	103.8
1502	52.1	1549	91.5	1596	113.3	1643	103.9
1503	52.7	1550	92.0	1597	112.9	1644	104.4
1504	53.4	1551	92.7	1598	112.2	1645	105.1
1505	54.0	1552	93.4	1599	111.4	1646	106.1
1506	54.5	1553	94.2	1600	110.5	1647	107.2
1507	55.0	1554	94.9	1601	109.5	1648	108.5
1508	55.6	1555	95.7	1602	108.5	1649	109.9
1509	56.3	1556	96.6	1603	107.7	1650	111.3
1510	57.2	1557	97.7	1604	107.1	1651	112.7
1511	58.5	1558	98.9	1605	106.6	1652	113.9
1512	60.2	1559	100.4	1606	106.4	1653	115.0
1513	62.3	1560	102.0	1607	106.2	1654	116.0
1514	64.7	1561	103.6	1608	106.2	1655	116.8

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
1515	67.1	1562	105.2	1609	106.2	1656	117.6
1516	69.2	1563	106.8	1610	106.4	1657	118.4
1517	70.7	1564	108.5	1611	106.5	1658	119.2
1518	71.9	1565	110.2	1612	106.8	1659	120.0
1519	72.7	1566	111.9	1613	107.2	1660	120.8
1520	73.4	1567	113.7	1614	107.8	1661	121.6
1521	73.8	1568	115.3	1615	108.5	1662	122.3
1522	74.1	1569	116.8	1616	109.4	1663	123.1
1523	74.0	1570	118.2	1617	110.5	1664	123.8
1524	73.6	1571	119.5	1618	111.7	1665	124.4
1666	125.0	1715	127.7	1764	82.0		
1667	125.4	1716	128.1	1765	81.3		
1668	125.8	1717	128.5	1766	80.4		
1669	126.1	1718	129.0	1767	79.1		
1670	126.4	1719	129.5	1768	77.4		
1671	126.6	1720	130.1	1769	75.1		
1672	126.7	1721	130.6	1770	72.3		
1673	126.8	1722	131.0	1771	69.1		
1674	126.9	1723	131.2	1772	65.9		
1675	126.9	1724	131.3	1773	62.7		
1676	126.9	1725	131.2	1774	59.7		
1677	126.8	1726	130.7	1775	57.0		
1678	126.6	1727	129.8	1776	54.6		
1679	126.3	1728	128.4	1777	52.2		
1680	126.0	1729	126.5	1778	49.7		
1681	125.7	1730	124.1	1779	46.8		
1682	125.6	1731	121.6	1780	43.5		
1683	125.6	1732	119.0	1781	39.9		
1684	125.8	1733	116.5	1782	36.4		
1685	126.2	1734	114.1	1783	33.2		
1686	126.6	1735	111.8	1784	30.5		
1687	127.0	1736	109.5	1785	28.3		
1688	127.4	1737	107.1	1786	26.3		
1689	127.6	1738	104.8	1787	24.4		
1690	127.8	1739	102.5	1788	22.5		
1691	127.9	1740	100.4	1789	20.5		
1692	128.0	1741	98.6	1790	18.2		
1693	128.1	1742	97.2	1791	15.5		
1694	128.2	1743	95.9	1792	12.3		
1695	128.3	1744	94.8	1793	8.7		
1696	128.4	1745	93.8	1794	5.2		

Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h	Time in s	Speed in km/h
1697	128.5	1746	92.8	1795	0.0		
1698	128.6	1747	91.8	1796	0.0		
1699	128.6	1748	91.0	1797	0.0		
1700	128.5	1749	90.2	1798	0.0		
1701	128.3	1750	89.6	1799	0.0		
1702	128.1	1751	89.1	1800	0.0		
1703	127.9	1752	88.6				
1704	127.6	1753	88.1				
1705	127.4	1754	87.6				
1706	127.2	1755	87.1				
1707	127.0	1756	86.6				
1708	126.9	1757	86.1				
1709	126.8	1758	85.5				
1710	126.7	1759	85.0				
1711	126.8	1760	84.4				
1712	126.9	1761	83.8				
1713	127.1	1762	83.2				
1714	127.4	1763	82.6				

7. Cycle identification

In order to confirm if the correct cycle version was chosen or if the correct cycle was implemented into the test bench operation system, checksums of the vehicle speed values for cycle phases and the whole cycle are listed in Table A1/13.

Table A1/13

- **1Hz checksums**

Cycle class	*Cycle phase*	*Checksum of 1 Hz target vehicle speeds*
[Reserved]		
[Reserved]		

[Reserved]		
Class 3b	Low	11140,.3
	Medium	17121,2
	High	25782,2
	Extra High	29714,9
	Total	83758,6

8. Cycle modification

Paragraph 8. of this Sub-Annex shall not apply to OVC-HEVs, NOVC-HEVs and NOVC-FCHVs.

8.1. General remarks

Driveability problems may occur for vehicles with critical power to mass ratios.

Since these problems are related mainly to cycle phases with a combination of high vehicle speed and high accelerations rather than to the maximum speed of the cycle, the downscaling procedure shall be applied to improve driveability.

8.2. This paragraph describes the method to modify the cycle profile using the downscaling procedure.

8.2.1. [Reserved]

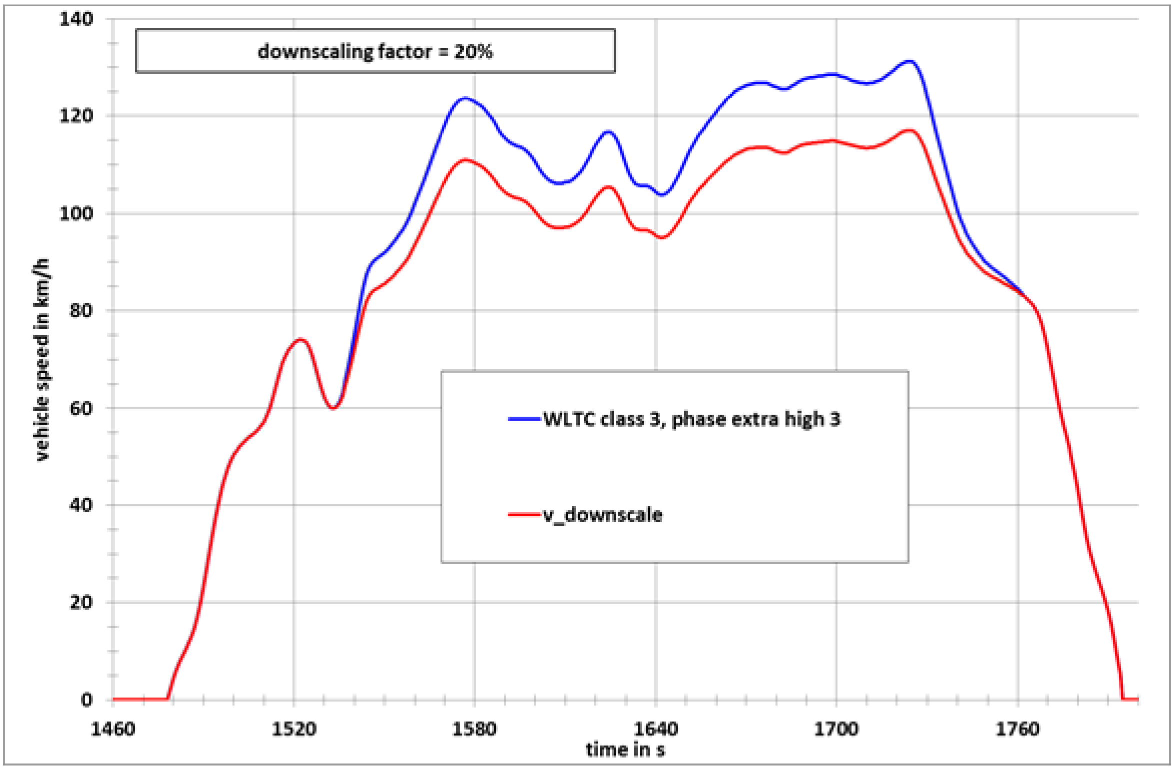
8.2.2. [Reserved]

8.2.3. Downscaling procedure for Class 3 vehicles

Figure A1/16 shows an example for a downscaled extra high speed phase of the Class 3 WLTC.

Figure A1/16

Downscaled extra high speed phase of the class 3 WLTC



For the Class 3 cycle, the downscaling period is the time period between second 1533 and second 1762. Within this time period, the acceleration for the original cycle shall be calculated using the following equation:

$$a_{\mathrm{orig}_i} = \frac{v_{i+1} - v_i}{3.6}$$

where:

v_i is the vehicle speed, km/h;

i is the time between second 1533 and second 1762.

The downscaling shall be applied first in the time period between second 1533 and second 1724. Second 1724 is the time when the maximum speed of the extra high speed phase is reached. The downscaled speed trace shall be subsequently calculated using the following equation:

$$v_{\mathrm{dsc}_{i+1}} = v_{\mathrm{dsc}_i} + a_{\mathrm{orig}_i} \times (1 - f_{\mathrm{dsc}}) \times 3.6$$

for $i = 1533$ to 1723.

For $i = 1533$, $v_{\mathrm{dsc}_i} = v_{\mathrm{orig}_i}$

In order to meet the original vehicle speed at second 1763, a correction factor for the deceleration shall be calculated using the following equation:

$$f_{\mathrm{corr\_dec}} = \frac{v_{\mathrm{dsc\_1724}} - 82.6}{v_{\mathrm{orig\_1724}} - 82.6}$$

82.6 km/h is the original vehicle speed at second 1763.

The downscaled vehicle speed between second 1725 and second 1762 shall be subsequently calculated using the following equation:

$$v_{\mathrm{dsc}_i} = v_{\mathrm{dsc}_{i-1}} + a_{\mathrm{orig}_{i-1}} \times f_{\mathrm{corr\_dec}} \times 3.6$$

for $i = 1725$ to 1762.

8.3. Determination of the downscaling factor

The downscaling factor f_{dsc}, is a function of the ratio r_{max} between the maximum required power of the cycle phases where the downscaling is to be applied and the rated power of the vehicle, P_{rated}.

The maximum required power $P_{\mathrm{req,max,i}}$ (in kW) is related to a specific time i and the corresponding vehicle speed v_i in the cycle trace and is calculated using the following equation:

$$P_{\mathrm{req,max,i}} = \frac{\left((f_0 \times v_i) + \left(f_1 \times v_i^2\right) + \left(f_2 \times v_i^3\right) + (1.03 \times \mathrm{TM} \times v_i \times a_i)\right)}{3600}$$

where:

f_0, f_1, f_2 are the applicable road load coefficients, N, N/(km/h), and N/(km/h)² respectively;

TM is the applicable test mass, kg;

v_i is the speed at time i, km/h;

a_i is the acceleration at time i, km/h².

The cycle time i at which maximum power or power values close to maximum power is required is second 764 for the Class 1 cycle, second 1574 for the Class 2 cycle and second 1566 for the Class 3 cycle.

The corresponding vehicle speed values, v_i, and acceleration values, a_i, are as follows:

$v_i = 61.4$ km/h, $a_i = 0.22$ m/s² for Class 1,

$v_i = 109.9$ km/h, $a_i = 0.36$ m/s² for Class 2,

$v_i = 111.9$ km/h, $a_i = 0.50$ m/s² for Class 3.

r_{max} shall be calculated using the following equation:

$$r_{\mathrm{max}} = \frac{P_{\mathrm{req,max,i}}}{P_{\mathrm{rated}}}$$

The downscaling factor, f_{dsc}, shall be calculated using the following equations:

if $\mathrm{r_{max}} < \mathrm{r_0}$, then $\mathrm{f_{dsc}} = 0$

and no downscaling shall be applied.

If $\mathrm{r_{max}} \geq \mathrm{r_0}$, then $\mathrm{f_{dsc}} = \mathrm{a_1} \times \mathrm{r_{max}} + \mathrm{b_1}$

The calculation parameter/coefficients, $\mathrm{r_0}$, $\mathrm{a_1}$ and $\mathrm{b_1}$, are as follows:

Class 1 $\mathrm{r_0} = 0.978, \mathrm{a_1} = 0.680, \mathrm{b_1} = -0.665$

Class 2 $\mathrm{r_0} = 0.866, \mathrm{a_1} = 0.606, \mathrm{b_1} = -0.525.$

Class 3 $\mathrm{r_0} = 0.867, \mathrm{a_1} = 0.588\ \mathrm{b_1} = -0.510.$

The resulting $\mathrm{f_{dsc}}$ is mathematically rounded to 3 places of decimal and is applied only if it exceeds 0.010.

The following data shall be included in all relevant test reports:

(a) f_{dsc};

(b) v_{max};

(c) distance driven, m.

The distance shall be calculated as the sum of v_i in km/h divided by 3.6 over the whole cycle trace.

8.4. Additional requirements

For different vehicle configurations in terms of test mass and driving resistance coefficients, downscaling shall be applied individually.

If, after the application of downscaling the vehicle maximum speed is lower than the maximum speed of the cycle, the process described in paragraph 9. of this Sub-Annex shall be applied with the applicable cycle.

If the vehicle cannot follow the speed trace of the applicable cycle within the tolerance at speeds lower than its maximum speed, it shall be driven with the accelerator control fully activated during these periods. During such periods of operation, speed trace violations shall be permitted.

9. Cycle modifications for vehicles with a maximum speed lower than the maximum speed of the cycle specified in the previous paragraphs of this Sub-Annex

9.1. General remarks

This paragraph applies to vehicles that are technically able to follow the speed trace of the applicable cycle specified in paragraph 1. of this Sub-Annex (base cycle) at speeds lower than its maximum speed, but whose maximum speed is limited to a value lower than the maximum speed of the base cycle for other reasons. That applicable cycle shall be referred to as the "base cycle" and used to determine the capped speed cycle.

In the cases where downscaling in accordance with paragraph 8.2. is applied, the downscaled cycle shall be used as the base cycle.

The maximum speed of the base cycle shall be referred to as $v_{max,cycle}$.

The maximum speed of the vehicle shall be referred to as its capped speed v_{cap}.

If v_{cap} is applied to a Class 3b vehicle as defined in paragraph 3.3.2., the Class 3b cycle shall be used as the base cycle. This shall apply even if v_{cap} is lower than 120 km/h.

In the cases where v_{cap} is applied, the base cycle shall be modified as described in paragraph 9.2. in order to achieve the same cycle distance for the capped speed cycle as for the base cycle.

9.2. Calculation steps

9.2.1. Determination of the distance difference per cycle phase

An interim capped speed cycle shall be derived by replacing all vehicle speed samples v_i where $v_i > v_{cap}$ by v_{cap}.

9.2.1.1. If $v_{cap} < v_{max,medium}$, the distance of the medium speed phases of the base cycle $d_{base,medium}$ and the interim capped speed cycle $d_{cap,medium}$ shall be calculated using the following equation for both cycles:

$d_{medium} = \sum(\frac{(v_i+v_{i-1})}{2\times3.6} \times (t_i - t_{i-1}))$, for i = 591 to 1022

where:

$v_{max,medium}$ is the maximum vehicle speed of the medium speed phase as listed in Table A1/9 for the Class 3b cycle.

9.2.1.2. If $v_{cap} < v_{max,high}$, the distances of the high speed phases of the base cycle $d_{base,high}$ and the interim capped speed cycle $d_{cap,high}$ shall be calculated using the following equation for both cycles:

$d_{high} = \sum(\frac{(v_i+v_{i-1})}{2\times3.6} \times (t_i - t_{i-1}))$, for i = 1024 to 1477

$v_{max,high}$ is the maximum vehicle speed of the high speed phase as listed in Table A1/11 for the Class 3b cycle.

9.2.1.3 The distances of the extra high speed phase of the base cycle $d_{base,exhigh}$ and the interim capped speed cycle $d_{cap,exhigh}$ shall be calculated applying the following equation to the extra high speed phase of both cycles:

$d_{exhigh} = \sum(\frac{(v_i+v_{i-1})}{2\times3.6} \times (t_i - t_{i-1}))$, for i = 1479 to 1800

9.2.2. Determination of the time periods to be added to the interim capped speed cycle in order to compensate for distance differences

In order to compensate for a difference in distance between the base cycle and the interim capped speed cycle, corresponding time periods with $v_i = v_{cap}$ shall be added to the interim capped speed cycle as described in paragraphs 9.2.2.1. to 9.2.2.3.

9.2.2.1. Additional time period for the medium speed phase

If $v_{cap} < v_{max,medium}$, the additional time period to be added to the medium speed phase of the interim capped speed cycle shall be calculated using the following equation:

$$\Delta t_{medium} = \frac{(d_{base,medium} - d_{cap,medium})}{Vcap} \times 3.6$$

The number of time samples $n_{add,medium}$ with $v_i = v_{cap}$ to be added to the medium speed phase of the interim capped speed cycle equals Δt_{medium}, mathematically rounded to the nearest integer (e.g. 1.4 shall be rounded to 1, 1.5 shall be rounded to 2).

9.2.2.2 Additional time period for the high speed phase

If $v_{cap} < v_{max,high}$, the additional time period to be added to the high speed phases of the interim capped speed cycle shall be calculated using the following equation:

$$\Delta t_{high} = \frac{(d_{base,high} - d_{cap,high})}{Vcap} \times 3.6$$

The number of time samples $n_{add,high}$ with $v_i = v_{cap}$ to be added to the high speed phase of the interim capped speed cycle equals Δt_{high}, mathematically rounded to the nearest integer.

9.2.2.3 The additional time period to be added to the extra high speed phase of the interim capped speed cycle shall be calculated using the following equation:

$$\Delta t_{exhigh} = \frac{(d_{base,exhigh} - d_{cap,exhigh})}{Vcap} \times 3.6$$

The number of time samples $n_{add,exhigh}$ with $v_i = v_{cap}$ to be added to the extra high speed phase of the interim capped speed cycle equals Δt_{exhigh}, mathematically rounded to the nearest integer.

9.2.3. Construction of the final capped speed cycle

9.2.3.1 [Reserved]

9.2.3.2 Class 3 cycles

9.2.3.2.1 $v_{cap} < v_{max,medium}$

The first part of the final capped speed cycle consists of the vehicle speed trace of the interim capped speed cycle up to the last sample in the medium speed phase where $v = v_{cap}$. The time of this sample is referred to as t_{medium}.

Then $n_{add,medium}$ samples with $v_i = v_{cap}$ shall be added, so that the time of the last sample is $(t_{medium} + n_{add,medium})$.

The remaining part of the medium speed phase of the interim capped speed cycle, which is identical with the same part of the base cycle, shall then be added, so that the time of the last sample is $(1022 + n_{add,medium})$.

In a next step, the first part of the high speed phase of the interim capped speed cycle up to the last sample in the high speed phase where $v = v_{cap}$ shall be added. The time of this sample in the interim capped speed is referred to as t_{high}, so that the time of this sample in the final capped speed cycle is ($t_{high} + n_{add,medium}$).

Then, $n_{add,high}$ samples with $v_i = v_{cap}$ shall be added, so that the time of the last sample becomes ($t_{high} + n_{add,medium} + n_{add,high}$).

The remaining part of the high speed phase of the interim capped speed cycle, which is identical with the same part of the base cycle, shall then be added, so that the time of the last sample is ($1477 + n_{add,medium} + n_{add,high}$).

In a next step, the first part of the extra high speed phase of the interim capped speed cycle up to the last sample in the extra high speed phase where $v = v_{cap}$ shall be added. The time of this sample in the interim capped speed is referred to as t_{exhigh}, so that the time of this sample in the final capped speed cycle is ($t_{exhigh} + n_{add,medium} + n_{add,high}$).

Then $n_{add,exhigh}$ samples with $v_i = v_{cap}$ shall be added, so that the time of the last sample is ($t_{exhigh} + n_{add,medium} + n_{add,high} + n_{add,exhigh}$).

The remaining part of the extra high speed phase of the interim capped speed cycle, which is identical with the same part of the base cycle, shall then be added, so that the time of the last sample is ($1800 + n_{add,medium} + n_{add,high} + n_{add,exhigh}$).

The length of the final capped speed cycle is equivalent to the length of the base cycle except for differences caused by the rounding process for $n_{add,medium}$, $n_{add,high}$ and $n_{add,exhigh}$.

9.2.3.2.2 $v_{max,\ medium} \leq v_{cap} < v_{max,\ high}$

The first part of the final capped speed cycle consists of the vehicle speed trace of the interim capped speed cycle up to the last sample in the high speed phase where $v = v_{cap}$. The time of this sample is referred to as t_{high}.

Then, $n_{add,high}$ samples with $v_i = v_{cap}$ shall be added, so that the time of the last sample is ($t_{high} + n_{add,high}$).

The remaining part of the high speed phase of the interim capped speed cycle, which is identical with the same part of the base cycle, shall then be added, so that the time of the last sample is ($1477 + n_{add,high}$).

In a next step, the first part of the extra high speed phase of the interim capped speed cycle up to the last sample in the extra high speed phase where $v = v_{cap}$ shall be added. The time of this sample in the interim capped speed is referred to as t_{exhigh}, so that the time of this sample in the final capped speed cycle is ($t_{exhigh} + n_{add,high}$).

Then $n_{add,exhigh}$ samples with $v_i = v_{cap}$ shall be added, so that the time of the last sample is ($t_{exhigh} + n_{add,high} + n_{add,exhigh}$).

The remaining part of the extra high speed phase of the interim capped speed cycle, which is identical with the same part of the base cycle, shall then be added, so that the time of the last sample is ($1800 + n_{add,high} + n_{add,exhigh}$).

The length of the final capped speed cycle is equivalent to the length of the base cycle except for differences caused by the rounding process for $n_{add,high}$ and $n_{add,exhigh}$.

9.2.3.2.3 $v_{max, high} \leq v_{cap} < v_{max, exhigh}$

The first part of the final capped speed cycle consists of the vehicle speed trace of the interim capped speed cycle up to the last sample in the extra high speed phase where $v = v_{cap}$. The time of this sample is referred to as t_{exhigh}.

Then, $n_{add,exhigh}$ samples with $v_i = v_{cap}$ shall be added, so that the time of the last sample is $(t_{exhigh} + n_{add,exhigh})$.

The remaining part of the extra high speed phase of the interim capped speed cycle, which is identical with the same part of the base cycle, shall then be added, so that the time of the last sample is $(1800 + n_{add,exhigh})$.

The length of the final capped speed cycle is equivalent to the length of the base cycle except for differences caused by the rounding process for $n_{add,exhigh}$.

10. Allocation of cycles to vehicles

10.1. [Reserved]

Sub-Annex 2

Gear selection and shift point determination for vehicles equipped with manual transmissions

1. General approach

1.1. The shifting procedures described in this Sub-Annex shall apply to vehicles equipped with manual shift transmissions.

2. until 5.: [Reserved]

6.

6.1 Vehicles with a manual gearbox with a gear-shift indicator (GSI) are measured while shifting gears as recommended. According to VO (EU) 65/2012 and EG 661/2009 vehicles must be equipped with a GSI.

6.2 Vehicle with an automatic gearbox shift automatically. Depending on the driving mode in accordance to Sub-Annex 10, 3.1, the proper driving mode for the gearbox is to apply.

6.3 Vehicles equipped with a manual gearbox which are equipped with a GSI that only gives up-shifting instructions shall be shifted down at 1300 rpm engine speed the latest.

Sub-Annex 3

[Reserved]

Sub-Annex 4

Road load and dynamometer setting

1. Scope

This Sub-Annex describes the transfer of vehicle´s road load to a chassis dynamometer.

2. Terms and definitions

2.1. [Reserved]

2.2. [Reserved]

2.3. [Reserved]

2.4 f_0, f_1, f_2 are the road load coefficients of the road load equation $F = f_0 + f_1 \times v + f_2 \times v^2$ provided by the vehicle´s certificate of conformity (CoC) document.

f_0 is the constant road load coefficient and shall be rounded to one place of decimal, N;

f_1 is the first order road load coefficient and shall be rounded to three places of decimal, N/(km/h);

f_2 is the second order road load coefficient and shall be rounded to five places of decimal, $N/(km/h)^2$.

2.5. Rotational mass

2.5.1. Determination of m_r

m_r is the equivalent effective mass of all the wheels and vehicle components rotating with the wheels on the road while the gearbox is placed in neutral, in kilograms (kg).

2.5.2. Application of rotational mass to the road load

Coastdown times shall be transferred to forces and vice versa by taking into account the applicable test mass plus m_r. This shall apply to measurements on the road as well as on a chassis dynamometer.

2.5.3. Application of rotational mass for the inertia setting

If the vehicle is tested on a dynamometer in 4WD operation, the equivalent inertia mass of the chassis dynamometer shall be set to the applicable test mass.

2.6. Additional masses for setting the test mass shall be applied such that the weight distribution of that vehicle is approximately the same as that of the vehicle with its mass in running order. In the case of category N vehicles or passenger vehicles derived from category N vehicles, the additional masses shall be located in a representative manner and shall be justified to the approval authority upon their request. The weight distribution of the vehicle shall be included in all relevant test reports and shall be used for any subsequent road load determination testing.

3. General requirements

The manufacturer shall be responsible for the accuracy of the road load coefficients and shall ensure this for each production vehicle. Tolerances within the road load determination, simulation and calculation methods shall not be used to underestimate the road load of production vehicles.

3.1. Overall measurement accuracy, precision, resolution and frequency

4. – 6.: [Reserved]

7. Transferring road load to a chassis dynamometer

7.1. Preparation for chassis dynamometer test

7.1.0. Selection of dynamometer operation

The test shall be done on either a dynamometer in 2WD operation or 4WD operation, in accordance with paragraph 2.4.2.4. of Sub-Annex 6.

7.1.1. Laboratory conditions

7.1.1.1. Roller(s)

The chassis dynamometer roller(s) shall be clean, dry and free from foreign material that might cause tyre slippage. The dynamometer shall be run in the same coupled or uncoupled state as the subsequent Type 1 test. Chassis dynamometer speed shall be measured from the roller coupled to the power absorption unit.

7.1.1.1.1. Tyre slippage

Additional weight may be placed on or in the vehicle to eliminate tyre slippage. The laboratory shall perform the load setting on the chassis dynamometer with the additional weight. The additional weight shall be present for both load setting and the emissions and fuel consumption tests. The use of any additional weight shall be included in all relevant test sheets.

7.1.1.2. Room temperature

The laboratory atmospheric temperature shall be at a set point of 14 °C and shall not deviate by more than ± 5 °C during the test unless otherwise required by any subsequent test.

7.2. Preparation of chassis dynamometer

7.2.1. Inertia mass setting

The equivalent inertia mass of the chassis dynamometer shall be set according to paragraph 2.5.3. of this Sub-Annex. If the chassis dynamometer is not capable to meet the inertia setting exactly, the next higher inertia setting shall be applied with a maximum increase of 10 kg.

7.2.2. Chassis dynamometer warm-up

The chassis dynamometer shall be warmed up in accordance with the dynamometer laboratory's recommendations, or as appropriate, so that the frictional losses of the dynamometer may be stabilized.

7.3. Vehicle preparation

7.3.1. Tyre pressure adjustment

The tyre pressure at the soak temperature of a Type 1 test shall be set to no more than 50 per cent above the lower limit of the tyre pressure range for the selected tyre, as specified by the vehicle manufacturer, and shall be included in all relevant test reports.

7.3.2. If the determination of dynamometer settings cannot meet the criteria described in paragraph 8.1.3. due to non-reproducible forces, the vehicle shall be equipped with a vehicle coastdown mode. The vehicle coastdown mode shall be approved by GNT and the use of a vehicle coastdown mode shall be included in all relevant test reports.

7.3.3. Vehicle placement on the dynamometer

The tested vehicle shall be placed on the chassis dynamometer in a straight ahead position and restrained in a safe manner. In the case that a single roller chassis dynamometer is used, the centre of the tyre's contact patch on the roller shall be within ±25 mm or ±2 per cent of the roller diameter, whichever is smaller, from the top of the roller.

7.3.3.1. [Reserved]

7.3.4. Vehicle warm-up

7.3.4.1. The vehicle shall be warmed up with the WLTC Class 3b.

7.3.4.3. [Reserved]

8. Chassis dynamometer load setting

8.1. Chassis dynamometer load setting using the coastdown method

This method is applicable when the road load coefficients f_0, f_1 and f_2 have been determined.

8.1.1. Initial load setting

For a chassis dynamometer with coefficient control, the chassis dynamometer power absorption unit shall be adjusted with the arbitrary initial coefficients, A_d, B_d and C_d, of the following equation:

$$F_d = A_d + B_d v + C_d v^2$$

where:

F_d is the chassis dynamometer setting load, N;

v is the speed of the chassis dynamometer roller, km/h.

The following are recommended coefficients to be used for the initial load setting:

(a) $A_d = 0,5 \times A_t$, $B_d = 0,2 \times B_t$, $C_d = C_t$

for single-axis chassis dynamometers, or

$A_d = 0{,}5 \times A_t$, $B_d = 0{,}2 \times B_t$, $C_d = C_t$

for dual-axis chassis dynamometers, where A_t, B_t and C_t are the target road load coefficients;

(b) empirical values, such as those used for the setting for a similar type of vehicle.

For a chassis dynamometer of polygonal control, adequate load values at each reference speed shall be set to the chassis dynamometer power absorption unit.

8.1.2. Coastdown

The coastdown test on the chassis dynamometer shall be performed with the procedure given in paragraph 8.1.3.4.1. or in paragraph 8.1.3.4.2. of this Sub-Annex and shall start no later than 120 seconds after completion of the warm-up procedure. Consecutive coastdown runs shall be started immediately.

8.1.3. Verification

8.1.3.1. The target road load value shall be calculated using the target road load coefficient, A_t, B_t and C_t, for each reference speed, v_j:

$$F_{tj} = A_t + B_t v_j + C_t v_j^2$$

where:

A_t, B_t and C_t are the target road load parameters;

F_{tj} is the target road load at reference speed v_j, N;

v_j is the jth reference speed, km/h.

8.1.3.2. The measured road load shall be calculated using the following equation:

$$F_{mj} = \frac{1}{3.6} \times (TM + m_r) \times \frac{2 \times \Delta v}{\Delta t_j}$$

where:

F_{mj} is the measured road load for each reference speed v_j, N;

TM is the test mass of the vehicle, kg;

m_r is the equivalent effective mass of rotating components according to paragraph 2.5.1. of this Sub-Annex, kg;

Δt_j is the coastdown time corresponding to speed v_j, s.

8.1.3.3.

The simulated road load on the chassis dynamometer shall be calculated in accordance with the method as specified in paragraph 4.3.1.4., with the exception of measuring in opposite directions:

$$F_s = A_s + B_s \times v + C_s \times v^2$$

The simulated road load for each reference speed v_j shall be determined using the following equation, using the calculated A_s, B_s and C_s:

$$F_{sj} = A_s + B_s \times v_j + C_s \times v_j^2$$

8.1.3.4. For dynamometer load setting, two different methods may be used. If the vehicle is accelerated by the dynamometer, the methods described in paragraph 8.1.3.4.1. of this Sub-Annex shall be used. If the vehicle is accelerated under its own power, the methods in paragraphs 8.1.3.4.1. or 8.1.3.4.2. of this Sub-Annex shall be used. The minimum acceleration multiplied by speed shall be 6 m^2/sec^3. Vehicles which are unable to achieve 6 m^2/s^3 shall be driven with the acceleration control fully applied.

8.1.3.4.1. Fixed run method

8.1.3.4.1.1. The dynamometer software shall perform four coastdowns in total: From the first coastdown, the dynamometer setting coefficients for the second run according to paragraph 8.1.4. of this Sub-Annex shall be calculated. Following the first coastdown, the software shall perform three additional coastdowns with either the fixed dynamometer setting coefficients determined after the first coastdown or the adjusted dynamometer setting coefficients according to paragraph 8.1.4. of this Sub-Annex.

8.1.3.4.1.2. The final dynamometer setting coefficients A, B and C shall be calculated using the following equations:

$$A = A_t - \frac{\sum_{n=2}^{4}\left(A_{s_n} - A_{d_n}\right)}{3}$$

$$B = B_t - \frac{\sum_{n=2}^{4}\left(B_{s_n} - B_{d_n}\right)}{3}$$

$$C = C_t - \frac{\sum_{n=2}^{4}\left(C_{s_n} - C_{d_n}\right)}{3}$$

where:

A_t, B_t and C_t are the target road load parameters;

A_{s_n}, B_{s_n} and C_{s_n} are the simulated road load coefficients of the nth run;

A_{d_n}, B_{d_n} and C_{d_n} are the dynamometer setting coefficients of the nth run;

n is the index number of coastdowns including the first stabilisation run.

8.1.3.4.2. Iterative method

The calculated forces in the specified speed ranges shall either be within ±10 N after a least squares regression of the forces for two consecutive coastdowns when compared with the target values, or additional coastdowns shall be performed after adjusting the chassis dynamometer load setting in accordance with paragraph 8.1.4. until the tolerance is satisfied.

8.1.4. Adjustment

The chassis dynamometer setting load shall be adjusted according to the following equations:

$$F_{dj}^{*} = F_{dj} - F_{j} = F_{dj} - F_{sj} + F_{tj}$$

$$= \left(A_d + B_d v_j + C_d v_j^2\right) - \left(A_s + B_s v_j + C_s v_j^2\right) + \left(A_t + B_t v_j + C_t v_j^2\right)$$

$$= (A_d + A_t - A_s) + (B_d + B_t - B_s)v_j + (C_d + C_t - C_s)v_j^2$$

Therefore:

$A_d^{*} = A_d + A_t - A_s$

$B_d^{*} = B_d + B_t - B_s$

$C_d^{*} = C_d + C_t - C_s$

where:

F_{dj} is the initial chassis dynamometer setting load, N;

F_{dj}^{*} is the adjusted chassis dynamometer setting load, N;

F_j is the adjustment road load equal to $\left(F_{sj} - F_{tj}\right)$, N;

F_{sj} is the simulated road load at reference speed v_j, N;

F_{tj} is the target road load at reference speed v_j, N;

A_d^{*}, B_d^{*} and C_d^{*} are the new chassis dynamometer setting coefficients.

8.1.5. A_t, B_t and C_t shall be used as the final values of f_0, f_1 and f_2, and shall be used for the following purposes:

(a) Determination of downscaling, paragraph 8. of Sub-Annex 1;

(b) Determination of gearshift points, Sub-Annex 2;

(c) Interpolation of CO_2 and fuel consumption, paragraph 3.2.3. of Sub-Annex 7;

(d) Calculation of results of electric and hybrid-electric vehicles, paragraph 4. of Sub-Annex 8.

8.2. [Reserved]

8.2.1. Initial load setting

For a chassis dynamometer of coefficient control, the chassis dynamometer power absorption unit shall be adjusted with the arbitrary initial coefficients, A_d, B_d and C_d, of the following equation:

$F_d = A_d + B_d v + C_d v^2$

where:

F_d is the chassis dynamometer setting load, N;

v is the speed of the chassis dynamometer roller, km/h.

The following coefficients are recommended for the initial load setting:

(a) $A_d = 0.5 \times \frac{a_t}{r'}, B_d = 0.2 \times \frac{b_t}{r'}, C_d = \frac{c_t}{r'}$

for single-axis chassis dynamometers, or

$$A_d = 0.1 \times \frac{a_t}{r'},\ B_d = 0.2 \times \frac{b_t}{r'}, C_d = \frac{c_t}{r'}$$

for dual-axis chassis dynamometers, where:

a_t, b_t and c_t are the target running resistance coefficients; and

r' is the dynamic radius of the tyre on the chassis dynamometer obtained at 80 km/h, m.; or

(b) Empirical values, such as those used for the setting for a similar type of vehicle.

For a chassis dynamometer of polygonal control, adequate load values at each reference speed shall be set for the chassis dynamometer power absorption unit.

8.2.2. [Reserved]

8.2.3. Verification

8.2.3.1. The target running resistance (torque) curve shall be determined using the equation in paragraph 4.5.5.2.1. of this Sub-Annex and may be written as follows:

$$C_t^* = a_t + b_t \times v_j + c_t \times v_j^2$$

8.2.3.2. The simulated running resistance (torque) curve on the chassis dynamometer shall be calculated according to the method described and the measurement precision specified in paragraph 4.4.3.2 of this Sub-Annex, and the running resistance (torque) curve determination as described in paragraph 4.4.4. of this Sub-Annex with applicable corrections according to paragraph 4.5. of this Sub-Annex, all with the exception of measuring in opposite directions, resulting in a simulated running resistance curve:

$$C_s^* = C_{0s} + C_{1s} \times v_j + C_{2s} \times v_j^2$$

The simulated running resistance (torque) shall be within a tolerance of ± 10 N×r′ from the target running resistance at every speed reference point where r′ is the dynamic radius of the tyre in metres on the chassis dynamometer obtained at 80 km/h.

If the tolerance at any reference speed does not satisfy the criterion of the method described in this paragraph, the procedure specified in paragraph 8.2.3.3. of this Sub-Annex shall be used to adjust the chassis dynamometer load setting.

8.2.3.3. Adjustment

The chassis dynamometer load setting shall be adjusted using the following equation:

$$F_{dj}^{*} = F_{dj} - \frac{F_{ej}}{r'} = F_{dj} - \frac{F_{sj}}{r'} + \frac{F_{tj}}{r'}$$

$$= \left(A_d + B_d v_j + C_d v_j^2\right) - \frac{\left(a_s + b_s v_j + c_s v_j^2\right)}{r'} + \frac{\left(a_t + b_t v_j + c_t v_j^2\right)}{r'}$$

$$= \left\{A_d + \frac{(a_t - a_s)}{r'}\right\} + \left\{B_d + \frac{(b_t - b_s)}{r'}\right\} v_j + \left\{C_d + \frac{(c_t - c_s)}{r'}\right\} v_j^2$$

therefore:

$$A_d^{*} = A_d + \frac{a_t - a_s}{r'}$$

$$B_d^{*} = B_d + \frac{b_t - b_s}{r'}$$

$$C_d^{*} = C_d + \frac{c_t - c_s}{r'}$$

where:

F_{dj}^{*} is the new chassis dynamometer setting load, N;

F_{ej} is the adjustment road load equal to (F_{sj}-F_{tj}), Nm;

F_{sj} is the simulated road load at reference speed v_j, Nm;

F_{tj} is the target road load at reference speed v_j, Nm;

A_d^{*}, B_d^{*} and C_d^{*} are the new chassis dynamometer setting coefficients;

r' is the dynamic radius of the tyre on the chassis dynamometer obtained at 80 km/h, m.

Paragraphs 8.2.2. and 8.2.3. shall be repeated until the tolerance in paragraph 8.2.3.2. is met.

8.2.3.4. The mass of the driven axle(s), tyre specifications and chassis dynamometer load setting shall be included in all relevant test reports when the requirement of paragraph 8.2.3.2. of this Sub-Annex is fulfilled.

8.2.4. Transformation of running resistance coefficients to road load coefficients f_0, f_1, f_2

8.2.4.1 [Reserved]

8.2.4.2. Once the chassis dynamometer has been set within the specified tolerances, a vehicle coastdown procedure shall be performed on the chassis dynamometer as outlined in paragraph 4.3.1.3. of this Sub-Annex. The coastdown times shall be included in all relevant test sheets.

8.2.4.3. The road load F_j at reference speed v_j , N, shall be determined using the following equation:

$$F_j = \frac{1}{3.6} \times (TM + m_r) \times \frac{\Delta v}{\Delta t_j}$$

where:

F_j is the road load at reference speed v_j, N;

TM is the test mass of the vehicle, kg;

m_r is the equivalent effective mass of rotating components according to paragraph 2.5.1. of this Sub-Annex, kg;

$\Delta v = 10$ km/h

Δt_j is the coastdown time corresponding to speed v_j, s.

8.2.4.4. The coefficients f_0, f_1 and f_2 in the road load equation shall be calculated with a least squares regression analysis over the reference speed range.

Sub-Annex 5

Test equipment and calibrations

1. Test bench specifications and settings

1.1. Cooling fan specifications

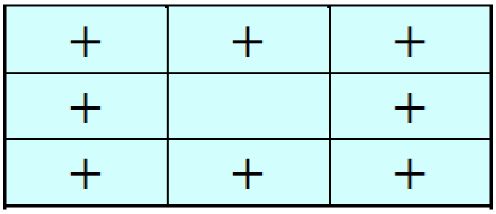
1.1.1. A variable speed current of air shall be blown towards the vehicle. The set point of the linear velocity of the air at the blower outlet shall be equal to the corresponding roller speed above roller speeds of 5 km/h. The linear velocity of the air at the blower outlet shall be within ±5 km/h or ±10 per cent of the corresponding roller speed, whichever is greater.

1.1.2. The above-mentioned air velocity shall be determined as an averaged value of a number of measuring points that:

(a) For fans with rectangular outlets, are located at the centre of each rectangle dividing the whole of the fan outlet into 9 areas (dividing both horizontal and vertical sides of the fan outlet into 3 equal parts). The centre area shall not be measured (as shown in Figure A5/1);

Figure A5/1

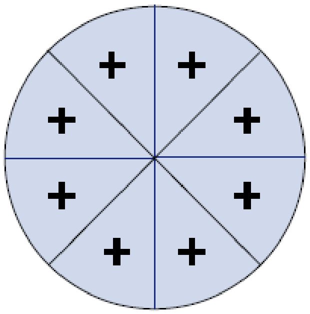
Fan with rectangular outlet



(b) For fans with circular outlets, the outlet shall be divided into 8 equal sectors by vertical, horizontal and 45° lines. The measurement points shall lie on the radial centre line of each sector (22.5°) at two–thirds of the outlet radius (as shown in Figure A5/2).

Figure A5/2

Fan with circular outlet



These measurements shall be made with no vehicle or other obstruction in front of the fan. The device used to measure the linear velocity of the air shall be located between 0 and 20 cm from the air outlet.

1.1.3. The outlet of the fan shall have the following characteristics:

(a) An area of at least 0.3 m^2; and

(b) A width/diameter of at least 0.8 metre.

1.1.4. The position of the fan shall be as follows:

(a) Height of the lower edge above ground: approximately 20 cm;

(b) Distance from the front of the vehicle: approximately 30 cm.

(c) Approximately on the longitudinal centreline of the vehicle.

1.1.5. At the request of the laboratory and if considered appropriate by GNT, the height, lateral position and distance from the vehicle of the cooling fan may be modified.

If the specified fan configuration is impractical for special vehicle designs, such as vehicles with rear-mounted engines or side air intakes, or it does not provide adequate cooling to properly represent in-use operation, at the request of the laboratory and if considered appropriate by GNT, the height, capacity, longitudinal and lateral position of the cooling fan may be modified and additional fans which may have different specifications (including constant speed fans) may be used.

1.1.6. In the cases described in paragraph 1.1.5., the position and capacity of the cooling fan(s) and details of the justification supplied to GNT shall be included in all relevant test reports. For any subsequent testing, similar positions and specifications shall be used in consideration of the justification to avoid non-representative cooling characteristics.

2. Chassis dynamometer

2.1. General requirements

2.1.1. The dynamometer shall be capable of simulating road load with three road load coefficients that can be adjusted to shape the load curve.

2.1.2. The chassis dynamometer may have a single or twin-roller configuration. In the case that twin-roller chassis dynamometers are used, the rollers shall be permanently coupled or the front roller shall drive, directly or indirectly, any inertial masses and the power absorption device.

2.2. Specific requirements

The following specific requirements relate to the dynamometer manufacturer's specifications.

2.2.1. The roller run-out shall be less than 0.25 mm at all measured locations.

2.2.2. The roller diameter shall be within ± 1.0 mm of the specified nominal value at all measurement locations.

2.2.3. The dynamometer shall have a time measurement system for use in determining acceleration rates and for measuring vehicle/dynamometer coastdown times. This time measurement system shall have an accuracy of at least ± 0.001 per cent. This shall be verified upon initial installation.

2.2.4. The dynamometer shall have a speed measurement system with an accuracy of at least ± 0.080 km/h. This shall be verified upon initial installation.

2.2.5. The dynamometer shall have a response time (90 per cent response to a tractive effort step change) of less than 100 ms with instantaneous accelerations that are at least 3 m/s^2. This shall be verified upon initial installation and after major maintenance.

2.2.6. The base inertia of the dynamometer shall be stated by the dynamometer manufacturer and shall be confirmed to within ± 0.5 per cent for each measured base inertia and ± 0.2 per cent relative to any arithmetic average value by dynamic derivation from trials at constant acceleration, deceleration and force.

2.2.7. Roller speed shall be measured at a frequency of not less than 10 Hz.

2.3. Additional specific requirements for a chassis dynamometer in 4WD operation

2.3.1. The 4WD control system of the dynamometer shall be designed such that the following requirements are fulfilled when tested with a vehicle driven over the WLTC.

2.3.1.1. Road load simulation shall be applied such that the dynamometer in 4WD operation reproduces the same proportioning of forces as would be encountered when driving the vehicle on a smooth, dry, level road surface.

2.3.1.2. Upon initial installation and after major maintenance, the requirements of paragraph 2.3.1.2.1. of this Sub-Annex and either paragraph 2.3.1.2.2. or 2.3.1.2.3. of this Sub-Annex shall be satisfied. The speed difference between the front and rear rollers is assessed by applying a 1 second moving average filter to roller speed data acquired at a minimum frequency of 20 Hz.

2.3.1.2.1. The difference in distance covered by the front and rear rollers shall be less than 0.2 per cent of the distance driven over the WLTC. The absolute number shall be integrated for the calculation of the total difference in distance over the WLTC.

2.3.1.2.2. The difference in distance covered by the front and rear rollers shall be less than 0.1 m in any 200 ms time period.

2.3.1.2.3. The speed difference of all roller speeds shall be within +/- 0.16 km/h.

2.4. Chassis dynamometer calibration

2.4.1. Force measurement system

The accuracy of the force transducer shall be at least ±10 N for all measured increments. This shall be verified upon initial installation, after major maintenance and within 370 days before testing.

2.4.2. Dynamometer parasitic loss calibration

The dynamometer's parasitic losses shall be measured and updated if any measured value differs from the current loss curve by more than 9.0 N. This shall be verified upon initial installation, after major maintenance and within 35 days before testing.

2.4.3. Verification of road load simulation without a vehicle

The dynamometer performance shall be verified by performing an unloaded coastdown test upon initial installation, after major maintenance, and within 7 days before testing. The arithmetic average coastdown force error shall be less than 10 N or 2 per cent, whichever is greater, at each reference speed point.

3. Exhaust gas dilution system

3.1. System specification

3.1.1. Overview

3.1.1.1. A full flow exhaust dilution system shall be used. The total vehicle exhaust shall be continuously diluted with ambient air under controlled conditions using a constant volume sampler. A critical flow venturi (CFV) or multiple critical flow venturis arranged in parallel, a positive displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM) may be used. The total volume of the mixture of exhaust and dilution air shall be measured and a continuously proportional sample of the volume shall be collected for analysis. The quantities of exhaust gas compounds shall be determined from the sample concentrations, corrected for their respective content of the dilution air and the totalised flow over the test period.

3.1.1.2. The exhaust dilution system shall consist of a connecting tube, a mixing device and dilution tunnel, dilution air conditioning, a suction device and a flow measurement device. Sampling probes shall be fitted in the dilution tunnel as specified in paragraphs 4.1., 4.2. and 4.3. of this Sub-Annex.

3.1.1.3. The mixing device referred to in paragraph 3.1.1.2. of this Sub-Annex shall be a vessel such as that illustrated in Figure A5/3 in which vehicle exhaust gases and the dilution air are combined so as to produce a homogeneous mixture at the sampling position.

3.2. General requirements

3.2.1. The vehicle exhaust gases shall be diluted with a sufficient amount of ambient air to prevent any water condensation in the sampling and measuring system at all conditions that may occur during a test.

3.2.2. The mixture of air and exhaust gases shall be homogeneous at the point where the sampling probes are located (paragraph 3.3.3. of this Sub-Annex). The sampling probes shall extract representative samples of the diluted exhaust gas.

3.2.3. The system shall enable the total volume of the diluted exhaust gases to be measured.

3.2.4. The sampling system shall be gas-tight. The design of the variable dilution sampling system and the materials used in its construction shall be such that the concentration of any compound in the diluted exhaust gases is not affected. If any component in the system (heat exchanger, cyclone separator, suction device, etc.) changes the concentration of any of the exhaust gas compounds and the systematic error cannot be corrected, sampling for that compound shall be carried out upstream from that component.

3.2.5. All parts of the dilution system in contact with raw or diluted exhaust gas shall be designed to minimise deposition or alteration of the particulate or particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

3.2.6. If the vehicle being tested is equipped with an exhaust pipe comprising several branches, the connecting tubes shall be connected as near as possible to the vehicle without adversely affecting their operation.

3.3. Specific requirements

3.3.1. Connection to vehicle exhaust

3.3.1.1. The start of the connecting tube is the exit of the tailpipe. The end of the connecting tube is the sample point, or first point of dilution.

For multiple tailpipe configurations where all the tailpipes are combined, the start of the connecting tube shall be taken at the last joint of where all the tailpipes are combined. In this case, the tube between the exit of the tailpipe and the start of the connecting tube may or may not be insulated or heated.

3.3.1.2. The connecting tube between the vehicle and dilution system shall be designed so as to minimize heat loss.

3.3.1.3. The connecting tube shall satisfy the following requirements:

(a) Be less than 3.6 metres long, or less than 6.1 metres long if heat-insulated. Its internal diameter shall not exceed 105 mm; the insulating materials shall have a thickness of at least 25 mm and thermal conductivity shall not exceed 0.1 $W/m^{-1}K^{-1}$ at 400 °C. Optionally, the tube may be heated to a temperature above the dew point. This may be assumed to be achieved if the tube is heated to 70 °C;

(b) Not cause the static pressure at the exhaust outlets on the vehicle being tested to differ by more than $\pm$ 0.75 kPa at 50 km/h, or more than $\pm$ 1.25 kPa for the duration of the test from the static pressures recorded when nothing is connected to the vehicle exhaust pipes. The pressure shall be measured in the exhaust outlet or in an extension having the same diameter and as near as possible to the end of the tailpipe. Sampling systems capable of maintaining the static pressure to within $\pm$ 0.25 kPa may be used if a written request from a manufacturer to the approval authority substantiates the need for the closer tolerance;

(c) No component of the connecting tube shall be of a material that might affect the gaseous or solid composition of the exhaust gas. To avoid generation of any particles from elastomer connectors, elastomers employed shall be as thermally stable as possible and have minimum exposure to the exhaust gas. It is recommended not to use elastomer connectors to bridge the connection between the vehicle exhaust and the connecting tube.

3.3.2. Dilution air conditioning

3.3.2.1. The dilution air used for the primary dilution of the exhaust in the CVS tunnel shall pass through a medium capable of reducing particles of the most penetrating particle size in the filter material by ≤ 99.95 per cent, or through a filter of at least class H13 of EN 1822:2009. This represents the specification of High Efficiency Particulate Air (HEPA) filters. The dilution air may optionally be charcoal-scrubbed before being passed to the HEPA filter. It is recommended that an additional coarse particle filter be situated before the HEPA filter and after the charcoal scrubber, if used.

3.3.2.2. [Reserved]

3.3.3. Dilution tunnel

3.3.3.1. Provision shall be made for the vehicle exhaust gases and the dilution air to be mixed. A mixing device may be used.

3.3.3.2. The homogeneity of the mixture in any cross-section at the location of the sampling probe shall not vary by more than ± 2 per cent from the arithmetic average of the values obtained for at least five points located at equal intervals on the diameter of the gas stream.

3.3.3.3. . For PM and PN emissions sampling, a dilution tunnel shall be used that:

(a) Consists of a straight tube of electrically-conductive material that is grounded;

(b) Causes turbulent flow (Reynolds number ≥ 4,000) and be of sufficient length to cause complete mixing of the exhaust and dilution air;

(c) Is at least 200 mm in diameter;

(d) May be insulated and/or heated.

3.3.4. Suction device

3.3.4.1. This device may have a range of fixed speeds to ensure sufficient flow to prevent any water condensation. This result is obtained if the flow is either:

(a) Twice as high as the maximum flow of exhaust gas produced by accelerations of the driving cycle; or

(b) Sufficient to ensure that the CO_2 concentration in the dilute exhaust sample bag is less than 3 per cent by volume for petrol and diesel, less than 2.2 per cent by volume for LPG and less than 1.5 per cent by volume for NG/biomethane.

3.3.4.2. Compliance with the requirements in paragraph 3.3.4.1. of this Sub-Annex may not be necessary if the CVS system is designed to inhibit condensation by such techniques, or combination of techniques, as:

(a) Reducing water content in the dilution air (dilution air dehumidification);

(b) Heating of the CVS dilution air and of all components up to the diluted exhaust flow measurement device and, optionally, the bag sampling system including the sample bags and also the system for the measurement of the bag concentrations.

In such cases, the selection of the CVS flow rate for the test shall be justified by showing that condensation of water cannot occur at any point within the CVS, bag sampling or analytical system.

3.3.5. Volume measurement in the primary dilution system

3.3.5.1. The method of measuring total dilute exhaust volume incorporated in the constant volume sampler shall be such that measurement is accurate to ± 2 per cent under all operating conditions. If the device cannot compensate for variations in the temperature of the mixture of exhaust gases and dilution air at the measuring point, a heat exchanger shall be used to maintain the temperature to within ± 6 °C of the specified operating temperature for a PDP CVS, ± 11 °C for a CFV CVS, ± 6 °C for a UFM CVS, and ± 11 °C for an SSV CVS.

3.3.5.2. If necessary, some form of protection for the volume measuring device may be used e.g. a cyclone separator, bulk stream filter, etc.

3.3.5.3. A temperature sensor shall be installed immediately before the volume measuring device. This temperature sensor shall have an accuracy of ±1 °C and a response time of 0,1 seconds at 62 per cent of a given temperature variation (value measured in silicone oil).

3.3.5.4. Measurement of the pressure difference from atmospheric pressure shall be taken upstream from and, if necessary, downstream from the volume measuring device.

3.3.5.5. The pressure measurements shall have a precision and an accuracy of ± 0.4 kPa during the test. See Table A5/5.

3.3.6. Recommended system description

Figure A5/3 is a schematic drawing of exhaust dilution systems that meet the requirements of this Sub-Annex.

The following components are recommended:

(a) A dilution air filter, which may be pre-heated if necessary. This filter shall consist of the following filters in sequence: an optional activated charcoal filter (inlet side), and a HEPA filter (outlet side). It is recommended that an additional coarse particle filter be situated before the HEPA filter and after the charcoal filter, if used. The purpose of the charcoal filter is to reduce and stabilize the hydrocarbon concentrations of ambient emissions in the dilution air;

(b) A connecting tube by which vehicle exhaust is admitted into a dilution tunnel;

(c) An optional heat exchanger as described in paragraph 3.3.5.1. of this Sub-Annex;

(d) A mixing device in which exhaust gas and dilution air are mixed homogeneously, and which may be located close to the vehicle so that the length of the connecting tube is minimized;

(e) A dilution tunnel from which particulate and particles are sampled;

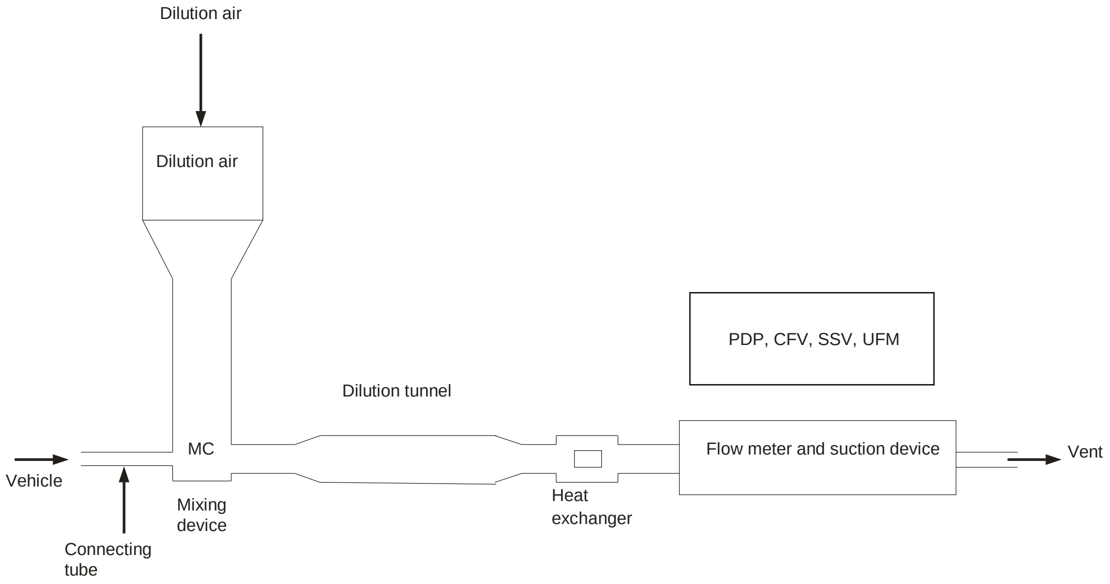
(f) Some form of protection for the measurement system may be used e.g. a cyclone separator, bulk stream filter, etc.;

(g) A suction device of sufficient capacity to handle the total volume of diluted exhaust gas.

Exact conformity with these figures is not essential. Additional components such as instruments, valves, solenoids and switches may be used to provide additional information and co-ordinate the functions of the component system.

Figure A5/3

Exhaust dilution system



3.3.6.1. Positive displacement pump (PDP)

A positive displacement pump (PDP) full flow exhaust dilution system satisfies the requirements of this Sub-Annex by metering the flow of gas through the pump at constant temperature and pressure. The total volume is measured by counting the revolutions made by the calibrated positive displacement pump. The proportional sample is achieved by sampling with pump, flow meter and flow control valve at a constant flow rate.

3.3.6.2. Critical flow venturi (CFV)

3.3.6.2.1. The use of a CFV for the full flow exhaust dilution system is based on the principles of flow mechanics for critical flow. The variable mixture flow rate of dilution and exhaust gas is maintained at sonic velocity that is directly proportional to the square root of the gas temperature. Flow is continually monitored, computed and integrated throughout the test.

3.3.6.2.2. The use of an additional critical flow sampling venturi ensures the proportionality of the gas samples taken from the dilution tunnel. As both pressure and temperature are equal at the two venturi inlets, the volume of the gas flow diverted for sampling is proportional to the total volume of diluted exhaust gas mixture produced, and thus the requirements of this Sub-Annex are fulfilled.

3.3.6.2.3. A measuring CFV tube shall measure the flow volume of the diluted exhaust gas.

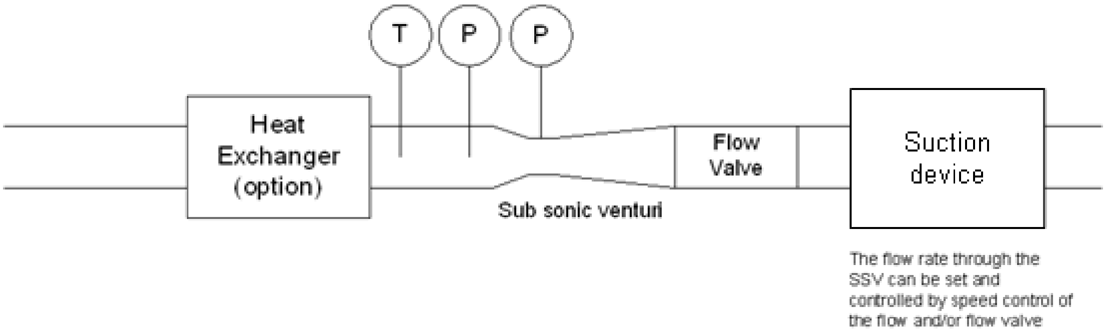
3.3.6.3. Subsonic flow venturi (SSV)

3.3.6.3.1. The use of an SSV (Figure A5/4) for a full flow exhaust dilution system is based on the principles of flow mechanics. The variable mixture flow rate of dilution and exhaust gas is maintained at a subsonic velocity that is calculated from the physical dimensions of the subsonic venturi and measurement of the absolute temperature (T) and pressure (P) at the venturi inlet and the pressure in the throat of the venturi. Flow is continually monitored, computed and integrated throughout the test.

3.3.6.3.2. An SSV shall measure the flow volume of the diluted exhaust gas.

Figure A5/4

Schematic of a subsonic venturi tube (SSV)



3.3.6.4. Ultrasonic flow meter (UFM)

3.3.6.4.1. A UFM measures the velocity of the diluted exhaust gas in the CVS piping using the principle of ultrasonic flow detection by means of a pair, or multiple pairs, of ultrasonic transmitters/receivers mounted within the pipe as in Figure A5/5. The velocity of the flowing gas is determined by the difference in the time required for the ultrasonic signal to travel from transmitter to receiver in the upstream direction and the downstream direction. The gas velocity is converted to standard volumetric flow using a calibration factor for the tube diameter with real time corrections for the diluted exhaust temperature and absolute pressure.

3.3.6.4.2. Components of the system include:

(a) A suction device fitted with speed control, flow valve or other method for setting the CVS flow rate and also for maintaining constant volumetric flow at standard conditions;

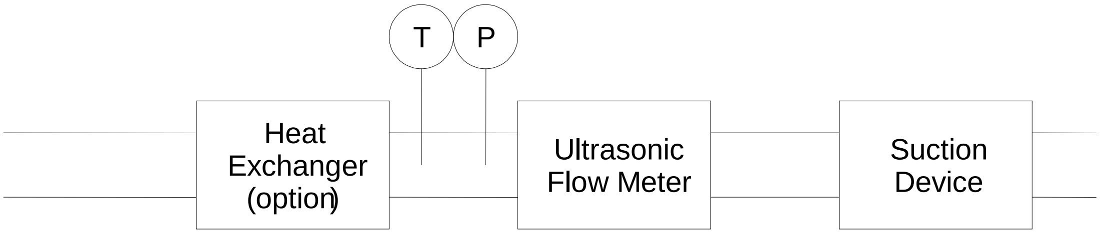
(b) A UFM;

(c) Temperature and pressure measurement devices, T and P, required for flow correction;

(d) An optional heat exchanger for controlling the temperature of the diluted exhaust to the UFM. If installed, the heat exchanger shall be capable of controlling the temperature of the diluted exhaust to that specified in paragraph 3.3.5.1. of this Sub-Annex. Throughout the test, the temperature of the air/exhaust gas mixture measured at a point immediately upstream of the suction device shall be within ± 6 °C of the arithmetic average operating temperature during the test.

Figure A5/5

Schematic of an ultrasonic flow meter (UFM)



3.3.6.4.3. The following conditions shall apply to the design and use of the UFM type CVS:

(a) The velocity of the diluted exhaust gas shall provide a Reynolds number higher than 4,000 in order to maintain a consistent turbulent flow before the ultrasonic flow meter;

(b) An ultrasonic flow meter shall be installed in a pipe of constant diameter with a length of 10 times the internal diameter upstream and 5 times the diameter downstream;

(c) A temperature sensor (T) for the diluted exhaust shall be installed immediately before the ultrasonic flow meter. This sensor shall have an accuracy of ±1 °C and a response time of 0,1 seconds at 62 per cent of a given temperature variation (value measured in silicone oil);

(d) The absolute pressure (P) of the diluted exhaust shall be measured immediately before the ultrasonic flow meter to within ± 0.3 kPa;

(e) If a heat exchanger is not installed upstream of the ultrasonic flow meter, the flow rate of the diluted exhaust, corrected to standard conditions, shall be maintained at a constant level during the test. This may be achieved by control of the suction device, flow valve or other method.

3.4. CVS calibration procedure

3.4.1. General requirements

3.4.1.1. The CVS system shall be calibrated by using an accurate flow meter and a restricting device and at the intervals listed in Table A5/4. The flow through the system shall be measured at various pressure readings and the control parameters of the system measured and related to the flows. The flow metering device (e.g. calibrated venturi, laminar flow element (LFE), calibrated turbine meter) shall be dynamic and suitable for the high flow rate encountered in constant volume sampler testing. The device shall be of certified accuracy.

3.4.1.2. The following paragraphs describe methods for calibrating PDP, CFV, SSV and UFM units using a laminar flow meter, which gives the required accuracy, along with a statistical check on the calibration validity.

3.4.2. Calibration of a positive displacement pump (PDP)

3.4.2.1. The following calibration procedure outlines the equipment, the test configuration and the various parameters that are measured to establish the flow rate of the CVS pump. All the parameters related to the pump are simultaneously measured with the parameters related to the flow meter that is connected in series with the pump. The calculated flow rate (given in m^3/min at pump inlet for the measured absolute pressure and temperature) shall be subsequently plotted versus a correlation function that includes the relevant pump parameters. The linear equation that relates the pump flow and the correlation function shall be subsequently determined. In the case that a CVS has a multiple speed drive, a calibration for each range used shall be performed.

3.4.2.2. This calibration procedure is based on the measurement of the absolute values of the pump and flow meter parameters relating the flow rate at each point. The following conditions shall be maintained to ensure the accuracy and integrity of the calibration curve:

3.4.2.2.1. The pump pressures shall be measured at tappings on the pump rather than at the external piping on the pump inlet and outlet. Pressure taps that are mounted at the top centre and bottom centre of the pump drive head plate are exposed to the actual pump cavity pressures, and therefore reflect the absolute pressure differentials.

3.4.2.2.2. Temperature stability shall be maintained during the calibration. The laminar flow meter is sensitive to inlet temperature oscillations that cause data points to be scattered. Gradual changes of ± 1 °C in temperature are acceptable as long as they occur over a period of several minutes.

3.4.2.2.3. All connections between the flow meter and the CVS pump shall be free of leakage.

3.4.2.3. During an exhaust emissions test, the measured pump parameters shall be used to calculate the flow rate from the calibration equation.

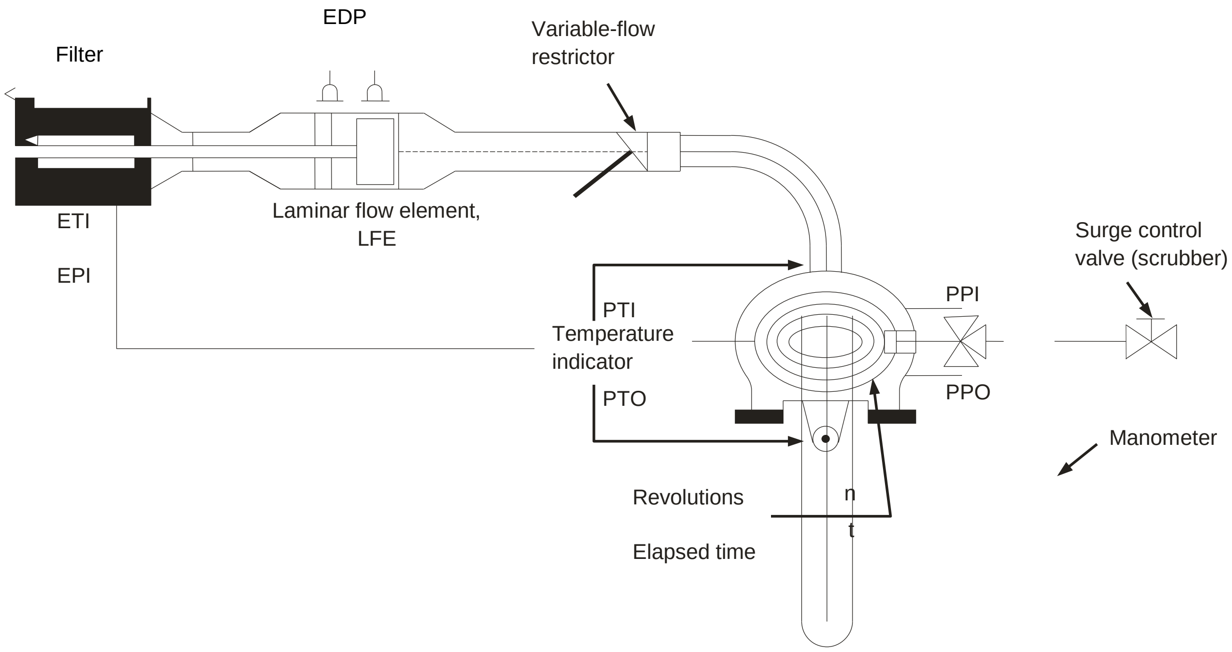
3.4.2.4. Figure A5/6 of this Sub-Annex shows an example of a calibration set-up. Variations are permissible, provided that the approval authority approves them as being of comparable accuracy. If the set-up shown in Figure A5/6 is used, the following data shall be found within the limits of accuracy given:

Barometric pressure (corrected), P_b	± 0.03 kPa
Ambient temperature, T	± 0.2 °C
Air temperature at LFE, ETI	± 0.15 °C
Pressure depression upstream of LFE, EPI	± 0.01 kPa
Pressure drop across the LFE matrix, EDP	± 0.0015 kPa
Air temperature at CVS pump inlet, PTI	± 0.2 °C
Air temperature at CVS pump outlet, PTO	± 0.2 °C
Pressure depression at CVS pump inlet, PPI	± 0.22 kPa
Pressure head at CVS pump outlet, PPO	± 0.22 kPa
Pump revolutions during test period, n	± 1 min^{-1}

Elapsed time for period (minimum 250 s), t ± 0.1 s

Figure A5/6

PDP calibration configuration



3.4.2.5. After the system has been connected as shown in Figure A5/6., the variable restrictor shall be set in the wide-open position and the CVS pump shall run for 20 minutes before starting the calibration.

3.4.2.5.1. The restrictor valve shall be reset to a more restricted condition in increments of pump inlet depression (about 1 kPa) that will yield a minimum of six data points for the total calibration. The system shall be allowed to stabilize for 3 minutes before the data acquisition is repeated.

3.4.2.5.2. The air flow rate Q_s at each test point shall be calculated in standard m^3/min from the flow meter data using the manufacturer's prescribed method.

3.4.2.5.3. The air flow rate shall be subsequently converted to pump flow V_0 in m^3/rev at absolute pump inlet temperature and pressure.

$$V_0 = \frac{Q_s}{n} \times \frac{T_p}{273.15\ K} \times \frac{101.325\ kPa}{P_p}$$

where:

V_0 is the pump flow rate at T_p and P_p, m^3/rev;

Q_s is the air flow at 101.325 kPa and 273.15 K (0 °C), m^3/min;

T_p is the pump inlet temperature, Kelvin (K);

P_p is the absolute pump inlet pressure, kPa;

n is the pump speed, min^{-1}.

3.4.2.5.4. To compensate for the interaction of pump speed pressure variations at the pump and the pump slip rate, the correlation function x_0 between the pump speed n, the pressure differential from pump inlet to pump outlet and the absolute pump outlet pressure shall be calculated using the following equation:

$$x_0 = \frac{1}{n}\sqrt{\frac{\Delta P_p}{P_e}}$$

where:

x_0 is the correlation function;

ΔP_p is the pressure differential from pump inlet to pump outlet, kPa;

P_e absolute outlet pressure$(PPO + P_b)$, kPa.

A linear least squares fit shall be performed to generate the calibration equations having the following form:

$$V_0 = D_0 - M \times x_0$$

$$n = A - B \times \Delta P_p$$

where B and M are the slopes, and A and D_0 are the intercepts of the lines.

3.4.2.6. A CVS system having multiple speeds shall be calibrated at each speed used. The calibration curves generated for the ranges shall be approximately parallel and the intercept values, D_0 shall increase as the pump flow range decreases.

3.4.2.7. The calculated values from the equation shall be within 0.5 per cent of the measured value of V_0. Values of M will vary from one pump to another. A calibration shall be performed at initial installation and after major maintenance.

3.4.3. Calibration of a critical flow venturi (CFV)

3.4.3.1. Calibration of a CFV is based upon the flow equation for a critical venturi:

$$Q_s = \frac{K_v P}{\sqrt{T}}$$

where:

Q_s is the flow, m^3/min;

K_v	is the calibration coefficient;
P	is the absolute pressure, kPa;
T	is the absolute temperature, Kelvin (K).

Gas flow is a function of inlet pressure and temperature.

The calibration procedure described in paragraph 3.4.3.2. to 3.4.3.3.3.4. inclusive of this Sub-Annex establishes the value of the calibration coefficient at measured values of pressure, temperature and air flow.

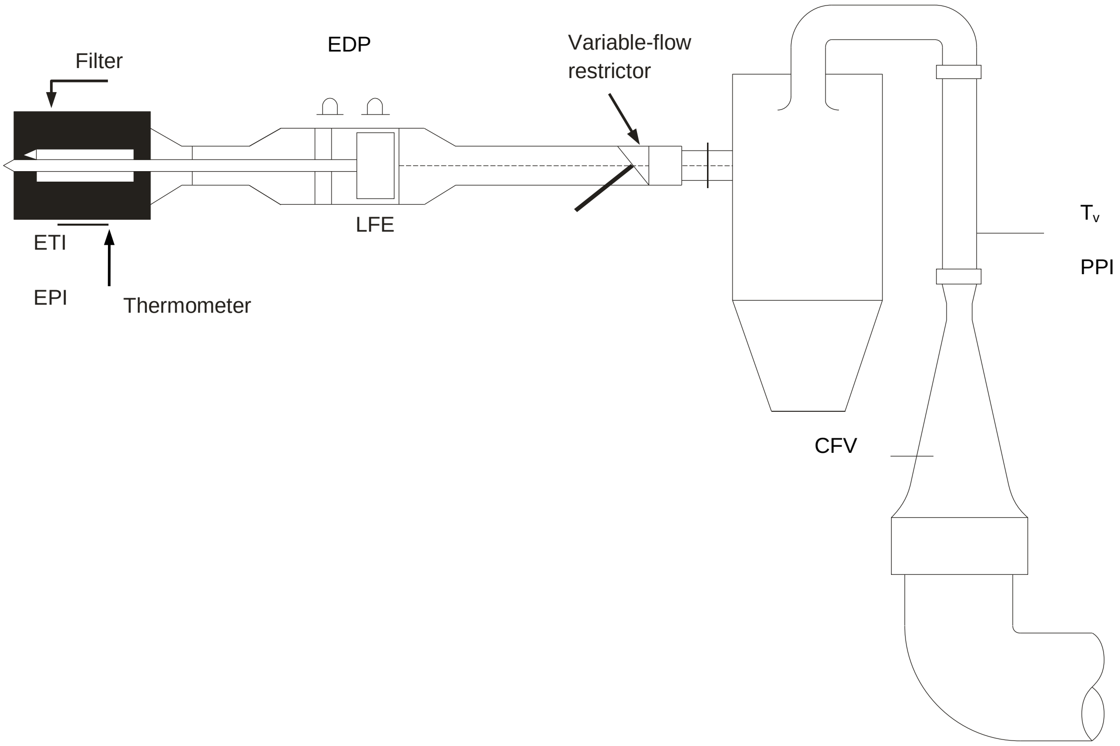
3.4.3.2. Measurements for flow calibration of a critical flow venturi are required and the following data shall be within the limits of accuracy given:

Barometric pressure (corrected), P_b	± 0.03 kPa,
LFE air temperature, flow meter, ETI	± 0.15 °C,
Pressure depression upstream of LFE, EPI	± 0.01 kPa,
Pressure drop across LFE matrix, EDP	± 0.0015 kPa,
Air flow, Q_s	± 0.5 per cent,
CFV inlet depression, PPI	± 0.02 kPa,
Temperature at venturi inlet, T_v	± 0.2 °C.

3.4.3.3. The equipment shall be set up as shown in Figure A5/7 and checked for leaks. Any leaks between the flow-measuring device and the critical flow venturi will seriously affect the accuracy of the calibration and shall therefore be prevented.

Figure A5/7

CFV calibration configuration



3.4.3.3.1. The variable-flow restrictor shall be set to the open position, the suction device shall be started and the system stabilized. Data from all instruments shall be collected.

3.4.3.3.2. The flow restrictor shall be varied and at least eight readings across the critical flow range of the venturi shall be made.

3.4.3.3.3. The data recorded during the calibration shall be used in the following calculation:

3.4.3.3.3.1. The air flow rate, Q_s at each test point shall be calculated from the flow meter data using the manufacturer's prescribed method.

Values of the calibration coefficient shall be calculated for each test point:

$$K_v = \frac{Q_s \sqrt{T_v}}{P_v}$$

where:

Q_s is the flow rate, m^3/min at 273.15 K (0 °C) and 101.325, kPa;

T_v is the temperature at the venturi inlet, Kelvin (K);

P_v is the absolute pressure at the venturi inlet, kPa.

3.4.3.3.3.2. K_v shall be plotted as a function of venturi inlet pressure P_v. For sonic flow K_v will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and K_v decreases. These values of K_v shall not be used for further calculations.

3.4.3.3.3.3. For a minimum of eight points in the critical region, an arithmetic average K_v and the standard deviation shall be calculated.

3.4.3.3.3.4. If the standard deviation exceeds 0.3 per cent of the arithmetic average K_v, corrective action shall be taken.

3.4.4. Calibration of a subsonic venturi (SSV)

3.4.4.1. Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, and the pressure drop between the SSV inlet and throat.

3.4.4.2. Data analysis

3.4.4.2.1. The airflow rate, Q_{SSV}, at each restriction setting (minimum 16 settings) shall be calculated in standard m³/s from the flow meter data using the manufacturer's prescribed method. The discharge coefficient, C_d, shall be calculated from the calibration data for each setting using the following equation:

$$C_d = \frac{Q_{SSV}}{d_V^2 \times p_p \times \sqrt{\left\{\frac{1}{T} \times \left(r_p^{1.426} - r_p^{1.713}\right) \times \left(\frac{1}{1 - r_D^4 \times r_p^{1.426}}\right)\right\}}}$$

where:

Q_{SSV} is the airflow rate at standard conditions (101.325 kPa, 273.15 K (0 °C)), m³/s;

T is the temperature at the venturi inlet, Kelvin (K);

d_V is the diameter of the SSV throat, m;

r_p is the ratio of the SSV throat pressure to inlet absolute static pressure, $1 - \frac{\Delta p}{p_p}$;

r_D is the ratio of the SSV throat diameter, d_V, to the inlet pipe inner diameter D;

C_d is the discharge coefficient of the SSV;

p_p is the absolute pressure at venturi inlet, kPa.

To determine the range of subsonic flow, C_d shall be plotted as a function of Reynolds number Re at the SSV throat. The Reynolds number at the SSV throat shall be calculated using the following equation:

$$\mathrm{Re} = A_1 \times \frac{Q_{SSV}}{d_V \times \mu}$$

where:

$$\mu = \frac{b \times T^{1.5}}{S + T}$$

A_1 is 25.55152 in SI, $\left(\frac{1}{m^3}\right)\left(\frac{min}{s}\right)\left(\frac{mm}{m}\right)$;

Q_{SSV} is the airflow rate at standard conditions (101.325 kPa, 273.15 K (0 °C)), m^3/s;

d_V is the diameter of the SSV throat, m;

μ is the absolute or dynamic viscosity of the gas, kg/ms;

b is 1.458×10^6 (empirical constant), kg/ms $K^{0.5}$;

S is 110.4 (empirical constant), Kelvin (K).

3.4.4.2.2. Because Q_{SSV} is an input to the Re equation, the calculations shall be started with an initial guess for Q_{SSV} or C_d of the calibration venturi, and repeated until Q_{SSV} converges. The convergence method shall be accurate to at least 0.1 per cent.

3.4.4.2.3. For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation shall be within ± 0.5 per cent of the measured C_d for each calibration point.

3.4.5. Calibration of an ultrasonic flow meter (UFM)

3.4.5.1. The UFM shall be calibrated against a suitable reference flow meter.

3.4.5.2. The UFM shall be calibrated in the CVS configuration that will be used in the test cell (diluted exhaust piping, suction device) and checked for leaks. See Figure A5/8.

3.4.5.3. A heater shall be installed to condition the calibration flow in the event that the UFM system does not include a heat exchanger.

3.4.5.4. For each CVS flow setting that will be used, the calibration shall be performed at temperatures from room temperature to the maximum that will be experienced during vehicle testing.

3.4.5.5. The manufacturer's recommended procedure shall be followed for calibrating the electronic portions (temperature (T) and pressure (P) sensors) of the UFM.

3.4.5.6. Measurements for flow calibration of the ultrasonic flow meter are required and the following data (in the case that a laminar flow element is used) shall be found within the limits of accuracy given:

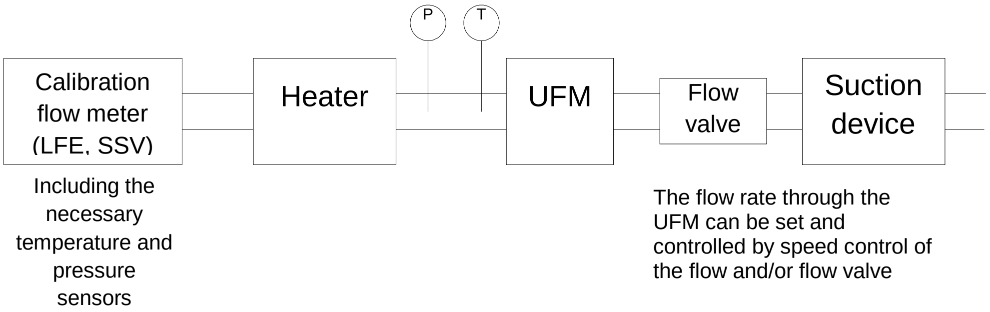
Barometric pressure (corrected), P_b	± 0.03 kPa,
LFE air temperature, flow meter, ETI	± 0.15 °C,
Pressure depression upstream of LFE, EPI	± 0.01 kPa,
Pressure drop across (EDP) LFE matrix	± 0.0015 kPa,
Air flow, Q_s	± 0.5 per cent,
UFM inlet depression, P_{act}	± 0.02 kPa,
Temperature at UFM inlet, T_{act}	± 0.2 °C.

3.4.5.7. Procedure

3.4.5.7.1. The equipment shall be set up as shown in Figure A5/8 and checked for leaks. Any leaks between the flow-measuring device and the UFM will seriously affect the accuracy of the calibration.

Figure A5/8

UFM calibration configuration



3.4.5.7.2. The suction device shall be started. Its speed and/or the position of the flow valve shall be adjusted to provide the set flow for the validation and the system stabilised. Data from all instruments shall be collected.

3.4.5.7.3. For UFM systems without a heat exchanger, the heater shall be operated to increase the temperature of the calibration air, allowed to stabilise and data from all the instruments recorded. The temperature shall be increased in reasonable steps until the maximum expected diluted exhaust temperature expected during the emissions test is reached.

3.4.5.7.4. The heater shall be subsequently turned off and the suction device speed and/or flow valve shall be adjusted to the next flow setting that will be used for vehicle emissions testing after which the calibration sequence shall be repeated.

3.4.5.8. The data recorded during the calibration shall be used in the following calculations. The air flow rate Q_s at each test point shall be calculated from the flow meter data using the manufacturer's prescribed method.

$$\mathrm{K_v} = \frac{\mathrm{Q_{reference}}}{\mathrm{Q_s}}$$

where:

$\mathrm{Q_s}$ is the air flow rate at standard conditions (101.325 kPa, 273.15 K (0 °C)), m^3/s;

$\mathrm{Q_{reference}}$ is the air flow rate of the calibration flow meter at standard conditions (101.325 kPa, 273.15 K (0 °C)), m^3/s;

$\mathrm{K_v}$ is the calibration coefficient.

For UFM systems without a heat exchanger, K_v shall be plotted as a function of T_{act}.

The maximum variation in K_v shall not exceed 0.3 per cent of the arithmetic average K_v value of all the measurements taken at the different temperatures.

3.5. System verification procedure

3.5.1. General requirements

3.5.1.1. The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of an emissions gas compound into the system whilst it is being operated under normal test conditions and subsequently analysing and calculating the emission gas compounds according to the equations of Sub-Annex 7. The CFO method described in paragraph 3.5.1.1.1. of this Sub-Annex and the gravimetric method described in paragraph 3.5.1.1.2. of this Sub-Annex are both known to give sufficient accuracy.

The maximum permissible deviation between the quantity of gas introduced and the quantity of gas measured is± 2 per cent.

3.5.1.1.1. Critical flow orifice (CFO) method

The CFO method meters a constant flow of pure gas (CO, CO_2, or C_3H_8) using a critical flow orifice device.

A known mass of pure carbon monoxide, carbon dioxide or propane gas shall be introduced into the CVS system through the calibrated critical orifice. If the inlet pressure is high enough, the flow rate q which is restricted by means of the critical flow orifice, is independent of orifice outlet pressure (critical flow). The CVS system shall be operated as in a normal exhaust emissions test and enough time shall be allowed for subsequent analysis. The gas collected in the sample bag shall be analysed by the usual equipment (paragraph 4.1. of this Sub- Annex) and the results compared to the concentration of the known gas samples if deviations exceed 2 per cent, the cause of the malfunction shall be determined and corrected.

3.5.1.1.2. Gravimetric method

The gravimetric method weighs a quantity of pure gas (CO, CO_2, or C_3H_8).

The weight of a small cylinder filled with either pure carbon monoxide, carbon dioxide or propane shall be determined with a precision of ± 0,01 g. The CVS system shall operate under normal exhaust emissions test conditions while the pure gas is injected into the system for a time sufficient for subsequent analysis. The quantity of pure gas involved shall be determined by means of differential weighing. The gas accumulated in the bag shall be analysed by means of the equipment normally used for exhaust gas analysis as described in paragraph 4.1.). The results shall be subsequently compared to the concentration figures computed previously. If deviations exceed ±2 per cent, the cause of the malfunction shall be determined and corrected.

4. Emissions measurement equipment

4.1. Gaseous emissions measurement equipment

4.1.1. System overview

4.1.1.1. A continuously proportional sample of the diluted exhaust gases and the dilution air shall be collected for analysis.

4.1.1.2. The mass of gaseous emissions shall be determined from the proportional sample concentrations and the total volume measured during the test. Sample concentrations shall be corrected to take into account the respective compound concentrations in dilution air.

4.1.2. Sampling system requirements

4.1.2.1. The sample of diluted exhaust gases shall be taken upstream from the suction device.

With the exception of paragraph 4.1.3.1. (hydrocarbon sampling system), paragraph 4.2. (PM measurement equipment) and paragraph 4.3. (PN measurement equipment), the dilute exhaust gas sample may be taken downstream of the conditioning devices (if any).

4.1.2.2. The bag sampling flow rate shall be set to provide sufficient volumes of dilution air and diluted exhaust in the CVS bags to allow concentration measurement and shall not exceed 0.3 per cent of the flow rate of the dilute exhaust gases, unless the diluted exhaust bag fill volume is added to the integrated CVS volume.

4.1.2.3. A sample of the dilution air shall be taken near the dilution air inlet (after the filter if one is fitted).

4.1.2.4. The dilution air sample shall not be contaminated by exhaust gases from the mixing area.

4.1.2.5. The sampling rate for the dilution air shall be comparable to that used for the dilute exhaust gases.

4.1.2.6. The materials used for the sampling operations shall be such as not to change the concentration of the emissions compounds.

4.1.2.7. Filters may be used in order to extract the solid particles from the sample.

4.1.2.8. Any valve used to direct the exhaust gases shall be of a quick-adjustment, quick-acting type.

4.1.2.9. Quick-fastening, gas-tight connections may be used between three-way valves and the sample bags, the connections sealing themselves automatically on the bag side. Other systems may be used for conveying the samples to the analyser (e.g. three-way stop valves).

4.1.2.10. Sample storage

4.1.2.10.1. The gas samples shall be collected in sample bags of sufficient capacity so as not to impede the sample flow.

4.1.2.10.2. The bag material shall be such as to affect neither the measurements themselves nor the chemical composition of the gas samples by more than ± 2 per cent after 30 minutes (e.g., laminated polyethylene/polyamide films, or fluorinated polyhydrocarbons).

4.1.3. Sampling systems

4.1.3.1. Hydrocarbon sampling system (heated flame ionisation detector, HFID)

4.1.3.1.1. The hydrocarbon sampling system shall consist of a heated sampling probe, line, filter and pump. The sample shall be taken upstream of the heat exchanger (if fitted). The sampling probe shall be installed at the same distance from the exhaust gas inlet as the particulate sampling probe and in such a way that neither interferes with samples taken by the other. It shall have a minimum internal diameter of 4 mm.

4.1.3.1.2. All heated parts shall be maintained at a temperature of 190 °C ± 10 °C by the heating system.

4.1.3.1.3. The arithmetic average concentration of the measured hydrocarbons shall be determined by integration of the second-by-second data divided by the phase or test duration.

4.1.3.1.4. The heated sampling line shall be fitted with a heated filter F_H having a 99 per cent efficiency for particles ≥ 0.3 µm to extract any solid particles from the continuous flow of gas required for analysis.

4.1.3.1.5. The sampling system delay time (from the probe to the analyser inlet) shall be no more than 4 seconds.

4.1.3.1.6. The HFID shall be used with a constant mass flow (heat exchanger) system to ensure a representative sample, unless compensation for varying CVS volume flow is made.

4.1.3.2. NO or NO and NO_2 sampling system (where applicable)

4.1.3.2.1. A continuous sample flow of diluted exhaust gas shall be supplied to the analyser.

4.1.3.2.2. The arithmetic average concentration of the NO or NO_2 shall be determined by integration of the second-by-second data divided by the phase or test duration.

4.1.3.2.3. The continuous NO or NO and NO_2 measurement shall be used with a constant flow (heat exchanger) system to ensure a representative sample, unless compensation for varying CVS volume flow is made.

4.1.4. Analysers

4.1.4.1. General requirements for gas analysis

4.1.4.1.1. The analysers shall have a measuring range compatible with the accuracy required to measure the concentrations of the exhaust gas sample compounds.

4.1.4.1.2. If not defined otherwise, measurement errors shall not exceed ± 2 per cent (intrinsic error of analyser) disregarding the reference value for the calibration gases.

4.1.4.1.3. The ambient air sample shall be measured on the same analyser with the same range.

4.1.4.1.4. No gas drying device shall be used before the analysers unless it is shown to have no effect on the content of the compound in the gas stream.

4.1.4.2. Carbon monoxide (CO) and carbon dioxide (CO_2) analysis

The analysers shall be of the non-dispersive infrared (NDIR) absorption type.

4.1.4.3. Hydrocarbons (HC) analysis for all fuels other than diesel fuel

The analyser shall be of the flame ionization (FID) type calibrated with propane gas expressed in equivalent carbon atoms (C 1).

4.1.4.4. Hydrocarbons (HC) analysis for diesel fuel and optionally for other fuels

The analyser shall be of the heated flame ionization type with detector, valves, pipework, etc., heated to 190 °C ± 10 °C. It shall be calibrated with propane gas expressed equivalent to carbon atoms (C 1).

4.1.4.5. Methane (CH_4) analysis

The analyser shall be either a gas chromatograph combined with a flame ionization detector (FID), or a flame ionization detector (FID) combined with a non-methane cutter (NMC-FID), calibrated with methane or propane gas expressed equivalent to carbon atoms (C 1).

4.1.4.6. Nitrogen oxides (NO_x) analysis

The analysers shall be of chemiluminescent (CLA) or non- dispersive ultra-violet resonance absorption (NDUV) types.

4.1.4.7. Nitrogen oxide (NO) analysis (NO emission values are to be reported separately from NO_x)

The analysers shall be of chemiluminescent (CLA) or non-dispersive ultra-violet resonance absorption (NDUV) types.

4.1.4.8. Nitrogen dioxide (NO_2) analysis (NO_2 emission values are to be reported separately from NO_x)

4.1.4.8.1. Measurement of NO from continuously diluted exhausts

4.1.4.8.1.1. A CLA analyser or a NDUV analyser may be used to measure the NO concentration continuously from diluted exhaust.

4.1.4.8.1.2. The CLA analyser shall be calibrated (zero/calibrated) in the NO mode using the NO certified concentration in the calibration gas cylinder with the NO_x converter bypassed (if installed).

4.1.4.8.1.3. The NO_2 concentration shall be determined by subtracting the NO concentration from the NO_x concentration in the CVS sample bags.

4.1.4.8.2. Measurement of NO_2 from continuously diluted exhausts

4.1.4.8.2.1. A specific NO_2 analyser (NDUV, QCL) may be used to measure the NO_2 concentration continuously from diluted exhaust.

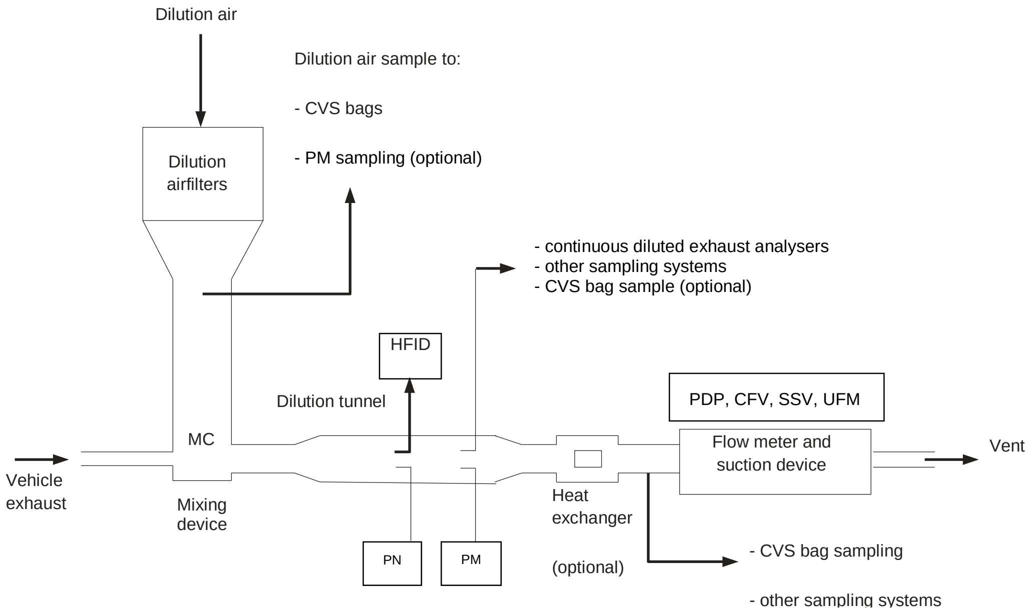
4.1.4.8.2.2. The analyser shall be calibrated (zeroed/ calibrated) in the NO_2 mode using the NO_2 certified concentration in the calibration gas cylinder.

4.1.5. Recommended system descriptions

4.1.5.1. Figure A5/9 is a schematic drawing of the gaseous emissions sampling system.

Figure A5/9

Full flow exhaust dilution system schematic



4.1.5.2. Examples of system components are as listed below.

4.1.5.2.1. Two sampling probes for continuous sampling of the dilution air and of the diluted exhaust gas/air mixture.

4.1.5.2.2. A filter to extract solid particles from the flows of gas collected for analysis.

4.1.5.2.3. Pumps and flow controller to ensure constant uniform flow of diluted exhaust gas and dilution air samples taken during the course of the test from sampling probes and flow of the gas samples shall be such that, at the end of each test, the quantity of the samples is sufficient for analysis.

4.1.5.2.4. Quick-acting valves to divert a constant flow of gas samples into the sample bags or to the outside vent.

4.1.5.2.5. Gas-tight, quick-lock coupling elements between the quick-acting valves and the sample bags. The coupling shall close automatically on the sampling bag side. As an alternative, other methods of transporting the samples to the analyser may be used (three-way stopcocks, for instance).

4.1.5.2.6. Bags for collecting samples of the diluted exhaust gas and of the dilution air during the test.

4.1.5.2.7. A sampling critical flow venturi to take proportional samples of the diluted exhaust gas (CFV-CVS only).

4.1.5.3. Additional components required for hydrocarbon sampling using a heated flame ionization detector (HFID) as shown in Figure A5/10.

4.1.5.3.1. Heated sample probe in the dilution tunnel located in the same vertical plane as the particulate and particle sample probes.

4.1.5.3.2. Heated filter located after the sampling point and before the HFID.

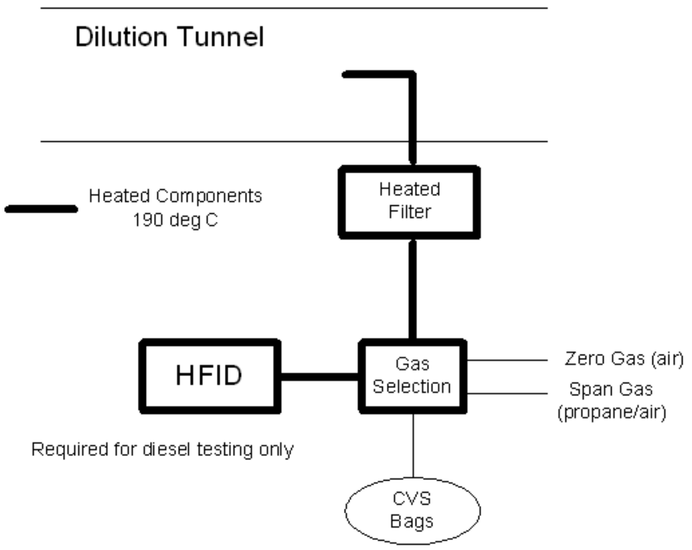
4.1.5.3.3. Heated selection valves between the zero/calibration gas supplies and the HFID.

4.1.5.3.4. Means of integrating and recording instantaneous hydrocarbon concentrations.

4.1.5.3.5. Heated sampling lines and heated components from the heated probe to the HFID.

Figure A5/10

Components required for hydrocarbon sampling using an HFID



4.2. PM measurement equipment

4.2.1. Specification

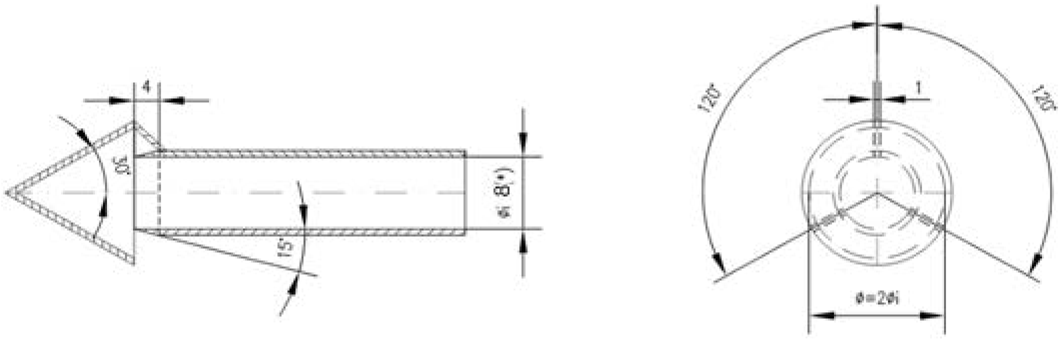
4.2.1.1. System overview

4.2.1.1.1. The particulate sampling unit shall consist of a sampling probe (PSP), located in the dilution tunnel, a particle transfer tube (PTT), a filter holder(s) (FH), pump(s), flow rate regulators and measuring units. See Figures A5/11, A5/12 and A5/13.

4.2.1.1.2. A particle size pre-classifier (PCF), (e.g. cyclone or impactor) may be used. In such case, it is recommended that it be employed upstream of the filter holder.

Figure A5/11

Alternative particulate sampling probe configuration



(*) Minimum internal diameter
Wall thickness ~ 1 mm - Material: stainless steel

4.2.1.2. General requirements

4.2.1.2.1. The sampling probe for the test gas flow for particulate shall be arranged within the dilution tunnel so that a representative sample gas flow can be taken from the homogeneous air/exhaust mixture and shall be upstream of a heat exchanger (if any).

4.2.1.2.2. The particulate sample flow rate shall be proportional to the total mass flow of diluted exhaust gas in the dilution tunnel to within a tolerance of ± 5 per cent of the particulate sample flow rate. The verification of the proportionality of the particulate sampling shall be made during the commissioning of the system and as required by the approval authority.

4.2.1.2.3. The sampled dilute exhaust gas shall be maintained at a temperature above 20 °C and below 52 °C within 20 cm upstream or downstream of the particulate sampling filter face. Heating or insulation of components of the particulate sampling system to achieve this is permitted.

In the event that the 52 °C limit is exceeded during a test where periodic regeneration event does not occur, the CVS flow rate shall be increased or double dilution shall be applied (assuming that the CVS flow rate is already sufficient so as not to cause condensation within the CVS, sample bags or analytical system).

4.2.1.2.4. The particulate sample shall be collected on a single filter mounted within a holder in the sampled dilute exhaust gas flow.

4.2.1.2.5. All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder that are in contact with raw and diluted exhaust gas shall be designed to minimise deposition or alteration of the particulate. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

4.2.1.2.6. If it is not possible to compensate for variations in the flow rate, provision shall be made for a heat exchanger and a temperature control device as specified in paragraphs 3.3.5.1. or 3.3.6.4.2. of this Sub-Annex, so as to ensure that the flow rate in the system is constant and the sampling rate accordingly proportional.

4.2.1.2.7. Temperatures required for the measurement of PM shall be measured with an accuracy of ±1 °C and a response time ($t_{90} - t_{10}$) of 15 seconds or less.

4.2.1.2.8. The sample flow from the dilution tunnel shall be measured with an accuracy of ± 2.5 per cent of reading or ± 1.5 per cent full scale, whichever is the least.

The accuracy specified above of the sample flow from the CVS tunnel is also applicable where double dilution is used. Consequently, the measurement and control of the secondary dilution air flow and diluted exhaust flow rates through the filter shall be of a higher accuracy.

4.2.1.2.9. All data channels required for the measurement of PM shall be logged at a frequency of 1 Hz or faster. Typically these would include:

(a) Diluted exhaust temperature at the particulate sampling filter;

(b) Sampling flow rate;

(c) Secondary dilution air flow rate (if secondary dilution is used);

(d) Secondary dilution air temperature (if secondary dilution is used).

4.2.1.2.10. For double dilution systems, the accuracy of the diluted exhaust transferred from the dilution tunnel V_{ep} defined in paragraph 3.3.2. of Sub-Annex 7 in the equation is not measured directly but determined by differential flow measurement.

The accuracy of the flow meters used for the measurement and control of the double diluted exhaust passing through the particulate sampling filters and for the measurement/control of secondary dilution air shall be sufficient so that the differential volume V_{ep} shall meet the accuracy and proportional sampling requirements specified for single dilution.

The requirement that no condensation of the exhaust gas occur in the CVS dilution tunnel, diluted exhaust flow rate measurement system, CVS bag collection or analysis systems shall also apply in the case that double dilution systems are used.

4.2.1.2.11. Each flow meter used in a particulate sampling and double dilution system shall be subjected to a linearity verification as required by the instrument manufacturer.

Figure A5/12

Particulate sampling system

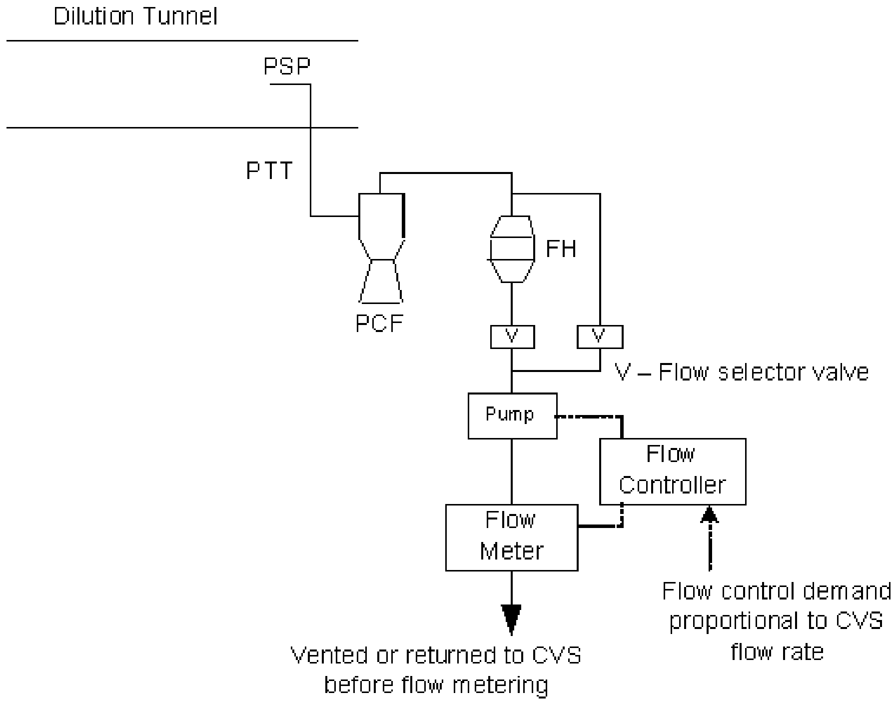
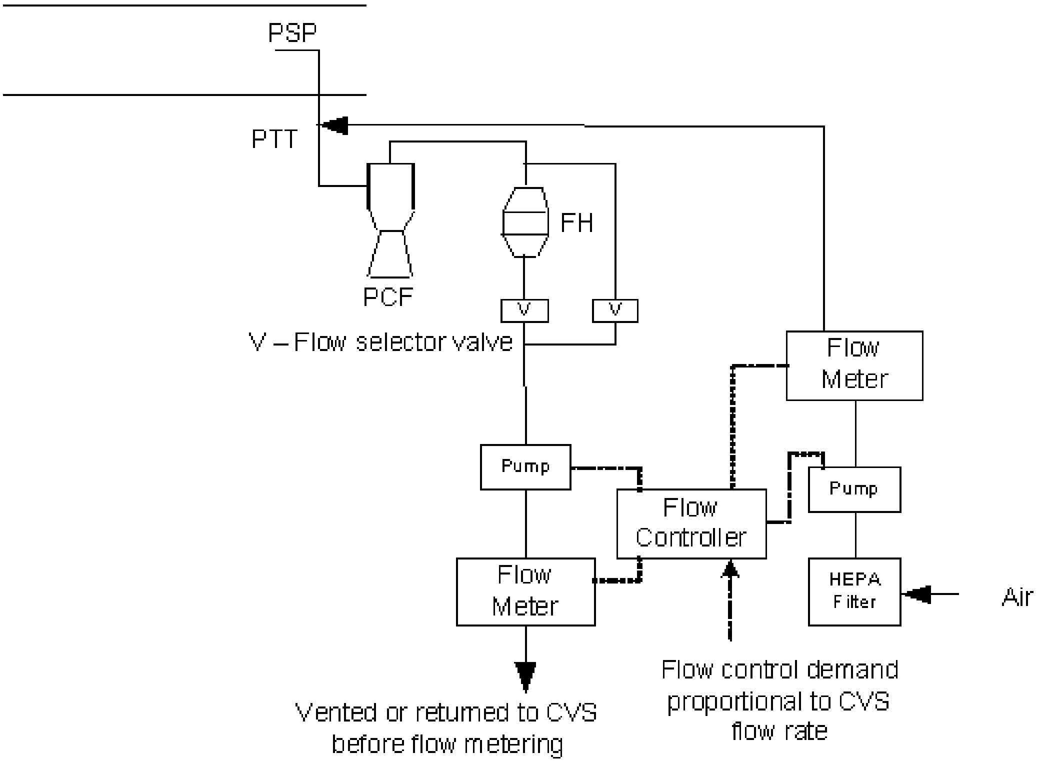

Dilution Tunnel
PSP
PTT
FH
PCF
V
V
V – Flow selector valve
Pump
Flow Controller
Flow Meter
Flow control demand proportional to CVS flow rate
Vented or returned to CVS before flow metering

Figure A5/13

Double dilution particulate sampling system



4.2.1.3. Specific requirements

4.2.1.3.1. Sample probe

4.2.1.3.1.1. The sample probe shall deliver the particle size classification performance specified in paragraph 4.2.1.3.1.4. of this Sub-Annex. It is recommended that this performance be achieved by the use of a sharp-edged, open-ended probe facing directly into the direction of flow plus a pre-classifier (cyclone impactor, etc.). An appropriate sample probe, such as that indicated in Figure A5/11, may alternatively be used provided it achieves the pre-classification performance specified in paragraph 4.2.1.3.1.4. of this Sub-Annex.

4.2.1.3.1.2. The sample probe shall be installed at least 10 tunnel diameters downstream of the exhaust gas inlet to the tunnel and have an internal diameter of at least 8 mm.

If more than one simultaneous sample is drawn from a single sample probe, the flow drawn from that probe shall be split into identical sub-flows to avoid sampling artefacts.

If multiple probes are used, each probe shall be sharp-edged, open-ended and facing directly into the direction of flow. Probes shall be equally spaced around the central longitudinal axis of the dilution tunnel, with a spacing between probes of at least 5 cm.

4.2.1.3.1.3. The distance from the sampling tip to the filter mount shall be at least five probe diameters, but shall not exceed 2,000 mm.

4.2.1.3.1.4. The pre-classifier (e.g. cyclone, impactor, etc.) shall be located upstream of the filter holder assembly. The pre-classifier 50 per cent cut point particle diameter shall be between 2.5 µm and 10 µm at the volumetric flow rate selected for sampling PM. The pre-classifier shall allow at least 99 per cent of the mass concentration of 1 µm particles entering the pre-classifier to pass through the exit of the pre-classifier at the volumetric flow rate selected for sampling PM.

4.2.1.3.2. Particle transfer tube (PTT)

Any bends in the PTT shall be smooth and have the largest possible radii.

4.2.1.3.3. Secondary dilution

4.2.1.3.3.1. As an option, the sample extracted from the CVS for the purpose of PM measurement may be diluted at a second stage, subject to the following requirements:

4.2.1.3.3.1.1. Secondary dilution air shall be filtered through a medium capable of reducing particles in the most penetrating particle size of the filter material by ≥ 99.95 per cent, or through a HEPA filter of at least class H13 of EN 1822:2009. The dilution air may optionally be charcoal-scrubbed before being passed to the HEPA filter. It is recommended that an additional coarse particle filter be situated before the HEPA filter and after the charcoal scrubber, if used.

4.2.1.3.3.1.2. The secondary dilution air should be injected into the PTT as close to the outlet of the diluted exhaust from the dilution tunnel as possible.

4.2.1.3.3.1.3. The residence time from the point of secondary diluted air injection to the filter face shall be at least 0.25 seconds, but no longer than 5 seconds.

4.2.1.3.3.1.4. If the double diluted sample is returned to the CVS, the location of the sample return shall be selected so that it does not interfere with the extraction of other samples from the CVS.

4.2.1.3.4. Sample pump and flow meter

4.2.1.3.4.1. The sample gas flow measurement unit shall consist of pumps, gas flow regulators and flow measuring units.

4.2.1.3.4.2. The temperature of the gas flow in the flow meter may not fluctuate by more than ± 3 °C except:

(a) When the sampling flow meter has real time monitoring and flow control operating at a frequency of 1 Hz or faster;

(b) During regeneration tests on vehicles equipped with periodically regenerating after-treatment devices.

Should the volume of flow change unacceptably as a result of excessive filter loading, the test shall be invalidated. When it is repeated, the flow rate shall be decreased.

4.2.1.3.5. Filter and filter holder

4.2.1.3.5.1. A valve shall be located downstream of the filter in the direction of flow. The valve shall open and close within 1 second of the start and end of test.

4.2.1.3.5.2. For a given test, the gas filter face velocity shall be set to an initial value within the range 20 cm/s to 105 cm/s and shall be set at the start of the test so that 105 cm/s will not be exceeded when the dilution system is being operated with sampling flow proportional to CVS flow rate.

4.2.1.3.5.3. Fluorocarbon coated glass fibre filters or fluorocarbon membrane filters shall be used.

All filter types shall have a 0.3 µm DOP (di-octylphthalate) or PAO (poly-alpha-olefin) CS 68649-12-7 or CS 68037-01-4 collection efficiency of at least 99 per cent at a gas filter face velocity of 5.33 cm/s measured according to one of the following standards:

(a) U.S.A. Department of Defense Test Method Standard, MIL-STD-282 method 102.8: DOP-Smoke Penetration of Aerosol-Filter Element;

(b) U.S.A. Department of Defense Test Method Standard, MIL-STD-282 method 502.1.1: DOP-Smoke Penetration of Gas-Mask Canisters;

(c) Institute of Environmental Sciences and Technology, IEST-RP-CC021: Testing HEPA and ULPA Filter Media.

4.2.1.3.5.4. The filter holder assembly shall be of a design that provides an even flow distribution across the filter stain area. The filter shall be round and have a stain area of at least 1,075 mm^2.

4.2.2. Weighing chamber (or room) and analytical balance specifications

4.2.2.1. Weighing chamber (or room) conditions

(a) The temperature of the weighing chamber (or room) in which the particulate sampling filters are conditioned and weighed shall be maintained to within 22 °C ± 2 °C (22 °C ± 1 °C if possible) during all filter conditioning and weighing.

(b) Humidity shall be maintained at a dew point of less than 10.5 °C and a relative humidity of 45 per cent ± 8 per cent.

(c) Limited deviations from weighing chamber (or room) temperature and humidity specifications shall be permitted provided their total duration does not exceed 30 minutes in any one filter conditioning period.

(d) The levels of ambient contaminants in the weighing chamber (or room) environment that would settle on the particulate sampling filters during their stabilisation shall be minimised.

(e) During the weighing operation no deviations from the specified conditions are permitted.

4.2.2.2. Linear response of an analytical balance

The analytical balance used to determine the filter weight shall meet the linearity verification criteria of Table A5/1 applying a linear regression. This implies a precision of at least ±2 µg and a resolution of at least 1 µg (1 digit = 1 µg). At least

4 equally-spaced reference weights shall be tested. The zero value shall be within ±1μg.

Table A5/1

Analytical balance verification criteria

Measurement system	*Intercept a0*	*Slope a1*	*Standard error of estimate (SEE)*	*Coefficient of determination r^2*
Particulate balance	≤ 1 μg	0,99 – 1,01	≤ 1per cent max	≥ 0,998';

4.2.2.3. Elimination of static electricity effects

The effects of static electricity shall be nullified. This may be achieved by grounding the balance through placement upon an antistatic mat and neutralization of the particulate sampling filters prior to weighing using a polonium neutraliser or a device of similar effect. Alternatively, nullification of static effects may be achieved through equalization of the static charge.

4.2.2.4. Buoyancy correction

The sample and reference filter weights shall be corrected for their buoyancy in air. The buoyancy correction is a function of sampling filter density, air density and the density of the balance calibration weight, and does not account for the buoyancy of the particulate matter itself.

If the density of the filter material is not known, the following densities shall be used:

(a) PTFE coated glass fibre filter: 2,300 kg/m^3;

(b) PTFE membrane filter: 2,144 kg/m^3;

(c) PTFE membrane filter with polymethylpentene support ring: 920 kg/m^3.

For stainless steel calibration weights, a density of 8,000 kg/m^3 shall be used. If the material of the calibration weight is different, its density shall be known and be used. International Recommendation OIML R 111-1 Edition 2004(E) (or equivalent) from International Organization of Legal Metrology on calibration weights should be followed.

The following equation shall be used:

$$\mathrm{m_f} = \mathrm{m_{uncorr}} \times \left(\frac{1 - \frac{\rho_\mathrm{a}}{\rho_\mathrm{w}}}{1 - \frac{\rho_\mathrm{a}}{\rho_\mathrm{f}}} \right)$$

where:

$\mathrm{Pe_f}$ is the corrected particulate sample mass, mg;

$\mathrm{Pe_{uncorr}}$ is the uncorrected particulate sample mass, mg;

ρ_a is the density of the air, kg/m^3;

ρ_w is the density of balance calibration weight, kg/m^3;

ρ_f is the density of the particulate sampling filter, kg/m^3.

The density of the air $\rho_a$shall be calculated using the following equation:

$$\rho_a = \frac{p_b \times M_{mix}}{R \times T_a}$$

p_b is the total atmospheric pressure, kPa;

T_a is the air temperature in the balance environment, Kelvin (K);

M_{mix} is the molar mass of air in a balanced environment, 28.836 g mol^{-1};

R is the molar gas constant, 8.3144 J mol^{-1} K^{-1}.

4.3. PN measurement equipment

4.3.1. Specification

4.3.1.1. System overview

4.3.1.1.1. The particle sampling system shall consist of a probe or sampling point extracting a sample from a homogenously mixed flow in a dilution system, a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer tubing. See Figure A5/14.

4.3.1.1.2. It is recommended that a particle size pre-classifier (PCF) (e.g. cyclone, impactor, etc.) be located prior to the inlet of the VPR. The PCF 50 per cent cut point particle diameter shall be between 2.5 µm and 10 µm at the volumetric flow rate selected for particle sampling. The PCF shall allow at least 99 per cent of the mass concentration of 1 µm particles entering the PCF to pass through the exit of the PCF at the volumetric flow rate selected for particle sampling.

A sample probe acting as an appropriate size-classification device, such as that shown in Figure A5/11, is an acceptable alternative to the use of a PCF.

4.3.1.2. General requirements

4.3.1.2.1. The particle sampling point shall be located within a dilution system. In the case that a double dilution system is used, the particle sampling point shall be located within the primary dilution system.

4.3.1.2.1.1. The sampling probe tip or PSP, and the PTT, together comprise the particle transfer system (PTS). The PTS conducts the sample from the dilution tunnel to the entrance of the VPR. The PTS shall meet the following conditions:

(a) The sampling probe shall be installed at least 10 tunnel diameters downstream of the exhaust gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel;

(b) The sampling probe shall be upstream of any conditioning device (e.g. heat exchanger);

(c) The sampling probe shall be positioned within the dilution tunnel so that the sample is taken from a homogeneous diluent/exhaust mixture.

4.3.1.2.1.2. Sample gas drawn through the PTS shall meet the following conditions:

(a) In the case that a full flow exhaust dilution system, is used it shall have a flow Reynolds number, Re, lower than 1,700;

(b) In the case that a double dilution system is used, it shall have a flow Reynolds number Re lower than 1,700 in the PTT i.e. downstream of the sampling probe or point;

(c) Shall have a residence time ≤ 3 seconds.

4.3.1.2.1.3. Any other sampling configuration for the PTS for which equivalent particle penetration at 30 nm can be demonstrated shall be considered acceptable.

4.3.1.2.1.4. The outlet tube (OT), conducting the diluted sample from the VPR to the inlet of the PNC, shall have the following properties:

(a) An internal diameter ≥ 4mm;

(b) A sample gas flow residence time of ≤ 0.8 seconds.

4.3.1.2.1.5. Any other sampling configuration for the OT for which equivalent particle penetration at 30 nm can be demonstrated shall be considered acceptable.

4.3.1.2.2. The VPR shall include devices for sample dilution and for volatile particle removal.

4.3.1.2.3. All parts of the dilution system and the sampling system from the exhaust pipe up to the PNC, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition of the particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

4.3.1.2.4. The particle sampling system shall incorporate good aerosol sampling practice that includes the avoidance of sharp bends and abrupt changes in cross-section, the use of smooth internal surfaces and the minimization of the length of the sampling line. Gradual changes in the cross-section are permitted.

4.3.1.3. Specific requirements

4.3.1.3.1. The particle sample shall not pass through a pump before passing through the PNC.

4.3.1.3.2. A sample pre-classifier is recommended.

4.3.1.3.3. The sample preconditioning unit shall:

(a) Be capable of diluting the sample in one or more stages to achieve a particle number concentration below the upper threshold of the single particle count mode of the PNC and a gas temperature below 35 °C at the inlet to the PNC;

(b) Include an initial heated dilution stage that outputs a sample at a temperature of ≥ 150 °C and ≤ 350 °C ± 10 °C, and dilutes by a factor of at least 10;

(c) Control heated stages to constant nominal operating temperatures, within the range ≥ 150 °C and ≤ 400 °C ± 10 °C;

(d) Provide an indication of whether or not heated stages are at their correct operating temperatures;

(e) Be designed to achieve a solid particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;

(f) Achieve a particle concentration reduction factor $f_r(d_i)$ for particles of 30 nm and 50 nm electrical mobility diameters that is no more than 30 per cent and 20 per cent respectively higher, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole;

The particle concentration reduction factor at each particle size $f_r(d_i)$ shall be calculated using the following equation:

$$f_r(d_i) = \frac{N_{in}(d_i)}{N_{out}(d_i)}$$

where:

$N_{in}(d_i)$ is the upstream particle number concentration for particles of diameter d_i;

$N_{out}(d_i)$ is the downstream particle number concentration for particles of diameter d_i;

d_i is the particle electrical mobility diameter (30, 50 or 100 nm).

$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.

The arithmetic average particle concentration reduction factor at a given dilution setting $\overline{f_r}$ shall be calculated using the following equation:

$$\overline{f_r} = \frac{f_r(30\ \text{nm}) + f_r(50\ \text{nm}) + f_r(100\ \text{nm})}{3}$$

It is recommended that the VPR is calibrated and validated as a complete unit;

(g) Be designed according to good engineering practice to ensure particle concentration reduction factors are stable across a test;

(h) Also achieve > 99.0 per cent vaporization of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥ 10,000 per cm^3, by means of heating and reduction of partial pressures of the tetracontane.

4.3.1.3.4. The PNC shall:

(a) Operate under full flow operating conditions;

(b) Have a counting accuracy of ± 10 per cent across the range 1 per cm^3 to the upper threshold of the single particle count mode of the PNC against a suitable traceable standard. At concentrations below 100 per cm^3, measurements averaged over extended sampling periods may be required to demonstrate the accuracy of the PNC with a high degree of statistical confidence;

(c) Have a resolution of at least 0.1 particles per cm^3 at concentrations below 100 per cm^3;

(d) Have a linear response to particle number concentrations over the full measurement range in single particle count mode;

(e) Have a data reporting frequency equal to or greater than a frequency of 0.5Hz;

(f) Have a t_{90} response time over the measured concentration range of less than 5 seconds;

(g) Incorporate a coincidence correction function up to a maximum 10 per cent correction, and may make use of an internal calibration factor as determined in paragraph 5.7.1.3.of this Sub-Annex but shall not make use of any other algorithm to correct for or define the counting efficiency;

(h) Have counting efficiencies at the different particle sizes as specified in Table A5/2.

Table A5/2

PNC counting efficiency

Particle size electrical mobility diameter (nm)	PNC counting efficiency (per cent)
23 ± 1	50 ± 12
41 ± 1	> 90

4.3.1.3.5. If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.

4.3.1.3.6. Where not held at a known constant level at the point at which PNC flow rate is controlled, the pressure and/or temperature at the PNC inlet shall be measured for the purposes of correcting particle number concentration measurements to standard conditions.

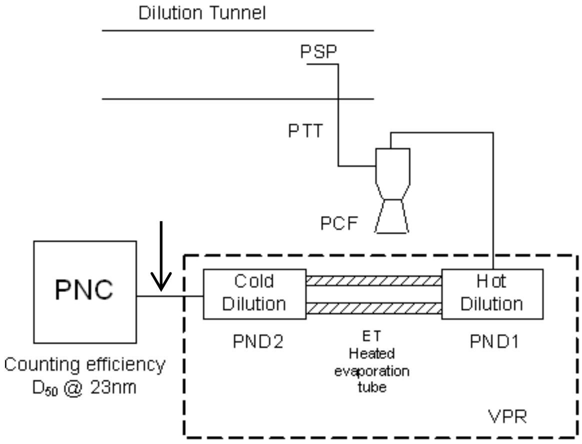
4.3.1.3.7. The sum of the residence time of the PTS, VPR and OT plus the t_{90} response time of the PNC shall be no greater than 20 seconds.

4.3.1.4. Recommended system description

The following paragraph contains the recommended practice for measurement of PN. However, systems meeting the performance specifications in paragraphs 4.3.1.2. and 4.3.1.3. of this Sub-Annex are acceptable.

Figure A5/14

A recommended particle sampling system



4.3.1.4.1. Sampling system description

4.3.1.4.1.1. The particle sampling system shall consist of a sampling probe tip or particle sampling point in the dilution system, a PTT, a PCF, and a VPR, upstream of the PNC unit.

4.3.1.4.1.2. The VPR shall include devices for sample dilution (particle number diluters: PND_1 and PND_2) and particle evaporation (evaporation tube, ET).

4.3.1.4.1.3. The sampling probe or sampling point for the test gas flow shall be arranged within the dilution tunnel so that a representative sample gas flow is taken from a homogeneous diluent/exhaust mixture.

5. Calibration intervals and procedures

5.1. Calibration intervals

Table A5/3

Instrument calibration intervals

Instrument checks	Interval	Criterion
Gas analyser linearization (calibration)	Every 6 months	± 2 per cent of reading
Mid span	Every 6 months	± 2 per cent
CO NDIR:	Monthly	-1 to 3 ppm

CO_2/H_2O interference		
NO_x converter check	Monthly	> 95 per cent
CH_4 cutter check	Yearly	98 per cent of ethane
FID CH_4 response	Yearly	See paragraph 5.4.3. of this Sub-Annex
FID air/fuel flow	At major maintenance	According to instrument manufacturer.
NO/NO_2 NDUV: H_2O, HC interference	At major maintenance	According to instrument manufacturer.
QCL	Yearly or at major maintenance	According to instrument manufacturer.
GC methods	See paragraph 7.2. of this Sub-Annex	See paragraph 7.2. of this Sub-Annex
LC methods	Yearly or at major maintenance	According to instrument manufacturer.
Photoacoustics	Yearly or at major maintenance	According to instrument manufacturer.
FTIR: linearity verification	Within 370 days before testing and after major maintenance	See NH_3 and N_2O procedures or paragraph 7.1 of Sub-Annex 5 of GTR 15
PNC (particle number counter)	See paragraph 5.7.1.1. of this Sub-Annex	See paragraph 5.7.1.3. of this Sub-Annex
VPR (volatile particle remover)	See paragraph 5.7.2.1. of this Sub-Annex	See paragraph 5.7.2. of this Sub-Annex

Table A5/4

Constant volume sampler (CVS) calibration intervals

CVS	Interval	Criterion
CVS flow	After overhaul	± 2 per cent
Dilution flow	Yearly	± 2 per cent
Temperature sensor	Yearly	± 1 °C
Pressure sensor	Yearly	± 0.4 kPa
Injection check	Weekly	± 2 per cent

Table A5/5

Environmental data calibration intervals

Climate	Interval	Criterion
Temperature	Yearly	± 1 °C
Moisture dew	Yearly	± 5 per cent RH
Ambient pressure	Yearly	± 0.4 kPa
Cooling fan	After overhaul	According to paragraph 1.1.1. of this Sub-Annex

5.2. Analyser calibration procedures

5.2.1. Each analyser shall be calibrated as specified by the instrument manufacturer or at least as often as specified in Table A5/3.

5.2.2. Each normally used operating range shall be linearized by the following procedure:

5.2.2.1. The analyser linearization curve shall be established by at least five calibration points spaced as uniformly as possible. The nominal concentration of the calibration gas of the highest concentration shall be not less than 80 per cent of the full scale.

5.2.2.2. The calibration gas concentration required may be obtained by means of a gas divider, diluting with purified N_2 or with purified synthetic air.

5.2.2.3. The linearization curve shall be calculated by the least squares method. If the resulting polynomial degree is greater than 3, the number of calibration points shall be at least equal to this polynomial degree plus 2.

5.2.2.4. The linearization curve shall not differ by more than ± 2 per cent from the nominal value of each calibration gas.

5.2.2.5. From the trace of the linearization curve and the linearization points it is possible to verify that the calibration has been carried out correctly. The different characteristic parameters of the analyser shall be indicated, particularly:

(a) Analyser and gas component;

(b) Range;

(c) Date of linearisation.

5.2.2.6. If the approval authority is satisfied that alternative technologies (e.g. computer, electronically controlled range switch, etc.) give equivalent accuracy, these alternatives may be used.

5.3. Analyser zero and calibration verification procedure

5.3.1. Each normally used operating range shall be checked prior to each analysis in accordance with paragraphs 5.3.1.1. and 5.3.1.2. of this Sub-Annex

5.3.1.1. The calibration shall be checked by use of a zero gas and by use of a calibration gas in accordance with paragraph 2.14.2.3. of Sub-Annex 6.

5.3.1.2. After testing, zero gas and the same calibration gas shall be used for re-checking in accordance with paragraph 2.14.2.4. of Sub-Annex 6.

5.4. FID hydrocarbon response check procedure

5.4.1. Detector response optimization

The FID shall be adjusted as specified by the instrument manufacturer. Propane in air shall be used on the most common operating range.

5.4.2. Calibration of the HC analyser

5.4.2.1. The analyser shall be calibrated using propane in air and purified synthetic air.

5.4.2.2. A calibration curve as described in paragraph 5.2.2. of this Sub-Annex shall be established.

5.4.3. Response factors of different hydrocarbons and recommended limits

5.4.3.1. The response factor $\mathrm{R_f}$ for a particular hydrocarbon compound is the ratio of the FID C_1 reading to the gas cylinder concentration, expressed as ppm C_1.

The concentration of the test gas shall be at a level to give a response of approximately 80 per cent of full-scale deflection for the operating range. The concentration shall be known to an accuracy of ± 2 per cent in reference to a gravimetric standard expressed in volume. In addition, the gas cylinder shall be preconditioned for 24 hours at a temperature between 20 and 30 °C.

5.4.3.2. Response factors shall be determined when introducing an analyser into service and at major service intervals thereafter. The test gases to be used and the recommended response factors are:

Propylene and purified air: $0.90 < \mathrm{R_f} < 1.10$

Toluene and purified air: $0.90 < \mathrm{R_f} < 1.10$

These are relative to an $\mathrm{R_f}$ of 1.00 for propane and purified air.

5.5. NO_x converter efficiency test procedure

5.5.1. Using the test set up as shown in Figure A5/15 and the procedure described below, the efficiency of converters for the conversion of NO_2 into NO shall be tested by means of an ozonator as follows:

5.5.1.1. The analyser shall be calibrated in the most common operating range following the manufacturer's specifications using zero and calibration gas (the NO content of which shall amount to approximately 80 per cent of the operating range and the NO_2 concentration of the gas mixture shall be less than 5 per cent of the NO concentration). The NO_x analyser shall be in the NO mode so that the calibration gas does not pass through the converter. The indicated concentration shall be included in all relevant test sheets.

5.5.1.2. Via a T-fitting, oxygen or synthetic air shall be added continuously to the calibration gas flow until the concentration indicated is approximately 10 per cent less than the indicated calibration concentration given in paragraph 5.5.1.1. of this Sub-Annex. The indicated concentration (c) shall be included in all relevant test sheets. The ozonator shall be kept deactivated throughout this process.

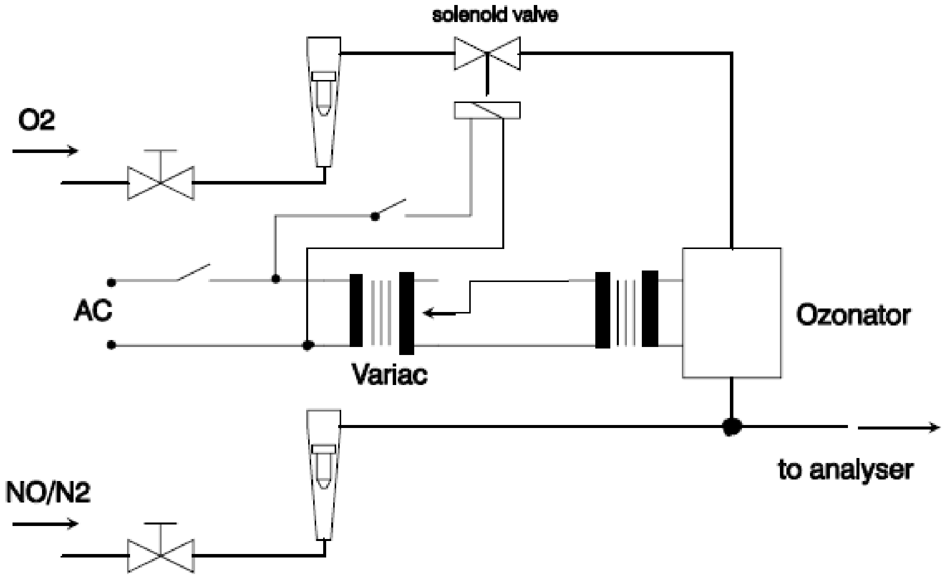
5.5.1.3. The ozonator shall now be activated to generate enough ozone to bring the NO concentration down to 20 per cent (minimum 10 per cent) of the calibration concentration given in paragraph 5.5.1.1. of this Sub-Annex. The indicated concentration (d) shall be included all relevant test sheets.

5.5.1.4. The NO_x analyser shall be subsequently switched to the NO_x mode, whereby the gas mixture (consisting of NO, NO_2, O_2 and N_2) now passes through the converter. The indicated concentration (a) shall be included in all relevant test sheets.

5.5.1.5. The ozonator shall now be deactivated. The mixture of gases described in paragraph 5.5.1.2. of this Sub-Annex shall pass through the converter into the detector. The indicated concentration (b) shall be included in all relevant test sheets.

Figure A5/15

NO_x converter efficiency test configuration



5.5.1.6. With the ozonator deactivated, the flow of oxygen or synthetic air shall be shut off. The NO_2 reading of the analyser shall then be no more than 5 per cent above the figure given in paragraph 5.5.1.1. of this Sub-Annex.

5.5.1.7. The per cent efficiency of the NO_x converter shall be calculated using the concentrations a, b, c and d determined in paragraphs 5.5.1.2. to 5.5.1.5. of this Sub-Annex inclusive using the following equation:

$$\text{Efficiency} = \left(1 + \frac{a - b}{c - d}\right) \times 100$$

The efficiency of the converter shall not be less than 95 per cent. The efficiency of the converter shall be tested in the frequency defined in Table A5/3.

5.6. Calibration of the microgram balance

The calibration of the microgram balance used for particulate sampling filter weighing shall be traceable to a national or international standard. The balance shall comply with the linearity requirements given in paragraph 4.2.2.2. The linearity verification shall be performed at least every 12 months or whenever a system repair or change is made that could influence the calibration.

5.7. Calibration and validation of the particle sampling system

Examples of calibration/validation methods are available at:

http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/pmpFCP.html.

5.7.1. Calibration of the PNC

5.7.1.1. The approval authority shall ensure the existence of a calibration certificate for the PNC demonstrating compliance with a traceable standard within a 13-month period prior to the emissions test. Between calibrations either the counting efficiency of the PNC shall be monitored for deterioration or the PNC wick shall be routinely changed every 6 months. See Figures A5/16 and A5/17. PNC counting efficiency may be monitored against a reference PNC or against at least two other measurement PNCs. If the PNC reports particle number concentrations within ± 10 per cent of the arithmetic average of the concentrations from the reference PNC, or a group of two or more PNCs, the PNC shall subsequently be considered stable, otherwise maintenance of the PNC is required. Where the PNC is monitored against two or more other measurement PNCs, it is permitted to use a reference vehicle running sequentially in different test cells each with its own PNC.

Figure A5/16

Nominal PNC annual sequence

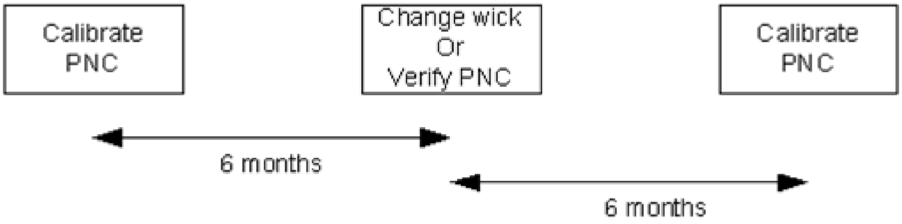
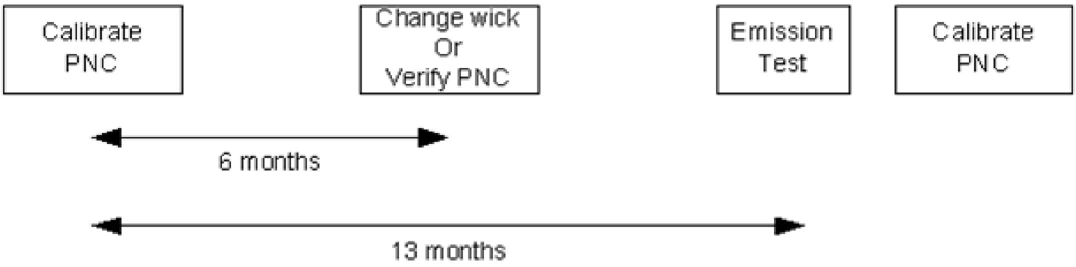


Figure A5/17

Extended PNC annual sequence (in the case that a full PNC calibration is delayed)



5.7.1.2. The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.

5.7.1.3. Calibration shall be traceable to a national or international standard calibration method by comparing the response of the PNC under calibration with that of:

(a) A calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles; or

(b) A second PNC that has been directly calibrated by the method described above.

5.7.1.3.1. In paragraph 5.7.1.3. (a) of this Sub-Annex, calibration shall be undertaken using at least six standard concentrations spaced as uniformly as possible across the PNC's measurement range.

5.7.1.3.2. In paragraph 5.7.1.3. (b) of this Sub-Annex, calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. At least 3 points shall be at concentrations below 1,000 per cm³, the remaining concentrations shall be linearly spaced between 1,000 per cm³ and the maximum of the PNC's range in single particle count mode.

5.7.1.3.3. In paragraphs 5.7.1.3.(a) and 5.7.1.3.(b) of this Sub-Annex, the selected points shall include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ± 10 per cent of the standard concentration for each concentration, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear least squares regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (r) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and r^2, the linear regression shall be forced through the origin (zero concentration on both instruments).

5.7.1.4. Calibration shall also include a check, according to the requirements of paragraph 4.3.1.3.4.(h) of this Sub-Annex, on the PNC's detection efficiency with particles of 23 nm electrical mobility diameter. A check of the counting efficiency with 41 nm particles is not required.

5.7.2. Calibration/validation of the VPR

5.7.2.1. Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument's fixed nominal operating temperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on particulate filter-equipped vehicles. The approval authority shall ensure the existence of a calibration or validation certificate for the VPR within a 6-month period prior to the emissions test. If the VPR incorporates temperature monitoring alarms, a 13 month validation interval is permitted.

It is recommended that the VPR is calibrated and validated as a complete unit.

The VPR shall be characterised for particle concentration reduction factor with solid particles of 30, 50 and 100 nm electrical mobility diameter. Particle concentration reduction factors $\mathrm{f_r(d)}$ for particles of 30 nm and 50 nm electrical mobility diameters shall be no more than 30 per cent and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the arithmetic average of the particle concentration reduction factor shall be within ± 10 per cent of the arithmetic average particle concentration reduction factor $\overline{\mathrm{f_r}}$ determined during the primary calibration of the VPR.

5.7.2.2. The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5,000 particles per cm³ at the VPR inlet. As an option, a polydisperse aerosol with an electrical mobility median diameter of 50 nm may be used for validation. The test aerosol shall be thermally stable at the VPR operating temperatures. Particle number concentrations shall be measured upstream and downstream of the components.

The particle concentration reduction factor for each monodisperse particle size, $\mathrm{f_r(d_i)}$, shall be calculated using the following equation:

$$\mathrm{f_r(d_i)} = \frac{\mathrm{N_{in}(d_i)}}{\mathrm{N_{out}(d_i)}}$$

where:

$\mathrm{N_{in}(d_i)}$ is the upstream particle number concentration for particles of diameter $\mathrm{d_i}$;

$\mathrm{N_{out}(d_i)}$ is the downstream particle number concentration for particles of diameter $\mathrm{d_i}$;

$\mathrm{d_i}$ is the particle electrical mobility diameter (30, 50 or 100 nm).

$\mathrm{N_{in}(d_i)}$ and $\mathrm{N_{out}(d_i)}$ shall be corrected to the same conditions.

The arithmetic average particle concentration reduction factor $\overline{\mathrm{f_r}}$ at a given dilution setting shall be calculated using the following equation:

$$\overline{\mathrm{f_r}} = \frac{\mathrm{f_r(30nm)} + \mathrm{f_r(50nm)} + \mathrm{f_r(100nm)}}{3}$$

Where a polydisperse 50 nm aerosol is used for validation, the arithmetic average particle concentration reduction factor $\overline{\mathrm{f_v}}$ at the dilution setting used for validation shall be calculated using the following equation:

$$\overline{\mathrm{f_v}} = \frac{\mathrm{N_{in}}}{\mathrm{N_{out}}}$$

where:

$\mathrm{N_{in}}$ is the upstream particle number concentration;

$\mathrm{N_{out}}$ is the downstream particle number concentration.

5.7.2.3. The VPR shall demonstrate greater than 99.0 per cent removal of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles of at least 30 nm electrical mobility diameter with an inlet concentration ≥ 10,000 per cm^3 when operated at its minimum dilution setting and manufacturers recommended operating temperature.

5.7.3. PN measurement system check procedures

On a monthly basis, the flow into the PNC shall have a measured value within 5 per cent of the PNC nominal flow rate when checked with a calibrated flow meter.

5.8. Accuracy of the mixing device

In the case that a gas divider is used to perform the calibrations as defined in paragraph 5.2. of this Sub-Annex, the accuracy of the mixing device shall be such that the concentrations of the diluted calibration gases may be determined to within ± 2 per cent. A calibration curve shall be verified by a mid-span check as described in paragraph 5.3. of this Sub-Annex. A calibration gas with a concentration below 50 per cent of the analyser range shall be within 2 per cent of its certified concentration.

6. Reference gases

6.1. Pure gases

6.1.1. All values in ppm mean volume-ppm (vpm)

6.1.2. The following pure gases shall be available, if necessary, for calibration and operation:

6.1.2.1. Nitrogen:

Purity: ≤ 1 ppm C_1, ≤1 ppm CO, ≤ 400 ppm CO_2, ≤ 0,1 ppm NO, ≤0,1 ppm N_2O, ≤0,1 ppm NH_3.

6.1.2.2. Synthetic air:

Purity: ≤1 ppm C_1, ≤1 ppm CO, ≤400 ppm CO_2, ≤0,1 ppm NO, ≤0,1 ppm NO_2; oxygen content between 18 and 21 per cent volume.

6.1.2.3. Oxygen:

Purity: > 99.5 per cent vol. O_2;

6.1.2.4. Hydrogen (and mixture containing helium or nitrogen):

Purity: ≤ 1 ppm C1, ≤ 400 ppm CO2; hydrogen content between 39 and 41 per cent volume;

6.1.2.5. Carbon monoxide:

Minimum purity 99.5 per cent;

6.1.2.6. Propane:

Minimum purity 99.5 per cent.

6.2. Calibration gases

The true concentration of a calibration gas shall be within ±1 per cent of the stated value or as given below, and shall be traceable to national or international standards.

Mixtures of gases having the following compositions shall be available with bulk gas specifications according to paragraphs 6.1.2.1. or 6.1.2.2. of this Sub-Annex:

(a) C_3H_8 in synthetic air (see paragraph 6.1.2.2. of this Sub-Annex);

(b) CO in nitrogen;

(c) CO_2 in nitrogen;

(d) CH_4 in synthetic air;

(e) NO in nitrogen (the amount of NO_2 contained in this calibration gas shall not exceed 5 per cent of the NO content)

(f) NO_2 in synthetic air or nitrogen (Tolerance: ±2 per cent)

(g) N_2O in nitrogen (Tolerance: ±2 per cent ot 0.25 ppm, whichever is greater)

(h) NH_3 in nitrogen (Tolerance: ±3 per cent)

Sub-Annex 6

WLTC+ test procedures and test conditions

1. Test procedures and test conditions

1.1 Description of tests

1.1.1. The WLTC+ test is used to verify the emissions of gaseous compounds, particulate matter, particle number, CO_2 mass emission, fuel consumption, electric energy consumption and electric ranges.

1.1.1.1. The tests shall be carried out according to the method described in paragraph 1.2. of this Sub-Annex or paragraph 3. of Sub-Annex 8 for pure electric, hybrid electric and compressed hydrogen fuel cell hybrid vehicles. Exhaust gases, particulate matter and particles shall be sampled and analysed by the prescribed methods.

1.1.2. The limit values are the maximum allowed ones for the respective pollutants and GHG emissions as specified in *GNT_Test_performance_limits*

1.1.2.1. [Reserved]

1.1.2.2. The test results shall be the values after the REESS energy change-based correction is applied.

1.1.2.3. [Reserved]

1.1.2.3.1. [Reserved]

1.1.2.3.2. [Reserved]

1.1.2.3.3. [Reserved]

1.1.2.3.4. [Reserved]

1.1.2.3.5. [Reserved]

1.1.2.3.6. [Reserved]

1.1.2.3.7. [Reserved]

1.1.2.3.8. [Reserved]

1.1.2.3.8.1. [Reserved]

1.1.2.3.8.2. [Reserved]

1.1.2.3.9. [Reserved]

1.1.2.4. Determination of phase-specific values

1.1.2.4.1. [Reserved]

1.1.2.4.2. Phase-specific values for fuel consumption

1.1.2.4.2.1. The fuel consumption value shall be calculated by the phase-specific CO_2 mass emission.

1.1.2.4.3. Phase-specific value for electric energy consumption

1.1.2.4.3.1. The phase-specific electric energy consumption is calculated by taking the arithmetic average of the phase specific values of the test result(s), without an adjustment factor.

1.2. WLTC+ test conditions

1.2.1. Overview

1.2.1.1. The WLTC+ test shall consist of prescribed sequences of dynamometer preparation, fuelling, soaking, and operating conditions.

1.2.1.2. The WLTC+ test shall consist of vehicle operation on a chassis. A proportional part of the diluted exhaust emissions shall be collected continuously for subsequent analysis using a constant volume sampler.

1.2.1.3. Background concentrations shall be measured for all compounds for which dilute mass emissions measurements are conducted. For exhaust emissions testing, this requires sampling and analysis of the dilution air.

1.2.1.3.1. Background particulate measurement

1.2.1.3.1.1. [Reserved]

1.2.1.3.1.1.1. [Reserved]

1.2.1.3.1.1.2. [Reserved]

1.2.1.3.1.1.3. [Reserved]

1.2.1.3.1.2. Dilution air background particulate mass level shall be determined by passing filtered dilution air through the particulate background filter. This shall be drawn from a point immediately downstream of the dilution air filters. Background levels in ⍰g/m^3 shall be determined as a rolling arithmetic average of at least 14 measurements with at least one measurement per week.

1.2.1.3.1.3. Dilution tunnel background particulate mass level shall be determined by passing filtered dilution air through the particulate background filter. This shall be drawn from the same point as the particulate matter sample. Where secondary dilution is used for the test, the secondary dilution system shall be active for the purposes of background measurement. One measurement may be performed on the day of test, either prior to or after the test.

1.2.1.3.2. Background particle number determination

1.2.1.3.2.1. [Reserved]

1.2.1.3.2.1.1. [Reserved]

1.2.1.3.2.1.2. [Reserved]

1.2.1.3.2.1.3. [Reserved]

1.2.1.3.2.2. Dilution air background particle number level shall be determined by sampling filtered dilution air. This shall be drawn from a point immediately downstream of the dilution air filters into the PN measurement system. Background levels in particles per cm^3 shall be determined as a rolling arithmetic average of least 14 measurements with at least one measurement per week.

1.2.1.3.2.3. Dilution tunnel background particle number level shall be determined by sampling filtered dilution air. This shall be drawn from the same point as the PN sample. Where secondary dilution is used for the test the secondary dilution system shall be active for the purposes of background measurement. One measurement may be performed on the day of test, either prior to or after the test using the actual PCRF and the CVS flow rate utilised during the test.

1.2.2. General test cell equipment

1.2.2.1. Parameters to be measured

1.2.2.1.1. The following temperatures shall be measured with an accuracy of ± 1.5 °C:

(a) Test cell ambient air;

(b) Dilution and sampling system temperatures as required for emissions measurement systems defined in Sub-Annex 5.

1.2.2.1.2. Atmospheric pressure shall be measurable with a resolution of $\pm$ 0.1 kPa.

1.2.2.1.3. Specific humidity H shall be measurable with a resolution of $\pm$ 1 g H_2O/kg dry air.

1.2.2.2. Test cell and soak area

1.2.2.2.1. Test cell

1.2.2.2.1.1. The test cell shall have a temperature set point of 14 °C. The tolerance of the actual value shall be within ± 3 °C. The air temperature and humidity shall be measured at the test cell's cooling fan outlet at a minimum frequency of 1 Hz. For the temperature at the start of the test, see paragraph 1.2.8.1. in Sub-Annex 6.

1.2.2.2.1.2. The specific humidity H of either the air in the test cell or the intake air of the engine shall be such that:

$5.5 \leq \mathrm{H} \leq 12.2$ (g H_2O/kg dry air)

1.2.2.2.1.3. Humidity shall be measured continuously at a minimum frequency of 1 Hz.

1.2.2.2.2. Soak area

The soak area shall have a temperature set point of 14 °C and the tolerance of the actual value shall be within ± 3 °C on a 5 minute running arithmetic average and shall not show a systematic deviation from the set point. The temperature shall be measured continuously at a minimum frequency of 1 Hz.

1.2.3. Test vehicle

1.2.3.1. General

The test vehicle shall conform in all its components with the production series.

For the measurement of emissions, the road load as determined in according with *GNT_Driving_Resistance* test procedure.

1.2.3.2. [Reserved]

1.2.3.3. Run-in

The vehicle shall be presented in good technical condition. It shall have been run-in and driven at least 3,000 km and maximum 30.000 km before the test. The engine, transmission and vehicle shall be run-in in accordance with the manufacturer's recommendations.

1.2.3.4 Board Computer

The Fuel and energy consumptions of the vehicle displayed by the board computer (if available) have to be monitored and recorded for the test cycle in order to have a comparison between measured and displayed values. Therefore a BC reset has to be done before start of the test.

1.2.4. Settings

1.2.4.1. Dynamometer settings and verification shall be performed according to Sub-Annex 4.

1.2.4.2. Dynamometer operation

1.2.4.2.1. Energy consumers

1.2.4.2.1.1 Daytime running lights (or, alternatively, low beam) are on.

1.2.4.2.1.2 All cabin temperatures must be at 23 °C ± 3 °C once the vehicle has reached its regular operating temperature. Therefore, a temperature measuring tip has to be installed at the front-seat passenger´s headrest. All measurements shall be recorded.

1.2.4.2.1.3 Air conditioning system

1.2.4.2.1.3.1 The automatic air condition is operated with A/C switch on, temperature at 23 C° and fan speed on automatic regulation with airflow on automatic regulation. If necessary, the settings for temperature have to be readjusted. All readjustments have to be recorded and proved, e.g. by photographs.

1.2.4.2.1.3.2 The manual air condition is operated with A/C switch on, temperature ½ (middle position) and fan speed on 1/3 to ¼ with airflow on floor and windscreen. If necessary, the settings for temperature have to be readjusted until 23 °C ± 3 °C are met. All readjustments have to be recorded and proved, e.g. by photographs.

1.2.4.2.1.4 No additional electric energy consumers shall be switched on.

1.2.4.2.2. The vehicle’s dynamometer operation mode

1.2.4.2.2.1. If neutral gear is safely selectable on transmission and no load is still engaged, the vehicle’s dynamometer operation mode on vehicle shall not be activated

1.2.4.2.2.2. Only if conditions listed in 1.2.4.2.2.1. are not satisfied, the vehicle’s dynamometer operation mode shall be activated by using the instruction reported in the CoC (e.g. using vehicle steering wheel buttons in a special sequence, using the manufacturer’s workshop tester, removing a fuse). The laboratory shall provide the GNT a list of the deactivated devices and justification for the deactivation. The dynamometer operation mode shall be approved by GNT and the use of a dynamometer operation mode shall be included in all relevant test reports.

1.2.4.2.3. The dynamometer operation mode shall not activate, modulate, delay or deactivate the operation of any part that affects the emissions and fuel consumption under the test conditions. Any device that affects the operation on a chassis dynamometer shall be set to ensure a proper operation.

1.2.4.2.4. If the test vehicle is tested in a two-wheel drive (2WD) mode, the test vehicle shall be tested on a single-axis chassis dynamometer which fulfils the requirements according to paragraph 2. of

Sub-Annex 5. At the request of the laboratory and with the approval of the GNT, the vehicle may be tested on a dual-axis chassis dynamometer.

1.2.4.2.5. If the test vehicle is tested in a mode which under WLTC+ conditions would enter into partially or permanent four-wheel drive (4WD) operation over the applicable cycle, the test vehicle shall be tested on a dual-axis chassis dynamometer which fulfils the requirements according to paragraph 2.3. of Sub-Annex 5. At the request of the laboratory and with the approval of the GNT, the vehicle may be tested on a single-axis chassis dynamometer if the following conditions are met:

a) the test vehicle is converted to permanent 2WD operation in all test modes;

b) the laboratory provides evidence to the GNT that the CO_2, fuel consumption and/or electrical energy consumption of the converted vehicle is the same or higher as for the non-converted vehicle being tested on a dual-axis chassis dynamometer.

1.2.4.3. The vehicle's exhaust system shall not exhibit any leak likely to reduce the quantity of gas collected.

1.2.4.4. The settings of the powertrain and vehicle controls shall be those prescribed by the manufacturer for series production.

1.2.4.5. Tyres type shall match with one of the allowed type reported in the TA document. Tyre pressure may be as specified in paragraph 4.2.2.3. of Sub-Annex 4. The same tyre pressure shall be used for the setting of the dynamometer and for all subsequent testing. The tyre pressure used shall be included in all relevant test reports. The tyres used for emissions testing shall be original equipment manufacturer´s quality. Summer tyres have to be used and the pattern depth has to be 50% minimum.

1.2.4.6. Reference fuel

1.2.4.6.1. Petrol: E10 as specified in Annex IX paragraph A.1 of EU2017/1151.

1.2.4.6.2. Ethanol: E85 as specified in Annex IX paragraph A.1 of EU2017/1151.

1.2.4.6.3. LPG as specified in Annex IX paragraph A.1 of EU2017/1151.

1.2.4.6.4. NG/Biomethane as specified in Annex IX paragraph A.1 of EU2017/1151.

1.2.4.6.5. Hydrogen for internal combustion engines as specified in Annex IX paragraph A.1 of EU2017/1151.

1.2.4.6.6. Diesel: B7 as specified in Annex IX paragraph A.2 of EU2017/1151.

1.2.4.6.7. Hydrogen for fuel cell vehicles as specified in Annex IX paragraph A.3 of EU2017/1151.

1.2.4.7. Test vehicle preparation

1.2.4.7.1. The vehicle shall be approximately horizontal during the test so as to avoid any abnormal distribution of the fuel.

1.2.4.7.2. If necessary, the laboratory shall provide additional fittings and adapters, as required to accommodate a fuel drain at the lowest point possible in the tank(s) as installed on the vehicle, and to provide for exhaust sample collection.

1.2.4.7.3. For PM sampling during a test when the regenerating device is in a stabilized loading condition (i.e. the vehicle is not undergoing a regeneration), it is recommended that the vehicle has completed > 1/3 of the mileage between scheduled regenerations or that the periodically regenerating device has undergone equivalent loading off the vehicle.

1.2.4.7.4 The types and amounts of lubricants and coolant for emissions testing shall be on maximum level and of manufacturer approved quality. This includes all fluids in the car (engine oil, gearbox oil, suspension fluids, brake fluid, windscreen wiper fluids (front and rear), refrigerant, coolant, AdBlue and the fuel tank).

1.2.5. Preliminary testing cycles

1.2.5.1. Preliminary testing cycles may be carried out if requested by the laboratory to follow the speed trace within the prescribed limits.

1.2.6. Test vehicle preconditioning

1.2.6.1. The fuel tank (or fuel tanks) shall be filled with the specified test fuel. If the existing fuel in the fuel tank (or fuel tanks) does not meet the specifications contained in paragraph 1.2.4.6. of this Sub-Annex, the existing fuel shall be drained prior to the fuel fill. The evaporative emission control system shall neither be abnormally purged nor abnormally loaded.

1.2.6.2. REESSs charging

The REESSs shall be charged before each cold start of official testing.

1.2.6.3. The test vehicle shall be moved to the test cell and the operations listed in paragraphs 1.2.6.3.1. to 1.2.6.3.9. inclusive shall be performed.

1.2.6.3.1. The test vehicle shall be placed, either by being driven or pushed, on a dynamometer and operated through the applicable WLTCs. The vehicle need not be cold, and may be used to set the dynamometer load.

1.2.6.3.2. The dynamometer load shall be set according to paragraphs 7. and 8. of Sub-Annex 4.

1.2.6.3.3. During preconditioning, the test cell temperature shall be the same as defined for the Type 1 test (paragraph 1.2.2.2.1. of this Sub-Annex).

1.2.6.3.4. The drive-wheel tyre pressure shall be set in accordance with paragraph 1.2.4.5. of this Sub-Annex.

1.2.6.3.5. Between the tests on the first gaseous reference fuel and the second gaseous reference fuel, for vehicles with positive ignition engines fuelled with LPG or NG/biomethane or so equipped that they can be fuelled with either petrol or LPG or NG/biomethane, the vehicle shall be preconditioned again before the test on the second reference fuel.

1.2.6.3.6. For preconditioning, the applicable WLTC shall be driven. Starting the engine and driving shall be performed according to paragraph 1.2.6.4. of this Sub-Annex.

The dynamometer shall be set according to Sub-Annex 4.

1.2.6.3.7. At the request of the laboratory or GNT, additional WLTCs may be performed in order to bring the vehicle and its control systems to a stabilized condition.

1.2.6.3.8. The extent of such additional preconditioning shall be included in all relevant test reports.

1.2.6.3.9. In a test facility in which there may be possible contamination of a low particulate emitting vehicle test with residue from a previous test on a high particulate emitting vehicle, it is recommended, for the purpose of sampling equipment preconditioning, that a 120 km/h steady state drive cycle of 20 minutes duration be driven by a low particulate emitting vehicle. Longer and/or higher speed running is permissible for sampling equipment preconditioning if required. Dilution tunnel background measurements shall be taken after the tunnel preconditioning, and prior to any subsequent vehicle testing.

1.2.6.4. The powertrain start procedure shall be initiated by means of the devices provided for this purpose according to the manufacturer's instructions.

A non-vehicle initiated switching of mode of operation during the test shall not be permitted unless otherwise specified.

1.2.6.4.1. If the initiation of the powertrain start procedure is not successful, e.g. the engine does not start as anticipated or the vehicle displays a start error, the test is void, preconditioning tests shall be repeated and a new test shall be driven.

1.2.6.4.2. The cycle starts on initiation of the powertrain start procedure.

1.2.6.4.3. In the cases where LPG or NG/biomethane is used as a fuel, it is permissible that the engine is started on petrol and switched automatically to LPG or NG/biomethane after a predetermined period of time that cannot be changed by the driver.

1.2.6.4.4. During stationary/idling vehicle phases, the brakes shall be applied with appropriate force to prevent the drive wheels from turning.

1.2.6.4.5. During the test, speed shall be measured against time or collected by the data acquisition system at a frequency of not less than 1 Hz so that the actual driven speed can be assessed.

1.2.6.4.6. The distance actually driven by the vehicle shall be included in all relevant test sheets for each WLTC+ phase.

1.2.6.5. Use of the transmission

1.2.6.5.1. Manual shift transmission

Vehicles with a manual gearbox with a gear-shift indicator (GSI) are measured while shifting gears as recommended. According to VO (EU) 65/2012 and EG 661/2009 vehicles must be equipped with a GSI.1.2.6.5.1.1. The tolerances given in paragraph 1.2.6.6. of this Sub-Annex shall apply.

1.2.6.5.1.2. The gear change shall be started and completed within ± 3.0 second of the prescribed gear shift point.

1.2.6.5.1.3. The clutch shall be depressed within ± 1.0 second of the prescribed clutch operating point.

1.2.6.5.1.4 Vehicles equipped with a manual gearbox which are equipped with a GSI that only gives up-shifting instructions shall be shifted down at 1300 rpm engine speed the latest.

1.2.6.5.2. Automatic shift transmission

1.2.6.5.2.1. Vehicles equipped with automatic shift transmissions shall be tested in the predominant mode. The accelerator control shall be used in such a way as to accurately follow the speed trace.

1.2.6.5.2.2. Vehicles equipped with automatic shift transmissions with driver-selectable modes shall fulfill the limits of criteria emissions in all automatic shift modes used for forward driving. On the basis of technical evidence provided by the laboratory and with the agreement of the GNT, the dedicated driver-selectable modes for very special limited purposes shall not be considered (e.g. maintenance mode, crawler mode).

1.2.6.5.2.3. [Reserved]

1.2.6.5.2.4. [Reserved]

1.2.6.5.2.5. The tolerances given in paragraph 1.2.6.6. of this Sub-Annex shall apply.

After initial engagement, the selector shall not be operated at any time during the test. Initial engagement shall be done 1 second before beginning the first acceleration.

1.2.6.5.2.6. Vehicles with an automatic transmission with a manual mode shall be tested according paragraph 1.2.6.5.2. of this Sub-Annex.

1.2.6.6. Speed trace tolerances

The following tolerances shall be permitted between the actual vehicle speed and the prescribed speed of the applicable test cycles. The tolerances are:

(a) Upper limit: 2.0 km/h higher than the highest point of the trace within ± 1.0 second of the given point in time;

(b) Lower limit: 2.0 km/h lower than the lowest point of the trace within ± 1.0 second of the given time.

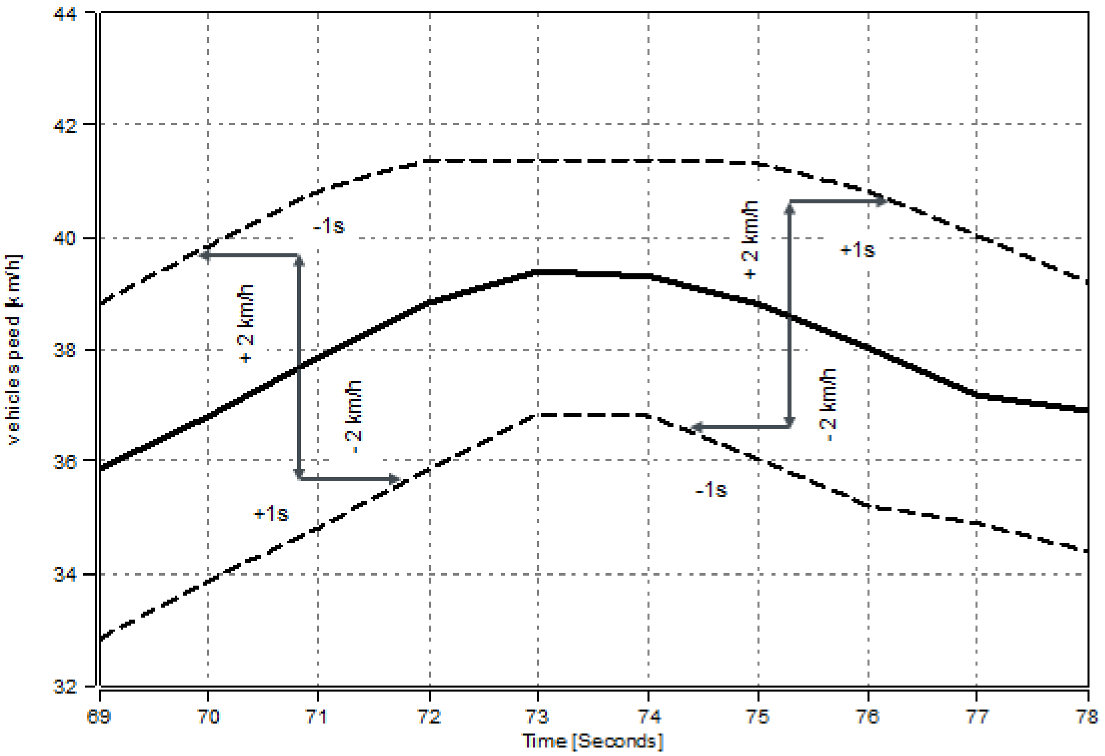
See Figure A6/2.

Speed tolerances greater than those prescribed shall be accepted provided the tolerances are never exceeded for more than 1 second on any one occasion.

There shall be no more than ten such deviations per test.

Figure A6/2

Speed trace tolerances



1.2.6.7. Accelerations

1.2.6.7.1. The vehicle shall be operated with the appropriate accelerator control movement necessary to accurately follow the speed trace.

1.2.6.7.2. The vehicle shall be operated smoothly, following representative shift points, speeds and procedures.

1.2.6.7.3. For manual transmissions, the accelerator controller shall be released during each shift and the shift shall be accomplished in minimum time.

1.2.6.7.4. If the vehicle cannot follow the speed trace, it shall be operated at maximum available power until the vehicle speed reaches the respective target speed again.

1.2.6.8. Decelerations

1.2.6.8.1. During decelerations of the cycle, the driver shall deactivate the accelerator control but shall not manually disengage the clutch until the point specified in paragraph 4.(c) of Sub-Annex 2.

1.2.6.8.1.1. If the vehicle decelerates faster than prescribed by the speed trace, the accelerator control shall be operated such that the vehicle accurately follows the speed trace.

1.2.6.8.1.2. If the vehicle decelerates too slowly to follow the intended deceleration, the brakes shall be applied such that it is possible to accurately follow the speed trace.

1.2.6.9. Unexpected engine stop

1.2.6.9.1. If the engine stops unexpectedly, the preconditioning or Type 1 test shall be declared void.

1.2.6.9.2. Otherwise, if the engine stops correctly due to start&stop strategy, the test shall be considered valid.

1.2.6.10. After completion of the cycle, the engine shall be switched off. The vehicle shall not be restarted until the beginning of the test for which the vehicle has been preconditioned.

1.2.7. Soaking

1.2.7.1. After preconditioning and before testing, the test vehicle shall be kept in an area with ambient conditions as specified in paragraph 1.2.2.2.2. of this Sub-Annex.

1.2.7.2. The vehicle shall be soaked for a minimum of 6 hours and a maximum of 36 hours with the engine compartment cover closed. Accelerated cooling systems shall not be used.

1.2.8. Emission and fuel consumption test (Type 1 test)

1.2.8.1. The test cell temperature at the start of the test shall be 14 °C ± 3 °C measured at minimum frequency of 1 Hz.

1.2.8.2. The test vehicle shall be pushed onto a dynamometer.

1.2.8.2.1. The drive wheels of the vehicle shall be placed on the dynamometer without starting the engine.

1.2.8.2.2. The drive-wheel tyre pressures shall be set in accordance with the provisions of paragraph 1.2.4.5. of this Sub-Annex.

1.2.8.2.3. The engine compartment cover shall be closed.

1.2.8.2.4. An exhaust connecting tube shall be attached to the vehicle tailpipe(s) immediately before starting the engine.

1.2.8.3. Starting of the powertrain and driving

1.2.8.3.1. The powertrain start procedure shall be initiated by means of the devices provided for this purpose according to the manufacturer's instructions.

1.2.8.3.2. The vehicle shall be driven as described in paragraphs 1.2.6.4. to 1.2.6.10. inclusive of this Sub-Annex over the applicable WLTC, as described in Sub-Annex 1.

1.2.8.4. RCB data shall be measured for each phase of the WLTC+ as defined in Appendix 2 to this Sub-Annex.

1.2.8.5. Actual vehicle speed shall be sampled with a measurement frequency of 10 Hz and the drive trace indices described in paragraph 7. of Sub-Annex 7 shall be calculated and documented.

1.2.9. Gaseous sampling

Gaseous samples shall be collected in bags and the compounds analysed at the end of the test or a test phase, or the compounds may be analysed continuously and integrated over the cycle.

1.2.9.1. The following steps shall be taken prior to each test.

1.2.9.1.1. The purged, evacuated sample bags shall be connected to the dilute exhaust and dilution air sample collection systems.

1.2.9.1.2. Measuring instruments shall be started according to the instrument manufacturers' instructions.

1.2.9.1.3. The CVS heat exchanger (if installed) shall be pre-heated or pre-cooled to within its operating test temperature tolerance as specified in paragraph 3.3.5.1. of Sub-Annex 5.

1.2.9.1.4. Components such as sample lines, filters, chillers and pumps shall be heated or cooled as required until stabilised operating temperatures are reached.

1.2.9.1.5. CVS flow rates shall be set according to paragraph 3.3.4. of Sub-Annex 5, and sample flow rates shall be set to the appropriate levels.

1.2.9.1.6. Any electronic integrating device shall be zeroed and may be re-zeroed before the start of any cycle phase.

1.2.9.1.7. For all continuous gas analysers, the appropriate ranges shall be selected. These may be switched during a test only if switching is performed by changing the calibration over which the digital resolution of the instrument is applied. The gains of an analyser's analogue operational amplifiers may not be switched during a test.

1.2.9.1.8. All continuous gas analysers shall be zeroed and calibrated using gases fulfilling the requirements of paragraph 6. of Sub-Annex 5.

1.2.10. Sampling for PM determination

1.2.10.1. The steps described in paragraphs 1.2.10.1.1. to 1.2.10.1.2.3. inclusive of this Sub-Annex shall be taken prior to each test.

1.2.10.1.1. Filter selection

1.2.10.1.1.1. A single particulate sample filter without back-up shall be employed for the complete applicable WLTC. In order to accommodate regional cycle variations, a single filter may be employed for the first three phases and a separate filter for the fourth phase.

1.2.10.1.2. Filter preparation

1.2.10.1.2.1. At least 1 hour before the test, the filter shall be placed in a petri dish protecting against dust contamination and allowing air exchange, and placed in a weighing chamber (or room) for stabilization.

At the end of the stabilization period, the filter shall be weighed and its weight shall be included in all relevant test sheets. The filter shall subsequently be stored in a closed petri dish or sealed filter holder until needed for testing. The filter shall be used within 8 hours of its removal from the weighing chamber (or room).

The filter shall be returned to the stabilization room within 1 hour after the test and shall be conditioned for at least 1 hour before weighing.

1.2.10.1.2.2. The particulate sample filter shall be carefully installed into the filter holder. The filter shall be handled only with forceps or tongs. Rough or abrasive filter handling will result in erroneous weight determination. The filter holder assembly shall be placed in a sample line through which there is no flow.

1.2.10.1.2.3. It is recommended that the microbalance be checked at the start of each weighing session, within 24 hours of the sample weighing, by weighing one reference item of approximately 100 mg. This item shall be weighed three times and the arithmetic average result included in all relevant test sheets. If the arithmetic average result of the weighings is ± 5 µg of the result from the previous weighing session, the weighing session and balance are considered valid.

1.2.11. PN sampling

1.2.11.1. The steps described in paragraphs 1.2.11.1.1. to 1.2.11.1.2. inclusive of this Sub-Annex shall be taken prior to each test:

1.2.11.1.1. The particle specific dilution system and measurement equipment shall be started and made ready for sampling;

1.2.11.1.2. The correct function of the PNC and VPR elements of the particle sampling system shall be confirmed according to the procedures listed in paragraphs 1.2.11.1.2.1. to 1.2.11.1.2.4. inclusive of this Sub-Annex.

1.2.11.1.2.1. A leak check, using a filter of appropriate performance attached to the inlet of the entire PN measurement system, VPR and PNC, shall report a measured concentration of less than 0.5 particles per cm^3.

1.2.11.1.2.2. Each day, a zero check on the PNC, using a filter of appropriate performance at the PNC inlet, shall report a concentration of ≤ 0.2 particles per cm^3. Upon removal of the filter, the PNC shall show an increase in measured concentration to at least 100 particles per cm^3 when sampling ambient air and a return to ≤ 0.2 particles per cm^3 on replacement of the filter.

1.2.11.1.2.3. It shall be confirmed that the measurement system indicates that the evaporation tube, where featured in the system, has reached its correct operating temperature.

1.2.11.1.2.4. It shall be confirmed that the measurement system indicates that the diluter PND_1 has reached its correct operating temperature.

1.2.12. Sampling during the test

1.2.12.1. The dilution system, sample pumps and data collection system shall be started.

1.2.12.2. The PM and PN sampling systems shall be started.

1.2.12.3. Particle number shall be measured continuously. The arithmetic average concentration shall be determined by integrating the analyser signals over each phase.

1.2. 12.4. Sampling shall begin before or at the initiation of the powertrain start procedure and end on conclusion of the cycle.

1.2.12.5. Sample switching

1.2.12.5.1. Gaseous emissions

1.2.12.5.1.1. Sampling from the diluted exhaust and dilution air shall be switched from one pair of sample bags to subsequent bag pairs, if necessary, at the end of each phase of the applicable WLTC+ to be driven.

1.2.12.5.2. Particulate

1.2.12.5.2.1. The requirements of paragraph 1.2.10.1.1.1. of this Sub-Annex shall apply.

1.2.12.6. Dynamometer distance shall be included in all relevant test sheets for each phase.

1.2.13. Ending the test

1.2.13.1. The engine shall be turned off immediately after the end of the last part of the test.

1.2.13.2. The constant volume sampler, CVS, or other suction device shall be turned off, or the exhaust tube from the tailpipe or tailpipes of the vehicle shall be disconnected.

1.2.13.3. The vehicle may be removed from the dynamometer.

1.2.14. Post-test procedures

1.2.14.1. Gas analyser check

1.2.14.1.1. Zero and calibration gas reading of the analysers used for continuous diluted measurement shall be checked. The test shall be considered acceptable if the difference between the pre-test and post-test results is less than 2 per cent of the calibration gas value.

1.2.14.2. Bag analysis

1.2.14.2.1. Exhaust gases and dilution air contained in the bags shall be analysed as soon as possible. Exhaust gases shall, in any event, be analysed not later than 30 minutes after the end of the cycle phase.

The gas reactivity time for compounds in the bag shall be taken into consideration.

1.2.14.2.2. As soon as practical prior to analysis, the analyser range to be used for each compound shall be set to zero with the appropriate zero gas.

1.2.14.2.3. The calibration curves of the analysers shall be set by means of calibration gases of nominal concentrations of 70 to 100 per cent of the range.

1.2.14.2.4. The zero settings of the analysers shall be subsequently rechecked: if any reading differs by more than 2 per cent of the range from that set in paragraph 1.2.14.2.2. of this Sub-Annex, the procedure shall be repeated for that analyser.

1.2.14.2.5. The samples shall be subsequently analysed.

1.2.14.2.6. After the analysis, zero and calibration points shall be rechecked using the same gases. The test shall be considered acceptable if the difference is less than 2 per cent of the calibration gas value.

1.2.14.2.7. The flow rates and pressures of the various gases through analysers shall be the same as those used during calibration of the analysers.

1.2.14.2.8. The content of each of the compounds measured shall be included in all relevant test sheets after stabilization of the measuring device.

1.2.14.2.9. The mass and number of all emissions, where applicable, shall be calculated according to Sub-Annex 7.

1.2.14.2.10. Calibrations and checks shall be performed either:

(a) Before and after each bag pair analysis; or

(b) Before and after the complete test.

In case (b), calibrations and checks shall be performed on all analysers for all ranges used during the test.

In both cases, (a) and (b), the same analyser range shall be used for the corresponding ambient air and exhaust bags.

1.2.14.3. Particulate sample filter weighing

1.2.14.3.1. The particulate sample filter shall be returned to the weighing chamber (or room) no later than 1 hour after completion of the test. It shall be conditioned in a petri dish, which is protected against dust contamination and allows air exchange, for at least 1 hour, and weighed. The gross weight of the filter shall be included in all relevant test sheets.

1.2.14.3.2. At least two unused reference filters shall be weighed within 8 hours of, but preferably at the same time as, the sample filter weighings. Reference filters shall be of the same size and material as the sample filter.

1.2.14.3.3. If the specific weight of any reference filter changes by more than ± 5µg between sample filter weighings, the sample filter and reference filters shall be reconditioned in the weighing chamber (or room) and reweighed.

1.2.14.3.4. The comparison of reference filter weighings shall be made between the specific weights and the rolling arithmetic average of that reference filter's specific weights. The rolling arithmetic average shall be calculated from the specific weights collected in the period after the reference filters were placed in the weighing chamber (or room). The averaging period shall be at least one day but not more than 15 days.

1.2.14.3.5. Multiple reconditionings and reweighings of the sample and reference filters are permitted until a period of 80 hours has elapsed following the measurement of gases from the emissions test. If, prior to or at the 80 hour point, more than half the number of reference filters meet the ± 5 µg criterion, the sample filter weighing may be considered valid. If, at the 80 hour point, two reference filters are employed and one filter fails the ± 5 µg criterion, the sample filter weighing may be considered valid under the condition that the sum of the absolute differences between specific and rolling means from the two reference filters shall be less than or equal to 10 µg.

1.2.14.3.6. In the case that less than half of the reference filters meet the ± 5 µg criterion, the sample filter shall be discarded, and the emissions test repeated. All reference filters shall be discarded and replaced within 48 hours. In all other cases, reference filters shall be replaced at least every 30 days and in such a manner that no sample filter is weighed without comparison to a reference filter that has been present in the weighing chamber (or room) for at least one day.

1.2.14.3.7. If the weighing chamber (or room) stability criteria outlined in paragraph 4.2.2.1. of Sub-Annex 5 are not met, but the reference filter weighings meet the above criteria, the vehicle manufacturer has the option of accepting the sample filter weights or voiding the tests, repairing the weighing chamber (or room) control system and re-running the test.

Sub-Annex 6 - Appendix 1

Emissions test procedure for all vehicles equipped with periodically regenerating systems

1. General

1.1. This Appendix defines the specific provisions regarding testing a vehicle equipped with periodically regenerating systems as defined in paragraph 3.8.1. of this Annex.

1.2. [Reserved]

1.3. [Reserved]

1.4. [Reserved]

1.5. [Reserved]

2. Test Procedure

The emission test shall be carried out with the unchanged, original equipment manufacturer's (OEM) control unit

2.1. Test Validity

2.1.1. If a regeneration is triggered during WLTC+ cycle, the test shall be considered void and it shall be repeated.

2.1.2. If necessary, a regeneration can be performed before the WLTC+ cycle repetition

2.1.3. If a new regeneration is triggered during the WLTC+ cycle repetition, the cycle shall be considered valid and no correction factor shall be applied in the test results calculations.

2.2. [Reserved]

2.2.1. [Reserved]

2.2.2. [Reserved]

2.2.3. [Reserved]

2.2.3.1. [Reserved]

2.2.3.2. [Reserved]

2.2.4. [Reserved]

2.2.5. [Reserved]

2.2.5.1. [Reserved]

2.2.6. [Reserved]

3. [Reserved]

Sub-Annex 6 -Appendix 2

Test procedure for electric power supply system monitoring

1. General

In the case that NOVC-HEVs and OVC-HEVs are tested, Appendices 2 and 3 of Sub-Annex 8 shall apply.

This Appendix defines the specific provisions regarding the correction of test results for CO_2 mass emission as a function of the energy balance ΔE_{REESS} for all REESSs.

The corrected values for CO_2 mass emission shall correspond to a zero energy balance ($\Delta E_{REESS} = 0$), and shall be calculated using a correction coefficient determined as defined below.

2. Measurement equipment and instrumentation

2.1. Current measurement

REESS depletion shall be defined as negative current.

2.1.1. The REESS current(s) shall be measured during the tests using a clamp-on or closed type current transducer. The current measurement system shall fulfil the requirements specified in Table A8/1. The current transducer(s) shall be capable of handling the peak currents at engine starts and temperature conditions at the point of measurement.

2.1.2. Current transducers shall be fitted to any of the REESS on one of the cables connected directly to the REESS and shall include the total REESS current.

In case of shielded wires, appropriate methods shall be applied in accordance with the GNT.

In order to easily measure REESS current using external measuring equipment, laboratories should preferably integrate appropriate, safe and accessible connection points in the vehicle

2.1.3. The measured current shall be integrated over time at a minimum frequency of 20 Hz, yielding the measured value of Q, expressed in ampere-hours Ah. The measured current shall be integrated over time, yielding the measured value of Q, expressed in ampere-hours Ah. The integration may be done in the current measurement system.

2.2. [Reserved]

2.2.1. [Reserved]

2.2.2. [Reserved]

3. REESS energy change-based correction procedure

3.1. Measurement of the REESS current shall start at the same time as the test starts and shall end immediately after the vehicle has driven the complete driving cycle.

3.2. The electricity balance Q measured in the electric power supply system, shall be used as a measure of the difference in the REESS energy content at the end of the cycle compared to the beginning of the cycle. The electricity balance shall be determined for the total WLTC+ for the applicable vehicle class.

3.3. Separate values of Q_{phase} shall be logged over the cycle phases required to be driven for the applicable vehicle class.

3.4. Correction of CO_2 mass emission over the whole cycle as a function of the correction criterion c.

3.4.1. Calculation of the correction criterion c

The correction criterion c is the ratio between the absolute value of the electric energy change $\Delta E_{REESS,j}$ and the fuel energy and shall be calculated using the following equations:

$$c = \left| \frac{\Delta E_{REESS,j}}{E_{fuel}} \right|$$

where:

c is the correction criterion;

$\Delta E_{REESS,j}$ is the electric energy change of all REESSs over period j determined according to paragraph 4.1. of this Appendix, Wh;

j is, in this paragraph, the whole applicable WLTC+ test cycle;

E_{Fuel} is the fuel energy according to the following equation:

$$E_{fuel} = 10 \times HV \times FC_{nb} \times d$$

where:

E_{fuel} is the energy content of the consumed fuel over the applicable WLTC+ test cycle, Wh;

HV is the heating value according to Table A6.App2/1, kWh/l;

FC_{nb} is the non-balanced fuel consumption of the Type 1 test, not corrected for the energy balance, determined according to paragraph 6. of Sub-Annex 7, l/100 km;

d is the distance driven over the corresponding applicable WLTC+ test cycle, km;

10 conversion factor to Wh.

3.4.2. The correction shall be applied if ΔE_{REESS} is negative (corresponding to REESS discharging) and the correction criterion c calculated according to paragraph 3.4.1. of this Sub-Annex is greater than the applicable tolerance according to Table A6.App2/2.

3.4.3. The correction shall be omitted and uncorrected values shall be used if the correction criterion c calculated according to paragraph 3.4.1. of this Sub-Annex is less than the applicable tolerance according to Table A6.App2/2.

3.4.4. The correction may be omitted and uncorrected values may be used if:

(a) ΔE_{REESS} is positive (corresponding to REESS charging) and the correction criterion c calculated according to paragraph 3.4.1. of this Sub-Annex is greater than the applicable tolerance according to Table A6.App2/2;

(b) the manufacturer can prove to the approval authority by measurement that there is no relation between ΔE_{REESS} and CO_2 mass emission and ΔE_{REESS} and fuel consumption respectively.

Table A6.App2/1

Energy content of fuel

Fuel	**Petrol**		**Diesel**
Content Ethanol/Biodiesel, per cent	E10	E85	B7
Heat value **(kWh/l)**	8.64	6.41	9.79

Table A6.App2/2

RCB correction criteria

Cycle	low + medium)	low + medium + high	low + medium + high + extra high
Correction criterion c	0.015	0.01	0.005

4. Applying the correction function

4.1. To apply the correction function, the electric energy change $\Delta E_{REESS,j}$ of a period j of all REESSs shall be calculated from the measured current and the nominal voltage:

$$\Delta E_{REESS,j} = \sum_{i=1}^{n} \Delta E_{REESS,j,i}$$

where:

$\Delta E_{REESS,j,i}$ is the electric energy change of REESS i during the considered period j, Wh;

and:

$$\Delta E_{REESS,j,i} = \frac{1}{3600} \times U_{REESS} \times \int_{t_0}^{t_{end}} I(t)_{j,i}\, dt$$

where:

U_{REESS} is the nominal REESS voltage determined according to DIN EN 60050-482, V;

$I(t)_{j,i}$ is the electric current of REESS i during the considered period j determined according to paragraph 2. of this Appendix, A;

t_0 is the time at the beginning of the considered period j, s;

t_{end} is the time at the end of the considered period j, s.

i is the index number of the considered REESS;

n is the total amount of REESS;

j is the index number for the considered period, where a period shall be any applicable cycle phase, combination of cycle phases and the applicable total cycle;

$\frac{1}{3600}$ is the conversion factor from Ws to Wh.

4.2. For correction of CO_2 mass emission, g/km, combustion process-specific Willans factors from Table A6.App2/3 shall be used.

4.3. The correction shall be performed and applied for the total cycle and for each of its cycle phases separately, and shall be included in all relevant test reports.

4.4. For this specific calculation, a fixed electric power supply system alternator efficiency shall be used:

$$\eta_{\mathrm{alternator}} = 0.67 \text{ for electric power supply system REESS alternators}$$

4.5. The resulting CO_2 mass emission difference for the considered period j due to load behaviour of the alternator for charging a REESS shall be calculated using the following equation:

$$\Delta M_{CO2,j} = 0.0036 \times \Delta E_{REESS,j} \times \frac{1}{\eta_{\mathrm{alternator}}} \times \mathrm{Willans}_{\mathrm{factor}} \times \frac{1}{d_j}$$

where:

$\Delta M_{CO2,j}$ is the resulting CO_2 mass emission difference of period j, g/km;

$\Delta E_{REESS,j}$ is the REESS energy change of the considered period j calculated according to paragraph 4.1. of this Appendix, Wh;

d_j is the driven distance of the considered period j, km;

j is the index number for the considered period, where a period shall be any applicable cycle phase, combination of cycle phases and the applicable total cycle;

0.0036 is the conversion factor from Wh to MJ;

$\eta_{\mathrm{alternator}}$ is the efficiency of the alternator according to paragraph 4.4. of this Appendix;

$\mathrm{Willans}_{\mathrm{factor}}$ is the combustion process specific Willans factor as defined in Table A6.App2/3, gCO_2/MJ;

4.5.1. The CO_2 values of each phase and the total cycle shall be corrected as follows:

$M_{CO2,p,3} = M_{CO2,p,1} - \Delta M_{CO2,j}$

$M_{CO2,c,3} = M_{CO2,c,2} - \Delta M_{CO2,j}$

where:

$\Delta M_{CO2,j}$ is the result from paragraph 4.5. of this Sub-Annex for a period j, g/km.

4.6. For the correction of CO_2 emission, g/km, the Willans factors in Table A6.App2/2 shall be used.

Table A6.App2/3

Willans factors

			Naturally aspirated	Pressure-charged
Positive ignition	Petrol (E10)	l/MJ	0.0756	0.0803
		gCO_2/MJ	174	184
	CNG (G20)	m^3/MJ	0.0719	0.0764
		gCO_2/MJ	129	137
	LPG	l/MJ	0.0950	0.101
		gCO_2/MJ	155	164
	E85	l/MJ	0.102	0.108
		gCO_2/MJ	169	179
Compression ignition	Diesel (B7)	l/MJ	0.0611	0.0611
		gCO_2/MJ	161	161

Sub-Annex 7

Calculations

1. General requirements

1.1. Calculations related specifically to hybrid, pure electric and compressed hydrogen fuel cell vehicles are described in Sub-Annex 8.

A stepwise prescription of result calculations is described in paragraph 4. of Sub-Annex 8.

1.2. The calculations described in this Sub-Annex shall be used for vehicles using combustion engines.

1.3. Rounding of test results

1.3.1. Intermediate steps in the calculations shall not be rounded.

1.3.2.. The final criteria emission results shall be rounded in one step to the number of places to the right of the decimal point indicated by the applicable emission standard plus one additional significant figure.

1.3.3. The NO_x correction factor, KH, shall be rounded to two decimal places.

1.3.4. The dilution factor, DF, shall be rounded to two decimal places.

1.3.5. For information not related to standards, good engineering judgement shall be used.

1.3.6. Rounding of CO_2 and fuel consumption results is described in paragraph 1.4. of this Sub-Annex.

1.4. Stepwise prescription for calculating the final test results for vehicles using combustion engines

The results shall be calculated in the order described in Table A7/1. All applicable results in the column "Output" shall be recorded. The column "Process" describes the paragraphs to be used for calculation or contains additional calculations.

For the purpose of this table, the following nomenclature within the equations and results is used:

c	complete applicable cycle;
p	every applicable cycle phase;
i	every applicable criteria emission component, without CO_2;
CO_2	CO_2 emission.

Table A7/1

Procedure for calculating final test results

Source	Input	Process	Output	Step no.
Annex 6	**Raw test results**	**Mass emissions** **Sub-Annex 7, paragraphs 3. to 3.2.2. inclusive**	$M_{i,p,1}$, **g/km;** $M_{CO2,p,1}$, **g/km.**	**1**
Output step 1	$M_{i,p,1}$, **g/km;** $M_{CO2,p,1}$, **g/km.**	**Calculation of combined cycle values:** $$\mathbf{M_{i,c,2}} = \frac{\sum_p \mathbf{M_{i,p,1}} \times \mathbf{d_p}}{\sum_p \mathbf{d_p}}$$ $$\mathbf{M_{CO2,c,2}} = \frac{\sum_p \mathbf{M_{CO2,p,1}} \times \mathbf{d_p}}{\sum_p \mathbf{d_p}}$$ **where:** $M_{i/CO2,c,2}$ **are the emission results over the total cycle;** d_p **are the driven distances of the cycle phases, p.**	$M_{i,c,2}$, **g/km;** $M_{CO2,c,2}$, **g/km.**	**2**
Output step 1 and 2	$M_{CO2,p,1}$, **g/km;** $M_{CO2,c,2}$, **g/km.**	**RCB correction** **Sub-Annex 6, Appendix 2**	$M_{CO2,p,3}$, **g/km;** $M_{CO2,c,3}$, **g/km.**	**3**
Output **step 2 and 3**	$M_{i,c,2}$, **g/km;** $M_{CO2,c,3}$, **g/km.**	**Emissions test procedure for all vehicles equipped with periodically regenerating systems,** K_i**.** **Sub-Annex 6, Appendix 1.** $M_{i,c,4} = K_i \times M_{i,c,2}$ **or**	$M_{i,c,4}$, **g/km;** $M_{CO2,c,4}$, **g/km.**	**4a**

		$M_{i,c,4} = K_i + M_{i,c,2}$ and $M_{CO2,c,4} = K_{CO2} \times M_{CO2,c,3}$ or $M_{CO2,c,4} = K_{CO2} + M_{CO2,c,3}$ Additive offset or multiplicative factor to be used according to Ki determination. If K_i is not applicable: $M_{i,c,4} = M_{i,c,2}$ $M_{CO2,c,4} = M_{CO2,c,3}$		
Output step 3 and 4a	$M_{CO2,p,3}$, g/km; $M_{CO2,c,3}$, g/km; $M_{CO2,c,4}$, g/km.	If K_i is applicable, align CO_2 phase values to the combined cycle value: $M_{CO2,p,4} = M_{CO2,p,3} \times AF_{Ki}$ for every cycle phase p; where: $AF_{Ki} = \frac{M_{CO2,c,4}}{M_{CO2,c,3}}$ If K_i is not applicable: $M_{CO2,p,4} = M_{CO2,p,3}$	$M_{CO2,p,4}$, g/km.	4b
Output step 4	$M_{i,c,4}$, g/km; $M_{CO2,c,4}$, g/km; $M_{CO2,p,4}$, g/km.	ATCT correction according to paragraph 3.8.2. of Sub-Annex 6a. Deterioration factors calculated according to Annex VII and applied to the criteria emissions values.	$M_{i,c,5}$, g/km; $M_{CO2,c,5}$, g/km; $M_{CO2,p,5}$, g/km.	5 "result of a single test"

Output step 5	For every test: $M_{i,c,5}$, g/km; $M_{CO2,c,5}$, g/km; $M_{CO2,p,5}$, g/km.	Averaging of tests and declared value. Sub-Annex 6, paragraphs 1.1.2. to 1.1.2.3. inclusive	$M_{i,c,6}$, g/km; $M_{CO2,c,6}$, g/km; $M_{CO2,p,6}$, g/km. $M_{CO2,c,declared}$, g/km.	6
Output step 6	$M_{CO2,c,6}$, g/km; $M_{CO2,p,6}$, g/km. $M_{CO2,c,declared}$, g/km.	Alignment of phase values. Sub-Annex 6, paragraph 1.1.2.4. and: $M_{CO2,c,7} = M_{CO2,c,declared}$	$M_{CO2,c,7}$, g/km; $M_{CO2,p,7}$, g/km.	7
Output steps 6 and 7	$M_{i,c,6}$, g/km; $M_{CO2,c,7}$, g/km; $M_{CO2,p,7}$, g/km.	Calculation of fuel consumption. Sub-Annex 7, paragraph 6. The calculation of fuel consumption shall be performed for the applicable cycle and its phases separately. For that purpose: (a) the applicable phase or cycle CO_2 values shall be used; (b) the criteria emission over the complete cycle shall be used. and: $M_{i,c,8} = M_{i,c,6}$ $M_{CO2,c,8} = M_{CO2,c,7}$ $M_{CO2,p,8} = M_{CO2,p,7}$	$FC_{c,8}$, l/100km; $FC_{p,8}$, l/100km; $M_{i,c,8}$, g/km; $M_{CO2,c,8}$, g/km; $M_{CO2,p,8}$, g/km.	8 "result of a Type 1 test for a test vehicle"

Step 8	For each of the test vehicles H and L: $M_{i,c,8}$, g/km; $M_{CO2,c,8}$, g/km; $M_{CO2,p,8}$, g/km; $FC_{c,8}$, l/100km; $FC_{p,8}$, l/100km.	If a test vehicle L was tested in addition to a test vehicle H, the resulting criteria emission value shall be the highest of the two values and referred to as $M_{i,c}$. In the case of the combined THC+NOx emissions, the highest value of the sum referring to either the VH or VL is to be used. Otherwise, if no vehicle L was tested, $M_{i,c} = M_{i,c,8}$ For CO_2 and FC, the values derived in step 8 shall be used, and CO_2 values shall be rounded to two decimal places, and FC values shall be rounded to three decimal places.	$M_{i,c}$, g/km; $M_{CO2,c,H}$, g/km; $M_{CO2,p,H}$, g/km; $FC_{c,H}$, l/100km; $FC_{p,H}$, l/100km; and if a vehicle L was tested: $M_{CO2,c,L}$, g/km; $M_{CO2,p,L}$, g/km; $FC_{c,L}$, l/100km; $FC_{p,L}$, l/100km.	9 "interpolation family result" Final criteria emission result
Step 9	$M_{CO2,c,H}$, g/km; $M_{CO2,p,H}$, g/km; $FC_{c,H}$, l/100km; $FC_{p,H}$, l/100km; and if a vehicle L was tested: $M_{CO2,c,L}$, g/km; $M_{CO2,p,L}$, g/km; $FC_{c,L}$, l/100km; $FC_{p,L}$, l/100km.	Fuel consumption and CO_2 calculations for individual vehicles in an CO_2 interpolation family. Sub-Annex 7, paragraph 3.2.3. CO_2 emissions must be expressed in grams per kilometre (g/km) rounded to the nearest whole number; FC values shall be rounded to one decimal place, expressed in (l/100km).	$M_{CO2,c,ind}$ g/km; $M_{CO2,p,ind}$, g/km; $FC_{c,ind}$ l/100km; $FC_{p,ind}$, l/100km.	10 "result of an individual vehicle" Final CO_2 and FC result

2. Determination of diluted exhaust gas volume

2.1. Volume calculation for a variable dilution device capable of operating at a constant or variable flow rate

2.1.1. The volumetric flow shall be measured continuously. The total volume shall be measured for the duration of the test.

2.2. Volume calculation for a variable dilution device using a positive displacement pump

2.2.1. The volume shall be calculated using the following equation:

$V = V_0 \times N$

where:

V is the volume of the diluted gas, in litres per test (prior to correction);

V_0 is the volume of gas delivered by the positive displacement pump in testing conditions, litres per pump revolution;

N is the number of revolutions per test.

2.2.1.1. Correcting the volume to standard conditions

The diluted exhaust gas volume, V, shall be corrected to standard conditions according to the following equation:

$$V_{mix} = V \times K_1 \times \left(\frac{P_B - P_1}{T_p}\right)$$

where:

$$K_1 = \frac{273.15\ (K)}{101.325\ (kPa)} = 2.6961$$

P_B is the test room barometric pressure, kPa;

P_1 is the vacuum at the inlet of the positive displacement pump relative to the ambient barometric pressure, kPa;

T_p is the arithmetic average temperature of the diluted exhaust gas entering the positive displacement pump during the test, Kelvin (K).

3. Mass emissions

3.1. General requirements

3.1.1. Assuming no compressibility effects, all gases involved in the engine's intake, combustion and exhaust processes may be considered to be ideal according to Avogadro's hypothesis.

3.1.2. The mass, M, of gaseous compounds emitted by the vehicle during the test shall be determined by the product of the volumetric concentration of the gas in question and the volume of the diluted exhaust gas with due regard for the following densities under the reference conditions of 273.15 K (0 °C) and 101.325 kPa:

Carbon monoxide (CO) $\rho = 1.25$ g/l

Carbon dioxide (CO_2) $\rho = 1.964$ g/l

Hydrocarbons:

for petrol (E10) ($C_1H_{1.93}O_{0.033}$) $\rho = 0.646$ g/l

for diesel (B7) ($C_1H_{1.86}O_{0.007}$) $\rho = 0.625$ g/l

for LPG ($C_1H_{2.525}$) $\rho = 0.649$ g/l

for NG/biomethane (CH_4) $\rho = 0.716$ g/l

for ethanol (E85) ($C_1H_{2.74}O_{0.385}$) $\rho = 0.934$ g/l

Nitrogen oxides (NO_x) $\rho = 2.053$ g/l

Nitrogen monoxide (NO) $\rho = 2.053$ g/l

Nitrogen dioxide (NO_2) $\rho = 2.053$ g/l

The density for NMHC mass calculations shall be equal to that of total hydrocarbons at 273.15 K (0 °C) and 101.325 kPa, and is fuel-dependent. The density for propane mass calculations (see paragraph 3.5. in Sub-Annex 5) is 1.967 g/l at standard conditions.

If a fuel type is not listed in this paragraph, the density of that fuel shall be calculated using the equation given in paragraph 3.1.3. of this Sub-Annex.

3.1.3. The general equation for the calculation of total hydrocarbon density for each reference fuel with a mean composition of $C_XH_YO_Z$ is as follows:

$$\rho_{THC} = \frac{MW_c + \frac{H}{C} \times MW_H + \frac{O}{C} \times MW_O}{V_M}$$

where:

ρ_{THC} is the density of total hydrocarbons and non-methane hydrocarbons, g/l;

MW_C is the molar mass of carbon (12.011 g/mol);

MW_H is the molar mass of hydrogen (1.008 g/mol);

MW_O is the molar mass of oxygen (15.999 g/mol);

V_M is the molar volume of an ideal gas at 273.15 K (0° C) and 101.325 kPa (22.413 l/mol);

H/C is the hydrogen to carbon ratio for a specific fuel $C_XH_YO_Z$;

O/C is the oxygen to carbon ratio for a specific fuel $C_XH_YO_Z$.

3.2. Mass emissions calculation

3.2.1. Mass emissions of gaseous compounds per cycle phase shall be calculated using the following equations:

$$M_{i,phase} = \frac{V_{mix,phase} \times \rho_i \times KH_{phase} \times C_{i,phase} \times 10^{-6}}{d_{phase}}$$

where:

M_i is the mass emission of compound i per test or phase, g/km;

V_{mix} is the volume of the diluted exhaust gas per test or phase expressed in litres per test/phase and corrected to standard conditions (273.15 K (0 °C) and 101.325 kPa);

ρ_i is the density of compound i in grams per litre at standard temperature and pressure (273.15 K (0 °C) and 101.325 kPa);

KH is a humidity correction factor applicable only to the mass emissions of oxides of nitrogen, NO_2 and NO_x, per test or phase;

C_i is the concentration of compound i per test or phase in the diluted exhaust gas expressed in ppm and corrected by the amount of compound i contained in the dilution air;

d is the distance driven over the applicable WLTC, km;

n is the number of phases of the applicable WLTC.

3.2.1.1. The concentration of a gaseous compound in the diluted exhaust gas shall be corrected by the amount of the gaseous compound in the dilution air using the following equation:

$$C_i = C_e - C_d \times \left(1 - \frac{1}{DF}\right)$$

where:

C_i is the concentration of gaseous compound i in the diluted exhaust gas corrected by the amount of gaseous compound i contained in the dilution air, ppm;

C_e is the measured concentration of gaseous compound i in the diluted exhaust gas, ppm;

C_d is the concentration of gaseous compound i in the dilution air, ppm;

DF is the dilution factor.

3.2.1.1.1. The dilution factor DF shall be calculated using the equation for the concerned fuel:

$$DF = \frac{13.4}{C_{CO2} + (C_{HC} + C_{CO}) \times 10^{-4}}$$ for petrol (E10)

$$DF = \frac{13.5}{C_{CO2} + (C_{HC} + C_{CO}) \times 10^{-4}}$$ for diesel (B7)

$$DF = \frac{11.9}{C_{CO2} + (C_{HC} + C_{CO}) \times 10^{-4}}$$ for LPG

$$DF = \frac{9.5}{C_{CO2} + (C_{HC} + C_{CO}) \times 10^{-4}}$$ for NG/biomethane

$$DF = \frac{12.5}{C_{CO2} + (C_{HC} + C_{CO}) \times 10^{-4}}$$ for ethanol (E85)

$$DF = \frac{35.03}{C_{H2O} - C_{H2O-DA} + C_{H2} \times 10^{-4}}$$ for hydrogen

With respect to the equation for hydrogen:

C_{H2O} is the concentration of H_2O in the diluted exhaust gas contained in the sample bag, per cent volume;

C_{H2O-DA} is the concentration of H_2O in the dilution air, per cent volume;

C_{H2} is the concentration of H_2 in the diluted exhaust gas contained in the sample bag, ppm.

If a fuel type is not listed in this paragraph, the DF for that fuel shall be calculated using the equations in paragraph 3.2.1.1.2. of this Sub-Annex.

If the manufacturer uses a DF that covers several phases, it shall calculate a DF using the mean concentration of gaseous compounds for the phases concerned.

The mean concentration of a gaseous compound shall be calculated using the following equation:

$$\overline{C}_i = \frac{\sum_{phase=1}^{n} (C_{i,phase} \times V_{mix,phase})}{\sum_{phase=1}^{n} V_{mix,phase}}$$

where:

C_i is mean concentration of a gaseous compound;

$C_{i,phase}$ is the concentration of each phase;

$V_{mix,phase}$ is the V_{mix} of the corresponding phase;

3.2.1.1.2. The general equation for calculating the dilution factor DF for each reference fuel with an arithmetic average composition of $C_xH_yO_z$ is as follows:

$$DF = \frac{X}{C_{CO2}+(C_{HC}+C_{CO})\times 10^{-4}}$$

where:

$$X = 100 \times \frac{x}{x+\frac{y}{2}+3.76\left(x+\frac{y}{4}-\frac{z}{2}\right)}$$

C_{CO2} is the concentration of CO_2 in the diluted exhaust gas contained in the sample bag, per cent volume;

C_{HC} is the concentration of HC in the diluted exhaust gas contained in the sample bag, ppm carbon equivalent;

C_{CO} is the concentration of CO in the diluted exhaust gas contained in the sample bag, ppm.

3.2.1.1.3. Methane measurement

3.2.1.1.3.1. For methane measurement using a GC-FID, NMHC shall be calculated using the following equation:

$$C_{NMHC} = C_{THC} - (Rf_{CH4} \times C_{CH4})$$

where:

C_{NMHC} is the corrected concentration of NMHC in the diluted exhaust gas, ppm carbon equivalent;

C_{THC} is the concentration of THC in the diluted exhaust gas, ppm carbon equivalent and corrected by the amount of THC contained in the dilution air;

C_{CH4} is the concentration of CH_4 in the diluted exhaust gas, ppm carbon equivalent and corrected by the amount of CH_4contained in the dilution air;

Rf_{CH4} is the FID response factor to methane as defined in paragraph 5.4.3.2. of Sub-Annex 5.

3.2.1.1.3.2. For methane measurement using an NMC-FID, the calculation of NMHC depends on the calibration gas/method used for the zero/calibration adjustment.

The FID used for the THC measurement (without NMC) shall be calibrated with propane/air in the normal manner.

For the calibration of the FID in series with an NMC, the following methods are permitted:

(a) The calibration gas consisting of propane/air bypasses the NMC;

(b) The calibration gas consisting of methane/air passes through the NMC.

It is highly recommended to calibrate the methane FID with methane/air through the NMC.

In case (a), the concentration of CH_4 and NMHC shall be calculated using the following equations:

$$C_{CH4} = \frac{C_{HC(w/NMC)} - C_{HC(w/oNMC)} \times (1-E_E)}{r_h \times (E_E - E_M)}$$

$$C_{NMHC} = \frac{C_{HC(w/oNMC)} \times (1 - E_M) - C_{HC(w/NMC)}}{E_E - E_M}$$

If $r_h < 1.05$, it may be omitted from the equation above for C_{CH4}.

In case (b), the concentration of CH_4 and NMHC shall be calculated using the following equations:

$$C_{CH4} = \frac{C_{HC(w/NMC)} \times r_h \times (1 - E_M) - C_{HC(w/oNMC)} \times (1 - E_E)}{r_h \times (E_E - E_M)}$$

$$C_{NMHC} = \frac{C_{HC(w/oNMC)} \times (1 - E_M) - C_{HC(w/NMC)} \times r_h \times (1 - E_M)}{E_E - E_M}$$

where:

$C_{HC(w/NMC)}$	is the HC concentration with sample gas flowing through the NMC, ppm C;
$C_{HC(w/oNMC)}$	is the HC concentration with sample gas bypassing the NMC, ppm C;
r_h	is the methane response factor as determined per paragraph 5.4.3.2. of Sub-Annex 5;
E_M	is the methane efficiency as determined per paragraph 3.2.1.1.3.3.1. of this Sub-Annex;
E_E	is the ethane efficiency as determined per paragraph 3.2.1.1.3.3.2. of this Sub-Annex.

If $r_h < 1.05$, it may be omitted in the equations for case (b) above for C_{CH4} and C_{NMHC}..

3.2.1.1.3.3. Conversion efficiencies of the non-methane cutter, NMC

The NMC is used for the removal of the non-methane hydrocarbons from the sample gas by oxidizing all hydrocarbons except methane. Ideally, the conversion for methane is 0 per cent, and for the other hydrocarbons represented by ethane is 100 per cent. For the accurate measurement of NMHC, the two efficiencies shall be determined and used for the calculation of the NMHC emission.

3.2.1.1.3.3.1. Methane conversion efficiency, E_M

The methane/air calibration gas shall be flowed to the FID through the NMC and bypassing the NMC and the two concentrations recorded. The efficiency shall be determined using the following equation:

$$E_M = 1 - \frac{C_{HC(w/NMC)}}{C_{HC(w/oNMC)}}$$

where:

$C_{HC(w/NMC)}$	is the HC concentration with CH_4 flowing through the NMC, ppm C;
$C_{HC(w/oNMC)}$	is the HC concentration with CH_4 bypassing the NMC, ppm C.

3.2.1.1.3.3.2. Ethane conversion efficiency, E_E

The ethane/air calibration gas shall be flowed to the FID through the NMC and bypassing the NMC and the two concentrations recorded. The efficiency shall be determined using the following equation:

$$E_E = 1 - \frac{C_{HC(w/NMC)}}{C_{HC(w/oNMC)}}$$

where:

$C_{HC(w/NMC)}$	is the HC concentration with C_2H_6 flowing through the NMC, ppm C;
$C_{HC(w/oNMC)}$	is the HC concentration with C_2H_6 bypassing the NMC, ppm C.

If the ethane conversion efficiency of the NMC is 0.98 or above, E_E shall be set to 1 for any subsequent calculation.

3.2.1.1.3.4. If the methane FID is calibrated through the cutter, E_M shall be 0.

The equation to calculate C_{H4} in paragraph 3.2.1.1.3.2. (case (b)) in this Sub-Annex becomes:

$$C_{CH4} = C_{HC(w/NMC)}$$

The equation to calculate C_{NMHC} in paragraph 3.2.1.1.3.2. (case (b)) in this Sub-Annex becomes:

$$C_{NMHC} = C_{HC(w/oNMC)} - C_{HC(w/NMC)} \times r_h$$

The density used for NMHC mass calculations shall be equal to that of total hydrocarbons at 273.15 K (0 °C) and 101.325 kPa and is fuel-dependent.

3.2.1.1.4. Flow-weighted arithmetic average concentration calculation

The following calculation method shall only be applied for CVS systems that are not equipped with a heat exchanger or for CVS systems with a heat exchanger that do not comply with paragraph 3.3.5.1. of Sub-Annex 5.

When the CVS flow rate, q_{VCVS}, over the test varies by more than ± 3 per cent of the arithmetic average flow rate, a flow-weighted arithmetic average shall be used for all continuous diluted measurements including PN:

$$C_e = \frac{\sum_{i=1}^{n} q_{VCVS}(i) \times \Delta t \times C(i)}{V}$$

where:

C_e is the flow-weighted arithmetic average concentration;

$q_{VCVS}(i)$ is the CVS flow rate at time $t = i \times \Delta t$, m³/min;

$C(i)$ is the concentration at time $t = i \times \Delta t$, ppm;

Δt sampling interval, s;

V total CVS volume, m³.

3.2.1.2. Calculation of the NO, NO_2 and NO_x humidity correction factor

In order to correct the influence of humidity on the results of oxides of nitrogen, the following calculations apply:

$$KH = \frac{1}{1 - 0.0329 \times (H - 10.71)}$$

where:

$$H = \frac{6.211 \times R_a \times P_d}{P_B - P_d \times R_a \times 10^{-2}}$$

and:

H is the specific humidity, grams of water vapour per kilogram dry air;

R_a is the relative humidity of the ambient air, per cent;

P_d is the saturation vapour pressure at ambient temperature, kPa;

P_B is the atmospheric pressure in the room, kPa.

The KH factor shall be calculated for each phase of the test cycle.

The ambient temperature and relative humidity shall be defined as the arithmetic average of the continuously measured values during each phase.

3.2.1.3. Determination of NO_2 concentration from NO and NO_x

Besides the direct measurement with a dedicated NO_2 analyser, NO_2 may also be determined by the difference between NO_x concentration from the bag corrected for dilution air concentration and NO concentration from continuous measurement corrected for dilution air concentration

3.2.1.3.1. NO concentrations

3.2.1.3.1.1. NO concentrations shall be calculated from the integrated NO analyser reading, corrected for varying flow if necessary.

3.2.1.3.1.2. The arithmetic average NO concentration shall be calculated using the following equation:

$$C_e = \frac{\int_{t_1}^{t_2} C_{NO}\, dt}{t_2 - t_1}$$

where:

$\int_{t_1}^{t_2} C_{NO}\, dt$	is the integral of the recording of the continuous dilute NO analyser over the test (t_2-t_1);
C_e	is the concentration of NO measured in the diluted exhaust, ppm;

3.2.1.3.1.3. Dilution air concentration of NO shall be determined from the dilution air bag. A correction shall be carried out according to paragraph 3.2.1.1. of this Sub-Annex.

3.2.1.3.2. NO_2 concentrations

3.2.1.3.2.1. Determination NO_2 concentration from direct diluted measurement

3.2.1.3.2.2. NO_2 concentrations shall be calculated from the integrated NO_2 analyser reading, corrected for varying flow if necessary.

3.2.1.3.2.3. The arithmetic average NO_2 concentration shall be calculated using the following equation:

$$C_e = \frac{\int_{t_1}^{t_2} C_{NO_2}\, dt}{t_2 - t_1}$$

where:

$\int_{t_1}^{t_2} C_{NO_2}\, dt$	is the integral of the recording of the continuous dilute NO_2 analyser over the test (t_2-t_1);
C_e	is the concentration of NO_2 measured in the diluted exhaust, ppm.

3.2.1.3.2.4. Dilution air concentration of NO_2 shall be determined from the dilution air bags. Correction is carried out according to paragraph 3.2.1.1. of this Sub-Annex.

3.2.2. Determination of the HC mass emissions from compression-ignition engines

3.2.2.1. To calculate HC mass emission for compression-ignition engines, the arithmetic average HC concentration shall be calculated using the following equation:

$$C_e = \frac{\int_{t_1}^{t_2} C_{HC} dt}{t_2 - t_1}$$

where:

$\int_{t_1}^{t_2} C_{HC} dt$ is the integral of the recording of the heated FID over the test (t_1 to t_2);

C_e is the concentration of HC measured in the diluted exhaust in ppm of C_i and is substituted for C_{HC} in all relevant equations.

3.2.2.1.1. Dilution air concentration of HC shall be determined from the dilution air bags. Correction shall be carried out according to paragraph 3.2.1.1. of this Sub-Annex.

3.2.3. [Reserved]

3.2.3.1. [Reserved]

3.2.3.2. [Reserved]

3.2.3.2.1. [Reserved]

3.2.3.2.2. [Reserved]

3.2.3.2.2.1. [Reserved]

3.2.3.2.2.2. [Reserved]

3.2.3.2.2.3. [Reserved]

3.2.3.2.2.4. [Reserved]

3.2.3.2.3. [Reserved]

3.2.3.2.4. [Reserved]

3.2.3.2.5. [Reserved]

3.2.4. [Reserved]

3.2.4.1. [Reserved]

3.2.4.1.1 [Reserved]

3.2.4.1.1.1. [Reserved]

3.2.4.1.1.2. [Reserved]

3.2.4.1.1.3. [Reserved]

3.3. PM

3.3.1. Calculation

PM shall be calculated using the following two equations:

$$PM = \frac{(V_{mix} + V_{ep}) \times P_e}{V_{ep} \times d}$$

where exhaust gases are vented outside tunnel;

and:

$$PM = \frac{V_{mix} \times P_e}{V_{ep} \times d}$$

where exhaust gases are returned to the tunnel;

where:

V_{mix} is the volume of diluted exhaust gases (see paragraph 2. of this Sub-Annex), under standard conditions;

V_{ep} is the volume of diluted exhaust gas flowing through the particulate sampling filter under standard conditions;

P_e is the mass of particulate matter collected by one or more sample filters, mg;

d is the distance driven corresponding to the test cycle , km.

3.3.1.1. Where correction for the background particulate mass from the dilution system has been used, this shall be determined in accordance with paragraph 1.2.1.3.1. of Sub-Annex 6. In this case, particulate mass (mg/km) shall be calculated using the following equations:

$$PM = \left\{\frac{P_e}{V_{ep}} - \left[\frac{P_a}{V_{ap}} \times \left(1 - \frac{1}{DF}\right)\right]\right\} \times \frac{(V_{mix} + V_{ep})}{d}$$

in the case that the exhaust gases are vented outside the tunnel;

and:

$$PM = \left\{\frac{P_e}{V_{ep}} - \left[\frac{P_a}{V_{ap}} \times \left(1 - \frac{1}{DF}\right)\right]\right\} \times \frac{(V_{mix})}{d}$$

in the case that the exhaust gases are returned to the tunnel;

where:

V_{ap} is the volume of tunnel air flowing through the background particulate filter under standard conditions;

P_a is the particulate mass from the dilution air, or the dilution tunnel background air, as determined by the one of the methods described in paragraph 1.2.1.3.1. of Sub-Annex 6;

DF is the dilution factor determined in paragraph 3.2.1.1.1. of this Sub-Annex.

Where application of a background correction results in a negative result, it shall be considered to be zero mg/km.

3.3.2. Calculation of PM using the double dilution method

$$V_{ep} = V_{set} - V_{ssd}$$

where:

V_{ep} is the volume of diluted exhaust gas flowing through the particulate sample filter under standard conditions;

V_{set} is the volume of the double diluted exhaust gas passing through the particulate sampling filters under standard conditions;

V_{ssd} is the volume of the secondary dilution air under standard conditions.

Where the secondary diluted sample gas for PM measurement is not returned to the tunnel, the CVS volume shall be calculated as in single dilution, i.e.:

$$V_{mix} = V_{mix\ indicated} + V_{ep}$$

where:

$V_{mix\ indicated}$ is the measured volume of diluted exhaust gas in the dilution system following extraction of the particulate sample under standard conditions.

4. Determination of PN

4.1. PN shall be calculated using the following equation:

$$PN = \frac{V \times k \times (\overline{C_s} \times \bar{f_r} - C_b \times \overline{f_{rb}}) \times 10^3}{d}$$

where:

PN is the particle number emission, particles per kilometre;

V is the volume of the diluted exhaust gas in litres per test (after primary dilution only in the case of double dilution) and corrected to standard conditions (273.15 K (0 °C) and 101.325 kPa);

k is a calibration factor to correct the PNC measurements to the level of the reference instrument where this is not applied internally within the PNC. Where the calibration factor is applied internally within the PNC, the calibration factor shall be 1;

$\overline{C_s}$ is the corrected particle number concentration from the diluted exhaust gas expressed as the arithmetic average number of particles per cubic centimetre from the emissions test including the full duration of the drive cycle. If the volumetric mean concentration results $\bar{C}$ from the PNC are not measured at standard conditions (273.15 K (0 °C) and 101.325 kPa), the concentrations shall be corrected to those conditions $\overline{C_s}$;

C_b is either the dilution air or the dilution tunnel background particle number concentration, as permitted by the approval authority, in particles per cubic centimetre, corrected for coincidence and to standard conditions (273.15 K (0 °C) and 101.325 kPa);

$\bar{f_r}$ is the mean particle concentration reduction factor of the VPR at the dilution setting used for the test;

$\overline{f_{rb}}$ is the mean particle concentration reduction factor of the VPR at the dilution setting used for the background measurement;

d is the distance driven corresponding to the applicable test cycle , km.

$\bar{C}$ shall be calculated from the following equation:

$$\bar{C} = \frac{\sum_{i=1}^{n} C_i}{n}$$

where:

C_i is a discrete measurement of particle number concentration in the diluted gas exhaust from the PNC; particles per cm³ and corrected for coincidence;

n is the total number of discrete particle number concentration measurements made during the applicable test cycle and shall be calculated using the following equation:

$$n = t \times f$$

where:

t is the time duration of the applicable test cycle, s;

f is the data logging frequency of the particle counter, Hz.

5. Calculation of cycle energy demand

Unless otherwise specified, the calculation shall be based on the target speed trace given in discrete time sample points.

For the calculation, each time sample point shall be interpreted as a time period. Unless otherwise specified, the duration Δt of these periods shall be 1 second.

The total energy demand E for the whole cycle or a specific cycle phase shall be calculated by summing E_i over the corresponding cycle time between t_{start} and t_{end} according to the following equation:

$$E = \sum_{t_{start}}^{t_{end}} E_i$$

where:

$E_i = F_i \times d_i$ if $F_i > 0$

$E_i = 0$ if $F_i \leq 0$

and:

t_{start} is the time at which the applicable test cycle or phase starts, s;

t_{end} is the time at which the applicable test cycle or phase ends, s;

E_i is the energy demand during time period (i-1) to (i), Ws;

F_i is the driving force during time period (i-1) to (i), N;

d_i is the distance travelled during time period (i-1) to (i), m.

$$F_i = f_0 + f_1 \times \left(\frac{v_i+v_{i-1}}{2}\right) + f_2 \times \frac{(v_i+v_{i-1})^2}{4} + (1.03 \times TM) \times a_i$$

where:

F_i is the driving force during time period (i-1) to (i), N;

v_i is the target speed at time t_i, km/h;

TM is the test mass, kg;

a_i is the acceleration during time period (i-1) to (i), m/s²;

f_0, f_1, f_2 are the road load coefficients for the test vehicle under consideration (TM_L, TM_H or TM_{ind}) in N, N/km/h and in N/(km/h)² respectively.

$$d_i = \frac{(v_i+v_{i-1})}{2 \times 3.6} \times (t_i - t_{i-1})$$

where:

d_i is the distance travelled in time period (i-1) to (i), m;

v_i is the target speed at time t_i, km/h;

t_i is time, s.

$$a_i = \frac{v_i - v_{i-1}}{3.6 \times (t_i - t_{i-1})}$$

where:

a_i is the acceleration during time period (i-1) to (i), m/s²;

v_i is the target speed at time t_i, km/h;

t_i is time, s.

6. Calculation of fuel consumption

6.1. The fuel characteristics required for the calculation of fuel consumption values shall be taken from Annex IX.

6.2. The fuel consumption values shall be calculated from the emissions of hydrocarbons, carbon monoxide, and carbon dioxide using the results of step 6 for criteria emissions and step 7 for CO_2 of Table A7/1.

6.2.1. The general equation in paragraph 6.12. using H/C and O/C ratios shall be used for the calculation of fuel consumption.

6.2.2. For all equations in paragraph 6. of this Sub-Annex:

FC is the fuel consumption of a specific fuel, l/100 km (or m³ per 100 km in the case of natural gas or kg/100 km in the case of hydrogen);

H/C is the hydrogen to carbon ratio of a specific fuel $C_XH_YO_Z$;

O/C is the oxygen to carbon ratio of a specific fuel $C_XH_YO_Z$;

MW_C is the molar mass of carbon (12.011 g/mol);

MW_H is the molar mass of hydrogen (1.008 g/mol);

MW_O is the molar mass of oxygen (15.999 g/mol);

ρ_{fuel} is the test fuel density, kg/l. For gaseous fuels, fuel density at 15 °C;

HC are the emissions of hydrocarbon, g/km;

CO are the emissions of carbon monoxide, g/km;

CO_2 are the emissions of carbon dioxide, g/km;

H_2O are the emissions of water, g/km;

H_2 are the emissions of hydrogen, g/km;

p_1 is the gas pressure in the fuel tank before the applicable test cycle, Pa;

p_2 is the gas pressure in the fuel tank after the applicable test cycle, Pa;

T_1 is the gas temperature in the fuel tank before the applicable test cycle, K;

T_2 is the gas temperature in the fuel tank after the applicable test cycle, K;

Z_1 is the compressibility factor of the gaseous fuel at p_1 and T_1;

Z_2 is the compressibility factor of the gaseous fuel at p_2 and T_2;

V is the interior volume of the gaseous fuel tank, m³;

d is the theoretical length of the applicable phase or cycle, km.

6.3. [Reserved]

6.4. [Reserved]

6.5. For a vehicle with a positive ignition engine fuelled with petrol (E10)

$$\mathrm{FC} = \left(\frac{0.1206}{\rho_{\mathrm{fuel}}}\right) \times [(0.829 \times \mathrm{HC}) + (0.429 \times \mathrm{CO}) + (0.273 \times \mathrm{CO_2})]$$

6.6. For a vehicle with a positive ignition engine fuelled with LPG

$$\mathrm{FC_{norm}} = \left(\frac{0.1212}{0.538}\right) \times [(0.825 \times \mathrm{HC}) + (0.429 \times \mathrm{CO}) + (0.273 \times \mathrm{CO_2})]$$

6.6.1. If the composition of the fuel used for the test differs from the composition that is assumed for the calculation of the normalised consumption, on the manufacturer's request a correction factor cf may be applied, using the following equation:

$$\mathrm{FC_{norm}} = \left(\frac{0.1212}{0.538}\right) \times \mathrm{cf} \times [(0.825 \times \mathrm{HC}) + (0.429 \times \mathrm{CO}) + (0.273 \times \mathrm{CO_2})]$$

The correction factor, cf, which may be applied, is determined using the following equation:

$$\mathrm{cf} = 0.825 + 0.0693 \times \mathrm{n_{actual}}$$

where:

$\mathrm{n_{actual}}$ is the actual H/C ratio of the fuel used.

6.7. For a vehicle with a positive ignition engine fuelled with NG/biomethane

$$\mathrm{FC_{norm}} = \left(\frac{0.1336}{0.654}\right) \times [(0.749 \times \mathrm{HC}) + (0.429 \times \mathrm{CO}) + (0.273 \times \mathrm{CO_2})]$$

6.8. [Reserved]

6.9. [Reserved]

6.10. For a vehicle with a compression engine fuelled with diesel (B7)

$$\mathrm{FC} = \left(\frac{0.1165}{\rho_{\mathrm{fuel}}}\right) \times [(0.858 \times \mathrm{HC}) + (0.429 \times \mathrm{CO}) + (0.273 \times \mathrm{CO_2})]$$

6.11. For a vehicle with a positive ignition engine fuelled with ethanol (E85)

$$\mathrm{FC} = \left(\frac{0.1743}{\rho_{\mathrm{fuel}}}\right) \times [(0.574 \times \mathrm{HC}) + (0.429 \times \mathrm{CO}) + (0.273 \times \mathrm{CO_2})]$$

6.12. Fuel consumption for any test fuel may be calculated using the following equation:

$$\mathrm{FC} = \frac{\mathrm{MW_C} + \frac{\mathrm{H}}{\mathrm{C}} \times \mathrm{MW_H} + \frac{\mathrm{O}}{\mathrm{C}} \times \mathrm{MW_O}}{\mathrm{MW_C} \times \rho_{\mathrm{fuel}} \times 10} \times \left(\frac{\mathrm{MW_C}}{\mathrm{MW_C} + \frac{\mathrm{H}}{\mathrm{C}} \times \mathrm{MW_H} + \frac{\mathrm{O}}{\mathrm{C}} \times \mathrm{MW_O}} \times \mathrm{HC} + \frac{\mathrm{MW_C}}{\mathrm{MW_{CO}}} \times \mathrm{CO} + \frac{\mathrm{MW_C}}{\mathrm{MW_{CO_2}}} \times \mathrm{CO_2}\right)$$

6.13. Fuel consumption for a vehicle with a positive ignition engine fuelled by hydrogen:

$$\mathrm{FC} = 0.024 \times \frac{\mathrm{V}}{\mathrm{d}} \times \left(\frac{1}{\mathrm{Z_1}} \times \frac{\mathrm{p_1}}{\mathrm{T_1}} - \frac{1}{\mathrm{Z_2}} \times \frac{\mathrm{p_2}}{\mathrm{T_2}}\right)$$

With approval of the approval authority and for vehicles fuelled either with gaseous or liquid hydrogen, the manufacturer may choose to calculate fuel consumption using either the equation for FC below or a method using a standard protocol such as SAE J2572.

$$\mathrm{FC} = 0.1 \times (0.1119 \times \mathrm{H_2O} + \mathrm{H_2})$$

The compressibility factor, Z, shall be obtained from the following table:

Table A7/2

Compressibility factor Z

		T (K)									
		5	100	200	300	400	500	600	700	800	900
p (bar)	33	0.859	1.051	1.885	2.648	3.365	4.051	4.712	5.352	5.973	6.576
	53	0.965	0.922	1.416	1.891	2.338	2.765	3.174	3.57	3.954	4.329
	73	0.989	0.991	1.278	1.604	1.923	2.229	2.525	2.810	3.088	3.358
	93	0.997	1.042	1.233	1.470	1.711	1.947	2.177	2.400	2.617	2.829
	113	1.000	1.066	1.213	1.395	1.586	1.776	1.963	2.146	2.324	2.498
	133	1.002	1.076	1.199	1.347	1.504	1.662	1.819	1.973	2.124	2.271
	153	1.003	1.079	1.187	1.312	1.445	1.580	1.715	1.848	1.979	2.107
	173	1.003	1.079	1.176	1.285	1.401	1.518	1.636	1.753	1.868	1.981
	193	1.003	1.077	1.165	1.263	1.365	1.469	1.574	1.678	1.781	1.882
	213	1.003	1.071	1.147	1.228	1.311	1.396	1.482	1.567	1.652	1.735
	233	1.004	1.071	1.148	1.228	1.312	1.397	1.482	1.568	1.652	1.736
	248	1.003	1.069	1.141	1.217	1.296	1.375	1.455	1.535	1.614	1.693
	263	1.003	1.066	1.136	1.207	1.281	1.356	1.431	1.506	1.581	1.655
	278	1.003	1.064	1.130	1.198	1.268	1.339	1.409	1.480	1.551	1.621
	293	1.003	1.062	1.125	1.190	1.256	1.323	1.390	1.457	1.524	1.590
	308	1.003	1.060	1.120	1.182	1.245	1.308	1.372	1.436	1.499	1.562
	323	1.003	1.057	1.116	1.175	1.235	1.295	1.356	1.417	1.477	1.537
	338	1.003	1.055	1.111	1.168	1.225	1.283	1.341	1.399	1.457	1.514
	353	1.003	1.054	1.107	1.162	1.217	1.272	1.327	1.383	1.438	1.493

In the case that the required input values for p and T are not indicated in the table, the compressibility factor shall be obtained by linear interpolation between the compressibility factors indicated in the table, choosing the ones that are the closest to the sought value.

7. Calculation of drive trace indices

7.1. General requirement

The prescribed speed between time points in Tables A1/1 to A1/12 shall be determined by a linear interpolation method at a frequency of 10 Hz.

In the case that the accelerator control is fully activated, the prescribed speed shall be used instead of the actual vehicle speed for drive trace index calculations during such periods of operation.

7.2. Calculation of drive trace indices

The following indices shall be calculated according to SAE J2951(Revised JAN2014):

(a) ER : Energy Rating

(b) DR : Distance Rating

(c) EER : Energy Economy Rating

(d) ASCR : Absolute Speed Change Rating

(e) IWR : Inertial Work Rating

(f) RMSSE : Root Mean Squared Speed Error

Sub-Annex 8

The WLTC to be driven is the WLTC Class 3b. Calculations and other specifications are to apply unless not otherwise defined in *GNT_Overall_GNCAP_Test_Procedure.xlsx* or explicitly stated.

Furthermore, additional provisions made in *GNT_Special_Requirements_for_Hybrid_Electric_Vehicles_(HEV).docx* overrule the provisions made in this Sub-Annex in case of doubt.

Pure electric, hybrid electric and compressed hydrogen fuel cell hybrid vehicles

0. Preface

This Green NCAP test procedure was based on Regulation (EU) 2017/1151. The interpolation family concept is not applicable for the Green NCAP assessment program. Hence, the requirements laid down in this test procedure target to obtain measurement values for pollutant and CO_2 emission constituents, fuel / energy consumption and all other elements to be determined in order to rate the vehicle's environmental performance. All references to vehicle L and H are to be interpreted as vehicle M.

1. General requirements

Unless stated otherwise, all requirements in this Sub-Annex shall apply to vehicles with and without driver-selectable modes. Unless explicitly stated otherwise in this Sub-Annex, all of the requirements and procedures specified in Sub-Annex 6 shall continue to apply for NOVC-HEVs, OVC-HEVs, NOVC-FCHVs and PEVs. Special provisions regarding driver selectable modes can be found in *GNT_Special_Requirements_for_Hybrid_Electric_Vehicles_(HEV).docx.*

1.1. Units, accuracy and resolution of electric parameters

Units, accuracy and resolution of measurements shall be as shown in Table A8/1.

Table A8/1

Parameters, units and accuracy of measurements

Parameter	Units	Accuracy	Resolution
Electrical energy (1)	Wh	± 1 per cent	0.001 kWh(2)
Electrical current	A	± 0.3 per cent FSD or ± 1 per cent of reading (3,4)	0.1 A
Electric voltage	V	± 0.3 per cent FSD or ± 1 per cent of reading (3)	0.1 V

(1) Equipment: static meter for active energy.
(2) AC watt-hour meter, Class 1 according to IEC 62053-21 or equivalent.
(3) Whichever is greater.
(4) Current integration frequency 20 Hz or more.

1.2. Emission and fuel consumption testing

Parameters, units and accuracy of measurements shall be the same as those required for pure ICE vehicles.

1.3. Units and precision of final test results

Units and their precision for the communication of the final results shall follow the indications given in Table A8/2. For the purpose of calculation in paragraph 4. of this Sub-Annex, the unrounded values shall apply.

Table A8/2

Units and precision of final test results

Parameter	Units	Communication of final test result
$PER_{(p)}$[2], PER_{city}, $AER_{(p)}$[2], AER_{city}, $EAER_{(p)}$[2], $EAER_{city}$, R_{CDA}[1], R_{CDC}, $R_{nominal}$[3] , $R_{RealWorld}$[3]	km	Rounded to nearest whole number
$FC_{CS(,p)}$[2], FC_{CD}, $FC_{weighted}$ for HEVs	l/100 km	Rounded to the first place of decimal
$FC_{CS(,p)}$[2] for FCHVs	kg/100 km	Rounded to the second place of decimal
$M_{CO2,CS(,p)}$[2], $M_{CO2,CD}$, M_{CO2},weighted	g/km	Rounded to the nearest whole number
$EC_{(p)}$[2], EC_{city}, $EC_{AC,CD}$, $EC_{AC,weighted}$	Wh/km	Rounded to the nearest whole number
E_{AC}	kWh	Rounded to the first place of decimal

[1] no vehicle individual parameter

[2] (p) means the considered period which can be a phase, a combination of phases or the whole cycle

[3] defined and calculated by GNT_RealWorld_Driving Range.docx

1.4. Vehicle classification

All OVC-HEVs, NOVC-HEVs, PEVs and NOVC-FCHVs shall be classified as Class 3 vehicles. The applicable test cycle for the Type 1 test procedure shall be determined according to paragraph 1.4.2. of this Sub-Annex based on the corresponding reference test cycle as described in paragraph 1.4.1. of this Sub-Annex.

1.4.1. Reference test cycle

1.4.1.1. The reference test cycle for Class 3 vehicles is specified in paragraph 3.3. of Sub-Annex 1.

1.4.1.2. For PEVs, the downscaling procedure, in accordance with paragraphs 8.2.3. and 8.3. of Sub-Annex 1, may be applied on the test cycles in accordance with paragraph 3.3. of Sub-Annex 1 by replacing the rated power with maximum net power in accordance with UN/ECE Regulation No. 85. In such a case, the downscaled cycle is the reference test cycle.

1.4.2. Applicable test cycle

1.4.2.1. Applicable WLTP test cycle

The reference test cycle according to paragraph 1.4.1. of this Sub-Annex shall be the applicable WLTC+ test cycle for the Type 1 test procedure.

In the case that paragraph 9. of Sub-Annex 1 is applied based on the reference test cycle as described in paragraph 1.4.1. of this Sub-Annex, this modified test cycle shall be the applicable WLTC+ for the Type 1 test procedure.

1.4.2.2. Applicable WLTP city test cycle

The Class 3 WLTP city test cycle ($WLTC_{city}$) for Class 3b vehicles is specified in paragraph 3.5. of Sub-Annex 1.

1.5. OVC-HEVs, NOVC-HEVs and PEVs with manual transmissions

The vehicles shall be driven in accordance with the technical gear shift indicator, if available, or in accordance with instructions incorporated in the manufacturer's handbook.

2. Run-in of test vehicle

The vehicle tested in accordance with this Annex shall be presented in good technical condition and shall be run-in in accordance with the manufacturer’s recommendations, at a minimum for 3000 km. Battery electric vehicles may be run-in at a minimum for 300 km. In the case that the REESSs are operated above the normal operating temperature range, the operator shall follow the procedure recommended by the vehicle manufacturer in order to keep the temperature of the REESS in its normal operating range. The manufacturer shall provide evidence that the thermal management system of the REESS is neither disabled nor reduced.

2.1. OVC-HEVs and NOVC-HEVs shall have been run-in in accordance with the requirements of paragraph 2.3.3. of Sub-Annex 6.

2.2. NOVC-FCHVs shall have been run-in at least 3000 km with their fuel cell and REESS installed.

2.3. PEVs shall have been run-in at least 300.

2.4. All REESS having no influence on CO_2 mass emissions or H_2 consumption shall be excluded from monitoring.

3. Test procedure

3.1. General requirements

3.1.1. For all OVC-HEVs, NOVC-HEVs, PEVs and NOVC-FCHVs, the following shall apply where applicable:

3.1.1.1. Vehicles shall be tested according to the applicable test cycles described in paragraph 1.4.2. of this Sub-Annex.

3.1.1.2. If the vehicle cannot follow the applicable test cycle within the speed trace tolerances in accordance with paragraph 2.6.8.3. of Sub-Annex 6, the accelerator control shall, unless stated otherwise, be fully activated until the required speed trace is reached again.

3.1.1.3. The powertrain start procedure shall be initiated by means of the devices provided for this purpose according to the manufacturer's instructions.

3.1.1.4. For OVC-HEVs, NOVC-HEVs and PEVs, exhaust emissions sampling and measurement of electric energy consumption shall begin for each applicable test cycle before or at the initiation of the vehicle start procedure and end at the conclusion of each applicable test cycle.

3.1.1.5. For OVC-HEVs and NOVC-HEVs, gaseous emission compounds, shall be analysed for each individual test phase It is permitted to omit the phase analysis for phases where no combustion engine operates.

3.1.1.6. Particle number shall be analysed for each individual phase and particulate matter emission shall be analysed for each applicable test cycle.

3.1.2. Forced cooling as described in paragraph 2.7.2. of Sub-Annex 6 shall apply only for the charge-sustaining Type 1 test for OVC-HEVs in accordance with paragraph 3.2. of this Sub-Annex and for testing NOVC-HEVs in accordance with paragraph 3.3. of this Sub-Annex.

3.2. OVC-HEVs

3.2.1. Vehicles shall be tested under charge-depleting operating condition (CD condition), and charge-sustaining operating condition (CS condition).

3.2.2. The applicable test sequence can be found in *GNT_Overall_GNCAP_Test_Procedure.xlsx*

3.2.2.1. Option 1: charge-depleting Type 1 test with no subsequent charge-sustaining Type 1 test.

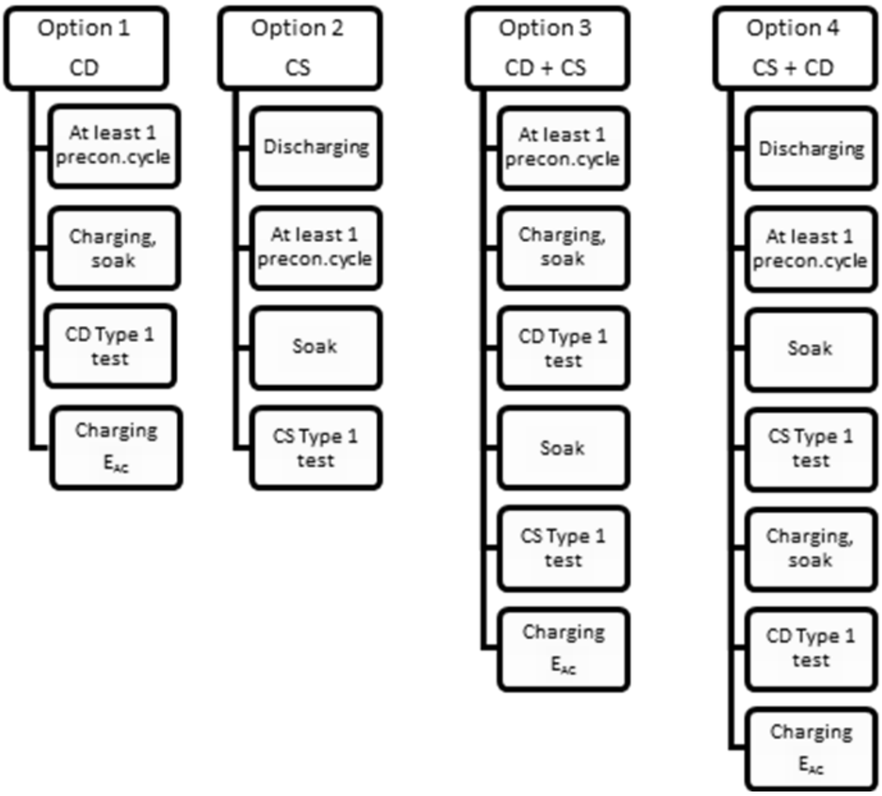
3.2.2.2. Option 2: charge-sustaining Type 1 test with no subsequent charge-depleting Type 1 test.

3.2.2.3. Option 3: charge-depleting Type 1 test with a subsequent charge-sustaining Type 1 test.

3.2.2.4. Option 4: charge-sustaining Type 1 test with a subsequent charge-depleting Type 1 test.

Figure A8/1

Possible test sequences in the case of OVC-HEV testing



3.2.3. The driver-selectable mode shall be set as described in *GNT_Special_Requirements_for_Hybrid_Electric_Vehicles_(HEV).docx*

3.2.4. Charge-depleting Type 1 test with no subsequent charge-sustaining Type 1 test (Option 1)

The test sequence according to Option 1, described in paragraphs 3.2.4.1. to 3.2.4.7. inclusive of this Sub-Annex, as well as the corresponding REESS state of charge profile, are shown in Figure A8.App1/1 in Appendix 1 to this Sub-Annex.

3.2.4.1. Preconditioning

The vehicle shall be prepared according to the procedures in paragraph 2.2. of Appendix 4 to this Sub-Annex.

3.2.4.2. Test conditions

3.2.4.2.1. The test shall be carried out with a fully charged REESS according to the charging requirements as described in paragraph 2.2.3. of Appendix 4 to this Sub-Annex and with the vehicle operated in charge-depleting operating condition as defined in paragraph 3.3.5. of this Annex.

3.2.4.2.2. Selection of a driver-selectable mode

For vehicles equipped with a driver-selectable mode, the mode for the charge-depleting Type 1 test shall be selected according to *GNT_Special_Requirements_for_Hybrid_Electric_Vehicles_(HEV).docx*.

3.2.4.3. Charge-depleting Type 1 test procedure

3.2.4.3.1. The charge-depleting Type 1 test procedure shall consist of a number of consecutive cycles, each followed by a soak period of no more than 30 minutes until charge-sustaining operating condition is achieved.

3.2.4.3.2. During soaking between individual applicable test cycles, the powertrain shall be deactivated and the REESS shall not be recharged from an external electric energy source. The instrumentation for measuring the electric current of all REESSs and for determining the electric voltage of all REESSs according to Appendix 3 of this Sub-Annex shall not be turned off between test cycle phases. In the case of ampere-hour meter measurement, the integration shall remain active throughout the entire test until the test is concluded.

Restarting after soak, the vehicle shall be operated in the driver-selectable mode according to paragraph 3.2.4.2.2. of this Sub-Annex.

3.2.4.3.3. In deviation from paragraph 5.3.1. of Sub-Annex 5 and without prejudice to paragraph 5.3.1.2. of Sub-Annex 5, analysers may be calibrated and zero- checked before and after the charge-depleting Type 1 test.

3.2.4.4. End of the charge-depleting Type 1 test

For vehicles without a charge-sustaining capability over the complete applicable WLTP test cycle, the end of the charge-depleting Type 1 test is reached by an indication on a standard on-board instrument panel to stop the vehicle, or when the vehicle deviates from the prescribed speed trace tolerance for 4 consecutive seconds or more. The accelerator control shall be deactivated and the vehicle shall be braked to standstill within 60 seconds.

3.2.4.5. Break-off criterion

3.2.4.5.1. Whether the break-off criterion has been reached for each driven applicable WLTP test cycle shall be evaluated.

3.2.4.5.2. The break-off criterion for the charge-depleting Type 1 test is reached when the relative electric energy change $\mathrm{REEC_i}$ as calculated using the following equation, is less than 0.04.

$$\mathrm{REEC_i} = \frac{|\Delta \mathrm{E_{REESS,i}}|}{\mathrm{E_{cycle}} \times \frac{1}{3600}}$$

where:

$\mathrm{REEC_i}$ is the relative electric energy change of the applicable test cycle considered i of the charge-depleting Type 1 test;

$\Delta \mathrm{E_{REESS,i}}$ is the change of electric energy of all REESSsF for the considered charge-depleting Type 1 test cycle i calculated according to paragraph 4.3. of this Sub-Annex, Wh;

$\mathrm{E_{cycle}}$ is the cycle energy demand of the considered applicable WLTP test cycle calculated according to paragraph 5. of Sub-Annex 7, Ws;

i is the index number for the considered applicable WLTP test cycle;

$\frac{1}{3600}$ is a conversion factor to Wh for the cycle energy demand.

3.2.4.6. REESS charging and measuring the recharged electric energy

3.2.4.6.1. The vehicle shall be connected to the mains within 120 minutes after the applicable WLTP test cycle n+1 in which the break-off criterion for the charge-depleting Type 1 test is reached for the first time.

The REESS is fully charged when the end-of-charge criterion, as defined in paragraph 2.2.3.2. of Appendix 4 to this Sub-Annex, is reached.

3.2.4.6.2. The electric energy measurement equipment, placed between the vehicle charger and the mains, shall measure the recharged electric energy $\mathrm{E_{AC}}$ delivered from the mains, as well as its duration. Electric energy measurement may be stopped when the end-of-charge criterion, as defined in paragraph 2.2.3.2. of Appendix 4 to this Sub-Annex, is reached.

3.2.4.7. Each individual applicable WLTP test cycle within the charge-depleting Type 1 test shall fulfil the applicable criteria emission limits according to paragraph 1.2. of Sub-Annex 6.

3.2.5. Charge-sustaining Type 1 test with no subsequent charge-depleting Type 1 test (Option 2)

The test sequence according to Option 2, as described in paragraphs 3.2.5.1. to 3.2.5.3.3. inclusive of this Sub-Annex, as well as the corresponding REESS state of charge profile, are shown in Figure A8.App1/2 in Appendix 1 to this Sub-Annex.

3.2.5.1. Preconditioning and soaking

The vehicle shall be prepared according to the procedures in paragraph 2.1. of Appendix 4 to this Sub-Annex.

3.2.5.2. Test conditions

3.2.5.2.1. Tests shall be carried out with the vehicle operated in charge-sustaining operating condition as defined in paragraph 3.3.6.of this Annex.

3.2.5.2.2. Selection of a driver-selectable mode

For vehicles equipped with a driver-selectable mode, the mode for the charge-sustaining Type 1 test shall be selected according to *GNT_Special_Requirements_for_Hybrid_Electric_Vehicles_(HEV).docx*.

3.2.5.3. Type 1 test procedure

3.2.5.3.1. Vehicles shall be tested according to the Type 1 test procedures described in Sub-Annex 6.

3.2.5.3.2. If required, CO_2 mass emission shall be corrected according to Appendix 2 to this Sub-Annex.

3.2.5.3.3. The test pursuant to paragraph 3.2.5.3.1. of this Sub-Annex shall fulfil the applicable criteria emission limits in accordance with paragraph 1.2. of Sub-Annex 6.

3.2.6. Charge-depleting Type 1 test with a subsequent charge-sustaining Type 1 test (Option 3)

The test sequence according to Option 3, as described in paragraphs 3.2.6.1. to 3.2.6.3. inclusive of this Sub-Annex, as well as the corresponding REESS state of charge profile, are shown in Figure A8.App1/3 in Appendix 1 to this Sub-Annex.

3.2.6.1. For the charge-depleting Type 1 test, the procedure described in paragraphs 3.2.4.1. to 3.2.4.5. inclusive as well as paragraph 3.2.4.7. of this Sub-Annex shall be followed.

3.2.6.2. Subsequently, the procedure for the charge-sustaining Type 1 test described in paragraphs 3.2.5.1. to 3.2.5.3. inclusive of this Sub-Annex shall be followed. Paragraphs 2.1.1. to 2.1.2. inclusive of Appendix 4to this Sub-Annex shall not apply.

3.2.6.3. REESS charging and measuring the recharged electric energy

3.2.6.3.1. The vehicle shall be connected to the mains within 120 minutes after the conclusion of the charge-sustaining Type 1 test.

The REESS is fully charged when the end-of-charge criterion as defined in paragraph 2.2.3.2. of Appendix 4 to this Sub-Annex is reached.

3.2.6.3.2. The energy measurement equipment, placed between the vehicle charger and the mains, shall measure the recharged electric energy E_{AC} delivered from the mains, as well as its duration. Electric energy measurement may be stopped when the end-of-charge criterion as defined in paragraph 2.2.3.2. of Appendix 4 to this Sub-Annex is reached.

3.2.7. Charge-sustaining Type 1 test with a subsequent charge-depleting Type 1 test (Option 4)

The test sequence according to Option 4, described in paragraphs 3.2.7.1. to 3.2.7.2. inclusive of this Sub-Annex, as well as the corresponding REESS state of charge profile, are shown in Figure A8.App1/4 of Appendix 1 to this Sub-Annex.

3.2.7.1. For the charge-sustaining Type 1 test, the procedure described in paragraphs 3.2.5.1. to 3.2.5.3. inclusive of this Sub-Annex, as well as paragraph 3.2.6.3.1. of this Sub-Annex shall be followed.

3.2.7.2. Subsequently, the procedure for the charge-depleting Type 1 test described in paragraphs 3.2.4.2. to 3.2.4.7. inclusive of this Sub-Annex shall be followed.

3.3. NOVC-HEVs

The test sequence described in paragraphs 3.3.1. to 3.3.3. inclusive of this Sub-Annex, as well as the corresponding REESS state of charge profile, are shown in Figure A8.App1/5 of Appendix 1 to this Sub-Annex.

3.3.1. Preconditioning and soaking

3.3.1.1. Vehicles shall be preconditioned in accordance with paragraph 2.6. of Sub-Annex 6.

In addition to the requirements of paragraph 2.6. of Sub-Annex 6, the level of the state of charge of the traction REESS for the charge-sustaining test may be set in accordance with the manufacturer’s recommendation before preconditioning in order to achieve a test under charge-sustaining operating condition.

3.3.1.2. Vehicles shall be soaked in accordance with paragraph 2.7. of Sub-Annex 6.

3.3.2. Test conditions

3.3.2.1. Vehicles shall be tested under charge-sustaining operating condition as defined in paragraph 3.3.6. of this Annex.

3.3.2.2. Selection of a driver-selectable mode

The applicable driver selectable mode can be found in *GNT Special Requirements for Hybrid Electric Vehicles (HEV).docx*. For vehicles equipped with a driver-selectable mode, the mode for the charge-sustaining Type 1 test shall be selected according to paragraph 3. of Appendix 6 to this Sub-Annex.

3.3.3. Type 1 test procedure

3.3.3.1. Vehicles shall be tested according to the Type 1 test procedure described in Sub-Annex 6.

3.3.3.2. If required, the CO_2 mass emission shall be corrected according to Appendix 2 to this Sub-Annex.

3.3.3.3. The charge-sustaining Type 1 test shall fulfil the applicable criteria emission limits in accordance with paragraph 1.2. of Sub-Annex 6.

3.4. PEVs

3.4.1. General requirements

The determination of the vehicle’s driving range shall be performed by measuring the REESS capacity according to the Document *GNT_Real_World_Driving_Range_Test_WG.docx*, that describes the calculation of a “Nominal range”, a “Real word range” and a “Worst case range”.

The manufacturer shall give evidence to the GNT concerning the estimated pure electric range (PER) prior to the test. The PER determined by the applied test procedure shall confirm that the correct test procedure was applied.

3.4.2. [reserved]

3.4.3. Selection of a driver-selectable mode

For vehicles equipped with a driver-selectable mode, the mode for the test shall be selected according to paragraph 4. of Appendix 6 to this Sub-Annex.

3.4.4. PEV Type 1 test procedures

3.4.4.1. [reserved]

3.4.4.1.2. REESS current and voltage measurement

From the beginning of the test until the end of the test, the electric current of all REESSs shall be measured according to Appendix 3 to this Sub-Annex and the electric voltage shall be determined according to Appendix 3 to this Sub-Annex.

3.4.4.1.3. Break-off criterion needed for GNT_Real World Driving Range Test Procedure

The break-off criterion is reached when the vehicle exceeds the prescribed speed trace tolerance as specified in paragraph 2.6.8.3. of Sub-Annex 6 for 4 consecutive seconds or more. The accelerator control shall be deactivated. The vehicle shall be braked to standstill within 60 seconds.

3.5. NOVC-FCHVs

The test sequence, described in paragraphs 3.5.1. to 3.5.3. inclusive of this Sub-Annex, as well as the corresponding REESS state of charge profile, is shown in Figure A8.App1/5 in Appendix 1 to this Sub-Annex.

3.5.1. Preconditioning and soaking

Vehicles shall be conditioned and soaked according to paragraph 3.3.1. of this Sub-Annex.

3.5.2. Test conditions

3.5.2.1. Vehicles shall be tested under charge-sustaining operating conditions as defined in paragraph 3.3.6. of this Annex.

3.5.2.2. Selection of a driver-selectable mode

For vehicles equipped with a driver-selectable mode, the mode for the charge-sustaining Type 1 test shall be selected according to *GNT Special Requirements for Hybrid Electric Vehicles (HEV).docx.*

3.5.3. Type 1 test procedure

3.5.3.1. Vehicles shall be tested according to the Type 1 test procedure described in Sub-Annex 6 and fuel consumption calculated according to Appendix 7 to this Sub-Annex.

3.5.3.2. If required, fuel consumption shall be corrected according to Appendix 2 to this Sub-Annex.

4. Calculations for hybrid electric, pure electric and compressed hydrogen fuel cell vehicles

4.1. Calculations of gaseous emission compounds, particulate matter emission and particle number emission

4.1.1. Charge-sustaining mass emission of gaseous emission compounds, particulate matter emission and particle number emission for OVC-HEVs and NOVC-HEVs

The charge-sustaining particulate matter emission $\mathrm{PM}_{\mathrm{CS}}$ shall be calculated according to paragraph 3.3. of Sub-Annex 7.

The charge-sustaining particle number emission $\mathrm{PN}_{\mathrm{CS}}$ shall be calculated according to paragraph 4. of Sub-Annex 7.

4.1.1.1. Stepwise procedure for calculating the final test results of the charge-sustaining Type 1 test for NOVC-HEVs and OVC-HEVs

The results shall be calculated in the order described in Table A8/5. All applicable results in the column "Output" shall be recorded. The column "Process" describes the paragraphs to be used for calculation or contains additional calculations.

For the purpose of this table, the following nomenclature within the equations and results is used:

c	complete applicable test cycle;
p	every applicable cycle phase;
i	applicable criteria emission component (except CO_2);
CS	charge-sustaining
CO_2	CO_2 mass emission.

Table A8/5

Calculation of final charge-sustaining gaseous emission values

Source	*Input*	*Process*	*Output*	*Step No.*
Sub-Annex 6	Raw test results	Charge-sustaining mass emissions Paragraphs 3. to 3.2.2. of Sub-Annex 7.	$M_{i,CS,p,1}$, g/km; $M_{CO2,CS,p,1}$, g/km.	1
Output from step No. 1 of this table.	$M_{i,CS,p,1}$, g/km; $M_{CO2,CS,p,1}$, g/km.	Calculation of combined charge-sustaining cycle values: $M_{i,CS,c,2} = \frac{\sum_p M_{i,CS,p,1} \times d_p}{\sum_p d_p}$ $M_{CO2,CS,c,2} = \frac{\sum_p M_{CO2,CS,p,1} \times d_p}{\sum_p d_p}$ where: $M_{i,CS,c,2}$ is the charge-sustaining mass emission result over the total cycle; $M_{CO2,CS,c,2}$ is the charge-sustaining CO_2 mass emission result over the total cycle; d_p are the driven distances of the cycle phases p.	$M_{i,CS,c,2}$, g/km; $M_{CO2,CS,c,2}$, g/km.	2
Output from steps Nos. 1 and 2 of this table.	$M_{CO2,CS,p,1}$, g/km; $M_{CO2,CS,c,2}$, g/km.	REESS electric energy change correction Paragraphs 4.1.1.2. to 4.1.1.5. of this Sub-Annex.	$M_{CO2,CS,p,3}$, g/km; $M_{CO2,CS,c,3}$, g/km.	3
Output from steps Nos. 2 and 3 of this table.	$M_{i,CS,c,2}$, g/km; $M_{CO2,CS,c,3}$, g/km.	Charge-sustaining mass emission correction for all vehicles equipped with periodically regenerating systems K_i in accordance with Sub-Annex 6, Appendix 1. K_i shall always be 1. If K_i is not applicable: $M_{i,CS,c,4} = M_{i,CS,c,2}$ $M_{CO2,CS,c,4} = M_{CO2,CS,c,3}$	$M_{i,CS,c,4}$, g/km; $M_{CO2,CS,c,4}$, g/km.	4a
Output from steps Nos. 3 and 4a of this table.	$M_{CO2,CS,p,3}$, g/km; $M_{CO2,CS,c,3}$, g/km; $M_{CO2,CS,c,4}$, g/km.	If K_i is applicable, align CO_2 phase values to combined cycle value: $M_{CO2,CS,p,4} = M_{CO2,CS,p,3} \times AF_{Ki}$ for every cycle phase p; where: $AF_{Ki} = \frac{M_{CO2,CS,c,4}}{M_{CO2,CS,c,3}}$ If K_i is not applicable: $M_{CO2,CS,p,4} = M_{CO2,CS,p,3}$	$M_{CO2,CS,p,4}$, g/km.	4b

Source	*Input*	*Process*	*Output*	*Step No.*
Output from step No. 4 of this table.	$M_{i,CS,c,4}$, g/km; $M_{CO2,CS,p,4}$, g/km; $M_{CO2,CS,c,4}$, g/km;	ATCT correction in accordance with paragraph 3.8.2. of Sub-Annex 6a should not be performed. Deterioration factors calculated and applied in accordance with Annex VII.	$M_{i,CS,c,5}$, g/km; $M_{CO2,CS,c,5}$, g/km; $M_{CO2,CS,p,5}$, g/km.	5 Result of a single test.
Output from step No. 5 of this table.	For every test: $M_{i,CS,c,5}$, g/km; $M_{CO2,CS,c,5}$, g/km; $M_{CO2,CS,p,5}$, g/km.	Averaging of tests and declared value in accordance with paragraphs 1.2. to 1.2.3. of Sub-Annex 6.	$M_{i,CS,c,6}$, g/km; $M_{CO2,CS,c,6}$, g/km; $M_{CO2,CS,p,6}$, g/km; $M_{CO2,CS,c,declared}$, g/km.	6 $M_{i,CS}$ results of a Type 1 test for a test vehicle.
Output from step No. 6 of this table.				
Output from steps Nos. 6 and 7 of this table.				
Output from step No. 8 of this table.				

4.1.1.2. In the case that the correction according to paragraph 1.1.4. of Appendix 2 to this Sub-Annex was not applied, the following charge-sustaining CO₂ mass emission shall be used:

$$M_{CO2,CS} = M_{CO2,CS,nb}$$

where:

$M_{CO2,CS}$ is the charge-sustaining CO₂ mass emission of the charge-sustaining Type 1 test according to Table A8/5, step no. 3, g/km;

$M_{CO2,CS,nb}$ is the non-balanced charge-sustaining CO₂ mass emission of the charge-sustaining Type 1 test, not corrected for the energy balance, determined according to Table A8/5, step no. 2, g/km.

4.1.1.3. If the correction of the charge-sustaining CO₂ mass emission is required according to paragraph 1.1.3. of Appendix 2 to this Sub-Annex or in the case that the correction according to paragraph 1.1.4. of Appendix 2 to this Sub-Annex was applied, the CO₂ mass emission correction coefficient shall be determined according to paragraph 2. of Appendix 2 to this Sub-Annex. 〚'M〛 _(CO2,CS) is the charge-sustaining CO₂ mass emission of the charge-sustaining Type 1 test according to Table A8/5, step No. 3, g/km:

$$M_{CO2,CS} = M_{CO2,CS,nb} - K_{CO2} \times EC_{DC,CS}$$

where:

$M_{CO2,CS}$ is the charge-sustaining CO₂ mass emission of the charge-sustaining Type 1 test according to Table A8/5, step no. 2, g/km;

$M_{CO2,CS,nb}$ is the non-balanced CO₂ mass emission of the charge-sustaining Type 1 test, not corrected for the energy balance, determined according to Table A8/5, step no. 2, g/km;

$\mathrm{EC_{DC,CS}}$ is the electric energy consumption of the charge-sustaining Type 1 test according to paragraph 4.3. of this Sub-Annex, Wh/km;

$\mathrm{K_{CO2}}$ is the CO_2 mass emission correction coefficient according to paragraph 2.3.2. of Appendix 2 to this Sub-Annex, (g/km)/(Wh/km).

4.1.1.4. In the case that phase-specific CO_2 mass emission correction coefficients have not been determined, the phase-specific CO_2 mass emission shall be calculated using the following equation:

$$\mathrm{M_{CO2,CS,p}} = \mathrm{M_{CO2,CS,nb,p}} + \mathrm{K_{CO2}} \times \mathrm{EC_{DC,CS,p}}$$

where:

$\mathrm{M_{CO2,CS,p}}$ is the charge-sustaining CO_2 mass emission of phase p of the charge-sustaining Type 1 test in accordance with Table A8/5, step No. 3, g/km;

$\mathrm{M_{CO2,CS,nb,p}}$ is the non-balanced CO2 mass emission of phase p of the charge-sustaining Type 1 test, not corrected for the energy balance, determined in accordance with Table A8/5, step No. 1, g/km;

$\mathrm{EC_{DC,CS,p}}$ is the electric energy consumption of phase p of the charge-sustaining Type 1 test according to paragraph 4.3. of this Sub-Annex, Wh/km;

$\mathrm{K_{CO2}}$ is the CO_2 mass emission correction coefficient according to paragraph 2.3.2. of Appendix 2 to this Sub-Annex, (g/km)/(Wh/km).

4.1.1.5. [reserved]

4.1.2. [reserved]

4.1.3. [reserved]

4.1.3.2. [reserved]

4.1.4 Charge-depleting mass emission of gaseous emission compounds, particulate matter emission and particle number emission for OVC-HEVs

4.1.4.1. CO_2 mass emissions

$$\mathrm{M_{CO2,CD,avg}} = \frac{\sum_{j=1}^{k}(\mathrm{M_{CO2,CD,j}} \times \mathrm{d_j})}{\sum_{j=1}^{k}\mathrm{d_j}}$$

where:

$\mathrm{M_{CO2,CD,avg}}$ is the arithmetic average charge-depleting CO_2 mass emission, g/km;

$\mathrm{M_{CO2,CD,j}}$ is the CO_2 mass emission determined according to paragraph 3.2.1. of Sub-Annex 7 of phase j of the charge-depleting Type 1 test, g/km;

$\mathrm{d_j}$ is the distance driven in phase j of the charge-depleting Type 1 test, km;

j is the index number of the considered phase;

k is the number of phases driven up to the end of the transition cycle n according to paragraph 3.2.4.4 of this Sub-Annex.

4.1.4.2. Calculation of gaseous pollutants (gp) mass emissions

The following calculations are to be applied for all rated gaseous pollutants. The expression “gp” has to be replaced by the corresponding exhaust pollutant component.

$$\mathrm{M_{gp,CD,avg}} = \frac{\sum_{j=1}^{k}(\mathrm{M_{gp,CD,j}} \times \mathrm{d_j})}{\sum_{j=1}^{k}\mathrm{d_j}}$$

where:

$M_{gp,CD,avg}$ is the arithmetic average charge-depleting CO_2 mass emission, g/km;

$M_{gp,CD,j}$ is the gaseous pollutants mass emission determined according to paragraph 3.2.1. of Sub-Annex 7 of phase j of the charge-depleting Type 1 test, g/km;

d_j is the distance driven in phase j of the charge-depleting Type 1 test, km;

j is the index number of the considered phase;

k is the number of phases driven up to the end of the transition cycle n according to paragraph 3.2.4.4 of this Sub-Annex.

4.1.4.3. Calculation of particulate number (PN) emissions

$$M_{PN,CD,avg} = \frac{\sum_{j=1}^{k}(M_{PN,CD,j} \times d_j)}{\sum_{j=1}^{k} d_j}$$

where:

$M_{PN,CD,avg}$ is the arithmetic average charge-depleting CO_2 mass emission, g/km;

$M_{PN,CD,j}$ is the CO_2 mass emission determined according to paragraph 3.2.1. of Sub-Annex 7 of phase j of the charge-depleting Type 1 test, g/km;

d_j is the distance driven in phase j of the charge-depleting Type 1 test, km;

j is the index number of the considered phase;

k is the number of phases driven up to the end of the transition cycle n according to paragraph 3.2.4.4 of this Sub-Annex.

Table A8/6

Calculation of final charge-sustaining fuel consumption for OVC-HEVs, NOVC-HEVs

Source	**Input**	**Process**	**Output**	**Step no.**
Output from step no. 6 and 7 of Table A8/5 of this Sub-Annex.	$M_{i,CS,c,6}$, g/km; $M_{CO2,CS,c,7}$, g/km; $M_{CO2,CS,p,7}$, g/km;	Calculation of fuel consumption according to paragraph 6. of Sub-Annex 7. The calculation of fuel consumption shall be performed separately for the applicable cycle and its phases. For that purpose: (a) the applicable phase or cycle CO_2 values shall be used; (b) the criteria emission over the complete cycle shall be used.	$FC_{CS,c,1}$, l/100km; $FC_{CS,p,1}$, l/100km;	1 "FC_{CS} results of a Type 1 test for a test vehicle"
Step no. 1 of this Table.				
Step no. 2 of this Table.				

4.2.1.2. Charge-sustaining fuel consumption for NOVC-FCHVs

4.2.1.2.1. Stepwise procedure for calculating the final test fuel consumption results of the charge-sustaining Type 1 test for NOVC-FCHVs

The results shall be calculated in the order described in the Tables A8/7. All applicable results in the column "Output" shall be recorded. The column "Process" describes the paragraphs to be used for calculation or contains additional calculations.

For the purpose of this table, the following nomenclature within the equations and results is used:

c complete applicable test cycle;

p every applicable cycle phase;

CS charge-sustaining

Table A8/7

Calculation of final charge-sustaining fuel consumption for NOVC-FCHVs

Source	**Input**	**Process**	**Output**	**Step no.**
Appendix 7 of this Sub-Annex.	Non-balanced charge-sustaining fuel consumption $FC_{CS,nb}$,kg/100km	Charge-sustaining fuel consumption according to paragraph 2.2.6. of Appendix 7. to this Sub-Annex	$FC_{CS,c,1}$, kg/100km;	1
Output from step no. 1 of this Table.	$FC_{CS,c,1}$, kg/100km;	REESS electric energy change correction Sub-Annex 8, paragraphs 4.2.1.2.2. to 4.2.1.2.3. inclusive of this Sub-Annex	$FC_{CS,c,2}$, kg/100km;	2
Output from step No. 2 of this table.	$FC_{CS,c,2}$, kg/100 km.	$FC_{CS,c,3} = FC_{CS,c,2}$	$FC_{CS,c,3}$, kg/100 km.	3 Result of a single test.
Output from step No. 3 of this table.				
Output from step no. 4 of this Table.				

4.2.1.2.2. In the case that the correction according to paragraph 1.1.4. of Appendix 2 to this Sub-Annex was not applied, the following charge-sustaining fuel consumption shall be used:

$$FC_{CS} = FC_{CS,nb}$$

where:

FC_{CS} is the charge-sustaining fuel consumption of the charge-sustaining Type 1 test according to Table A8/7, step no. 2, kg/100 km;

$FC_{CS,nb}$ is the non-balanced charge-sustaining fuel consumption of the charge-sustaining Type 1 test, not corrected for the energy balance, according to Table A8/7, step no. 1, kg/100 km.

4.2.1.2.3. If the correction of the fuel consumption is required according to paragraph 1.1.3. of Appendix 2 to this Sub-Annex or in the case that the correction according to paragraph 1.1.4. of Appendix 2 to this Sub-Annex was applied, the fuel consumption correction coefficient shall be determined according to paragraph 2. of Appendix 2 to this Sub-Annex. The corrected charge-sustaining fuel consumption shall be determined using the following equation:

$$FC_{CS} = FC_{CS,nb} + K_{fuel,FCHV} \times EC_{DC,CS}$$

where:

FC_{CS} is the charge-sustaining fuel consumption of the charge-sustaining Type 1 test according to Table A8/7, step no. 2, kg/100 km;

$FC_{CS,nb}$ is the non-balanced fuel consumption of the charge-sustaining Type 1 test, not corrected for the energy balance, according to Table A8/7, step no. 1, kg/100 km;

$EC_{DC,CS}$ is the electric energy consumption of the charge-sustaining Type 1 test according to paragraph 4.3. of this Sub-Annex, Wh/km;

$K_{fuel,FCHV}$ is the fuel consumption correction coefficient according to paragraph 2.3.1. of Appendix 2 to this Sub-Annex, (kg/100 km)/(Wh/km).

4.2.2. [removed]

4.2.3. [reserved]

4.2.4 Charge depleting fuel consumption for OVC-HEVs

$$FC_{CD} = \frac{\sum_{j=1}^{k}(UF_j \times FC_{CD,j})}{\sum_{j=1}^{k} UF_j}$$

where:

FC_{CD} is the utility factor weighted charge-depleting fuel consumption, l/100 km;

$FC_{CD,j}$ is the fuel consumption for phase j of the charge-depleting Type 1 test, determined according to paragraph 6. of Sub-Annex 7, l/100 km;

UF_j is 1;

j is the index number of the phase considered;

k is the number of phases driven up to the end of the transition cycle according to paragraph 3.2.4.4 of this Sub-Annex.

4.3. Calculation of electric energy consumption

For the determination of the electric energy consumption based on the current and voltage determined according to Appendix 3 of this Sub-Annex, the following equations shall be used:

$$EC_{DC,j} = -\frac{\Delta E_{REESS,j}}{d_j}$$

where:

$EC_{DC,j}$ is the electric energy consumption over the considered period j based on the REESS depletion, Wh/km;

$\Delta E_{REESS,j}$ is the electric energy change of all REESSs during the considered period j, Wh;

d_j is the distance driven in the considered period j, km;

and

$$\Delta E_{REESS,j} = \sum_{i=1}^{n} \Delta E_{REESS,j,i}$$

where:

$\Delta E_{REESS,j,i}$ is the electric energy change of REESS i during the considered period j, Wh;

and

$$\Delta E_{REESS,j,i} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} U(t)_{REESS,j,i} \times I(t)_{j,i}\, dt$$

where:

$U(t)_{REESS,j,i}$ is the voltage of REESS i during the considered period j determined according to Appendix 3 to this Sub-Annex, V;

t_0 is the time at the beginning of the considered period j, s;

t_{end} is the time at the end of the considered period j, s;

$I(t)_{j,i}$ is the electric current of REESS i during the considered period j determined according to Appendix 3 to this Sub-Annex, A;

i is the index number of the considered REESS;

n is the total number of REESS;

j is the index for the considered period, where a period can be any combination of phases or cycles;

$\frac{1}{3600}$ is the conversion factor from Ws to Wh.

4.3.1. [reserved]

4.3.2. [reserved]

4.3.2.2. Determination of the total electric energy consumption for OVC-HEVs

The total electric energy consumption of OVC-HEVs for charge depleting sequence is calculated according to the formula:

$$EC_{AC,CDsequence} = \frac{EC_{DC,CDsequence}}{\eta_{grid-to-output\ PHEV}}$$

where:

$EC_{AC,CDsequence}$ is the total electric energy consumption over the considered period j based on the REESS depletion and considering the electrical energy losses from the mains to the measurement location according to Appendix 3 of this Sub-Annex, Wh/km

$EC_{DC,j}$ is the electric energy consumption over the considered period j based on the REESS depletion, Wh/km;

$\eta_{grid-to-outputPHEV}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in *GNT_Real World Driving Range Test Procedure*

In case the considered period is a given test cycle, $EC_{DC,j}$ can be expressed as EC_{test} and $EC_{DC\_total,j}$ can be expressed as EC_{test_total} ,where the index “test” is the identification of the considered test.

4.3.3. Electric energy consumption for OVC-HEVs

4.3.3.1. Determination of electrical energy consumption at the vehicle’s REESS

For the determination of the electric energy consumption based on the current and voltage determined according to Appendix 3 of this Sub-Annex, the following equations shall be used:

$$EC_{DC,CD\ sequence} = -\frac{\Delta E_{REESS,j}}{d_j}$$

where:

$EC_{DC,CD\ sequence}$ is the electric energy consumption over the considered period (CD sequence) based on the REESS depletion, Wh/km;

$\Delta E_{REESS,j}$ is the electric energy change of all REESSs during the considered period j, Wh;

d_j is the distance driven in the considered period j, km;

and

$$\Delta E_{REESS,j} = \sum_{i=1}^{n} \Delta E_{REESS,j,i}$$

where:

$\Delta E_{REESS,j,i}$ is the electric energy change of REESS i during the considered period j, Wh;

and

$$\Delta E_{REESS,j,i} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} U(t)_{REESS,j,i} \times I(t)_{j,i}\, dt$$

where:

$U(t)_{REESS,j,i}$ is the voltage of REESS i during the considered period j determined according to Appendix 3 to this Sub-Annex, V;

t_0 is the time at the beginning of the considered period j, s;

t_{end} is the time at the end of the considered period j, s;

$I(t)_{j,i}$ is the electric current of REESS i during the considered period j determined according to Appendix 3 to this Sub-Annex, A;

i is the index number of the considered REESS;

n is the total number of REESS;

j is the index for the considered period, where a period can be any combination of phases or cycles;

$\frac{1}{3600}$ is the conversion factor from Ws to Wh.

4.3.3.2 [reserved]

4.3.3.3. Grid to REESS output efficiency for OVC-HEVs electric energy consumption calculations

The electric energy consumption over the considered period j based on the REESS depletion $EC_{DC,CD\ sequence}$ does not consider the energy losses occurring between the mains and the current and voltage measurement location according to Appendix 3 of this Sub-Annex.

The determination of the total electric energy consumption of OVC-HEVs shall consider the losses occurring between mains and the current and voltage measurement location according to Appendix 3 of this Sub-Annex.

E_{AC} is the electric energy delivered from the mains for a full recharge of the REESS in Wh, as paragraph 3.2 of this Sub-Annex.

$E_{DC,\ CD\ sequence}$ is the electric energy consumption over the CD sequence done in accordance with paragraph 4.3.3.1 of this Sub-Annex, Wh;

is the electric energy drawn from the battery in Wh, over the complete phase of REESS discharge procedure, calculated by the measured current and voltage, as described in paragraph 3.2 of this Sub-Annex.

For the calculation of the total electric energy consumption of OVC-HEV, the introduction of an efficiency factor is necessary. The “Grid to REESS output efficiency” describes the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in paragraph 3.2 of this Sub-Annex. The “grid to REESS output efficiency” is calculated as follows:

$$\eta_{\text{grid-to-outputPHEV}} = \frac{E_{\text{DC,CD sequence}}}{E_{\text{AC}}}$$

where:

$\eta_{\text{grid-to-outputPHEV}}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in paragraph 3.2 of this Sub-Annex.

4.3.4. Electric energy consumption of PEVs

4.3.4.1 Determination of electrical energy consumption at the vehicle’s REESS

For the determination of the electric energy consumption based on the current and voltage determined according to Appendix 3 of this Sub-Annex, the following equations shall be used:

$$EC_{DC,j} = -\frac{\Delta E_{REESS,j}}{d_j}$$

where:

$EC_{DC,j}$ is the electric energy consumption over the considered period j based on the REESS depletion, Wh/km;

$\Delta E_{REESS,j}$ is the electric energy change of all REESSs during the considered period j, Wh;

d_j is the distance driven in the considered period j, km;

and

$$\Delta E_{REESS,j} = \sum_{i=1}^{n} \Delta E_{REESS,j,i}$$

where:

$\Delta E_{REESS,j,i}$ is the electric energy change of REESS i during the considered period j, Wh;

and

$$\Delta E_{REESS,j,i} = \frac{1}{3600} \times \int_{t_0}^{t_{end}} U(t)_{REESS,j,i} \times I(t)_{j,i} \, dt$$

where:

$U(t)_{REESS,j,i}$ is the voltage of REESS i during the considered period j determined according to Appendix 3 to this Sub-Annex, V;

t_0 is the time at the beginning of the considered period j, s;

t_{end} is the time at the end of the considered period j, s;

$I(t)_{j,i}$ is the electric current of REESS i during the considered period j determined according to Appendix 3 to this Sub-Annex, A;

i is the index number of the considered REESS;

n is the total number of REESS;

j is the index for the considered period, where a period can be any combination of phases or cycles;

$\frac{1}{3600}$ is the conversion factor from Ws to Wh.

In case the considered period is a given test cycle, $EC_{DC,j}$ can be expressed as EC_{test}, where the index "test" is the identification of the considered test.

4.3.4.2 Grid to REESS output efficiency for PEV electric energy consumption calculations

The electric energy consumption over the considered period j based on the REESS depletion $\mathrm{EC_{DC,j}}$ does not consider the energy losses occurring between the mains and the current and voltage measurement location according to Appendix 3 of this Sub-Annex.

The determination of the total electric energy consumption of PEVs shall consider the losses occurring between mains and the current and voltage measurement location according to Appendix 3 of this Sub-Annex.

According to *GNT_Real World Driving Range Test Procedure:*

E_{AC} is the electric energy delivered from the mains for a full recharge of the REESS in Wh, as described in *GNT_Real World Driving Range Test Procedure.*

$E_{DC\text{-}discharge}$ is the electric energy drawn from the battery in Wh, over the complete phase of REESS discharge procedure, calculated by the measured current and voltage, as described in *GNT_Real World Driving Range Test Procedure.*

For the calculation of the total electric energy consumption of PEV, the introduction of an efficiency factor is necessary. The "Grid to REESS output efficiency" describes the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in *GNT_Real World Driving Range Test Procedure.* The "grid to REESS output efficiency" is calculated as follows:

$$\eta_{\mathrm{grid-to-output}} = \frac{\mathrm{E_{DC-discharge}}}{\mathrm{E_{AC}}}$$

where:

$\eta_{\mathrm{grid-to-output}}$ is the "grid to REESS output efficiency" [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in *GNT_Real World Driving Range Test Procedure.*

4.3.4.3 Determination of the total electric energy consumption for PEV

The total electric energy consumption of PEVs for a given period is calculated according to the formula:

$$\mathrm{EC_{DC\_total,j}} = \frac{\mathrm{EC_{DC,j}}}{\eta_{\mathrm{grid-to-output}}}$$

where:

$\mathrm{EC_{DC\_total,j}}$ is the total electric energy consumption over the considered period j based on the REESS depletion and considering the electrical energy losses from the mains to the measurement location according to Appendix 3 of this Sub-Annex, Wh/km

$\mathrm{EC_{DC,j}}$ is the electric energy consumption over the considered period j based on the REESS depletion, Wh/km;

$\eta_{\mathrm{grid-to-output}}$ is the "grid to REESS output efficiency" [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy, as calculated in *GNT_Real World Driving Range Test Procedure*

In case the considered period is a given test cycle, $EC_{DC,j}$ can be expressed as EC_{test} and $EC_{DC\_total,j}$ can be expressed as EC_{test_total} ,where the index "test" is the identification of the considered test.

4.3.4.4. [reserved]

4.4. Calculation of electric ranges

The calculation of the electric ranges for PEV's is described in *GNT_Real World Driving Range Test Procedure*

4.4.1. All-electric ranges AER and $\mathrm{AER_{city}}$ for OVC-HEVs

4.4.1.1. All-electric range AER

The all-electric range AER for OVC-HEVs shall be determined from the charge-depleting Type 1 test described in paragraph 3.2.4.3. of this Sub-Annex as part of the Option 1 test sequence and is referenced in paragraph 3.2.6.1. of this Sub-Annex as part of the Option 3 test sequence by driving the applicable WLTP test cycle according to paragraph 1.4.2.1. of this Sub-Annex. The AER is defined as the distance driven from the beginning of the charge-depleting Type 1 test to the point in time where the combustion engine starts consuming fuel.

4.4.1.2. All-electric range city $\mathrm{AER_{city}}$

4.4.1.2.1. [reserved]

4.4.1.2.2. [reserved]

4.4.2. Pure electric range for PEVs

The determination of the electric ranges for PEV's is described in *GNT_Real World Driving Range Test Procedure*

4.4.2.1. [reserved]

4.4.2.1.1. [reserved]

4.4.2.1.2.[reserved]

4.4.2.1.3. [reserved]

4.4.2.2. [reserved]

4.4.2.2.1. [reserved]

4.4.2.2.2. [reserved]

4.4.2.2.3. [reserved]

4.4.3. Charge-depleting cycle range for OVC-HEVs

The charge-depleting cycle range R_{CDC} shall be determined from the charge-depleting Type 1 test described in paragraph 3.2.4.3. of this Sub-Annex as part of the Option 1 test sequence and is referenced in paragraph 3.2.6.1. of this Sub-Annex as part of the Option 3 test sequence. The $\mathrm{R_{CDC}}$ is the distance driven from the beginning of the charge-depleting Type 1 test to the end of the transition cycle according to paragraph 3.2.4.4 of this Sub-Annex.

4.4.4. Equivalent all-electric range for OVC-HEVs

4.4.4.1. Determination of cycle-specific equivalent all-electric range, only to be used for determination of cycle-specific energy consumption according to paragraph 4.3.3.1.

The cycle-specific equivalent all-electric range shall be calculated using the following equation:

$$\mathrm{EAER} = \left(\frac{\mathrm{M_{CO2,CS}} - \mathrm{M_{CO2,CD,avg}}}{\mathrm{M_{CO2,CS}}}\right) \times \mathrm{R_{CDC}}$$

where:

EAER is the cycle-specific equivalent all-electric range, km;

$M_{CO2,CS}$ is the charge-sustaining CO_2 mass emission according to Table A8/5, step no. 7, g/km;

$M_{CO2,CD,avg}$ is the arithmetic average charge-depleting CO_2 mass emission according to the equation below, g/km;

R_{CDC} is the charge-depleting cycle range according to paragraph 4.4.2. of this Sub-Annex, km;

and

$$M_{CO2,CD,avg} = \frac{\sum_{j=1}^{k}(M_{CO2,CD,j} \times d_j)}{\sum_{j=1}^{k} d_j}$$

where:

$M_{CO2,CD,avg}$ is the arithmetic average charge-depleting CO_2 mass emission, g/km;

$M_{CO2,CD,j}$ is the CO_2 mass emission determined according to paragraph 3.2.1. of Sub-Annex 7 of phase j of the charge-depleting Type 1 test, g/km;

d_j is the distance driven in phase j of the charge-depleting Type 1 test, km;

j is the index number of the considered phase;

k is the number of phases driven up to the end of the transition cycle n according to paragraph 3.2.4.4 of this Sub-Annex.

4.4.4.2. [reserved]

4.4.5. [reserved]

4.5. [reserved]

4.5.1 [reserved]

4.5.2. [reserved]

4.5.3. [reserved]

4.5.4. [reserved]

4.5.4.1. [reserved]

4.5.4.2. [reserved]

4.5.4.3. [reserved]

4.5.5. [reserved]

4.5.5.1. [reserved]

4.5.5.2. [reserved]

4.5.5.3. [reserved]

4.5.6 [reserved]

4.5.6.1. [reserved]

4.5.6.2. [reserved]

4.5.6.3. [reserved]

4.5.7 [reserved]

4.5.7.1. [reserved]

4.5.7.2.[reserved]

4.6. [reserved]

4.6.1. [reserved]

4.6.2.[reserved]

4.7. Stepwise procedure for calculating the final test results of PEVs

The results shall be calculated in the order described in Table A8/10. All applicable results in the column "Output" shall be recorded. The column "Process" describes the paragraphs to be used for calculation or contains additional calculations.

4.7.1. Stepwise procedure for calculating the final test results of PEVs.

For the purpose of this table, the following nomenclature within the questions and results is used:

j index for the considered period.

Table A8/10

Calculation of final PEV values

Source	*Input*	*Process*	*Output*	*Step no.*
Sub-Annex 8	Test results GNT-Real_World_Driving_Range_Test_WG	Results measured in accordance with Appendix 3 to this Sub-Annex and pre-calculated in accordance with paragraph 4.3.4.1. of this Sub-Annex. Usable battery energy in accordance with paragraph 5. of GNT-Real_World_Driving_Range_Test_WG. Recharged electric energy in accordance with paragraph 5. of GNT-Real_World_Driving_Range_Test_WG. Recharged electric energy absorbed by the vehicle in accordance to paragraph 6.1.1. of GNT-Real_World_Driving_Range_Test_WG. Output available for each test. In the case that the interpolation method is applied, the output is available for vehicle H and vehicle L.	$\Delta E_{REESS,j}$, Wh; d_j, km; $E_{DC\text{-}discharge}$, Wh; E_{AC}, Wh. $E_{DC\text{-}charge}$, Wh;	1
Output step 1	$\Delta E_{REESS,j}$, Wh; d_j, km; $E_{DC\text{-}discharge}$, Wh Wh.	Calculation of electric energy consumption at the REESSs in accordance with paragraph 4.4.3.4.1. of this Sub-Annex. Output available for each test.	$EC_{DC,j}$, Wh/km; $EC_{test\ j}$, Wh/km	2

		In the case that the interpolation method is applied, the output is available for vehicle H and vehicle L.		
GNT_Real World Driving Range Test Procedure	E_{AC}, Wh $E_{DC\text{-}discharge}$, Wh	Calculation of the "grid to REESS output" efficiency, according to paragraph 4.3.4.2. of this Sub-Annex	$\eta_{grid-to-output}$, [-]	3
Output step 2 Output step 3	$EC_{DC,j}$, Wh/km $\eta_{grid-to-output}$, [-]	Calculation of the total electric energy consumption for a given period, considering charging and discharging electric energy losses, according to paragraph 4.3.4.3 of this Sub-Annex.	$EC_{DC\_total,j}$, Wh/km	4
Output step 1 Output step 2	$E_{DC\text{-}discharge}$, Wh $EC_{DC,j}$, Wh/km; $EC_{test\ j}$, Wh/km EC_{WLTC_def} ,Wh EC_{WLTC_warm} ,Wh EC_{BAB} ,Wh $EC_{WLTC\_def\_rep}$,Wh $EC_{PEMS+cold}$,Wh $EC_{PEMS+cold\_rep}$,Wh $EC_{PEMS,eco}$,Wh $EC_{PEMS,heavy}$,Wh $EC_{WLTC,CAT}$,Wh	Calculation of driving ranges "nominal", "real-world", "worst case", according to GNT-Real_World_Driving_Range_Test_WG	$R_{nominal}$, km $R_{real\ world}$, km R_{BAB}, km $R_{WLTC,CAT}$, km $R_{PEMS,\ heavy}$, km $R_{worst\ case}$, km	5
[reserved]				
[reserved]				
[reserved]				
[reserved]				
[reserved]				
[reserved]				

4.7.2. [reserved]

4.8. Energy consumption for OVC-HEVs tested in CD mode

4.8.1. Calculation of fuel consumption and equivalent fuel energy consumption

Calculation of fuel consumption shall be done in accordance with paragraph 4.1.4. of this Sub-Annex and the calculation of the equivalent energy consumption shall be done in accordance with paragraph 4.3. of this Sub-Annex.

4.8.1.1. Calculation of electrical energy consumption

The determination of electrical energy consumption at the vehicle's REESS shall be done in accordance with paragraph 4.3. of this Sub-Annex.

When $EC_{DC,j}$ is negative then $EC_{DC,j}$ is equal to zero.

4.8.1.2. Calculation of total energy consumption for OVC-HEVs

The total energy consumption for OVC-HEVs shall be the sum of the energy consumption of fuel and electrical energy consumption from total REESS considering the grid to REESS output efficiency. The following equations shall be used:

$$EC_{total,j} = EC_{DC\_total,j} + EC_{fuel,j}$$

where:

$\mathrm{EC}_{\mathrm{total,j}}$ is the total energy consumption, the sum of the fuel and electric energy consumption over a period j.

$\mathrm{EC}_{\mathrm{DC\_total,j}}$ is the total electric energy consumption over the considered period j based on the REESS depletion and considering the electrical energy losses from the mains to the measurement location according to Appendix 3 of this Sub-Annex, kWh/100 km

$\mathrm{EC}_{fuel,j}$ is the fuel energy consumption in kWh/100km and calculated in accordance with paragraph 4.3. of this Sub-Annex.

j is the index for the considered period, where a period can be urban, rural, motorway phases or the total trip;

and

$$\mathrm{EC}_{\mathrm{DC\_total,j}} = \frac{\mathrm{EC}_{\mathrm{DC,j}}}{\eta_{\mathrm{grid-to-output}}}$$

where:

$\mathrm{EC}_{\mathrm{DC\_total,j}}$ is the total electric energy consumption over the considered period j based on the REESS depletion and considering the electrical energy losses from the mains to the measurement location according to Appendix 3 of this Sub-Annex, kWh/100 km

$\mathrm{EC}_{\mathrm{DC,j}}$ is the electric energy consumption over the considered period j based on the REESS depletion in kWh/100 km and calculated in accordance with paragraph 4.3. of this Sub-Annex.

$\eta_{\mathrm{grid-to-output,PHEV}}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy over the WLTC CD sequence, in accordance with paragraph 3.2 of this Sub-Annex.

and

$$\eta_{\mathrm{grid-to-output}} = \frac{\mathrm{E}_{\mathrm{DC,CD\ sequence}}}{\mathrm{E}_{\mathrm{AC}}}$$

where:

$\eta_{\mathrm{grid-to-output,PHEV}}$ is the “grid to REESS output efficiency” [-], describing the relation between the total REESS recharge energy from the mains and the total REESS output energy over the WLTC CD sequence, in accordance with paragraph 3.2 of this Sub-Annex.

$\mathrm{EC}_{\mathrm{DC,CD\ sequence}}$ is the electric energy consumption over the WLTC CD sequence done in accordance with paragraph 4.3. of this Sub-Annex, Wh;

E_{AC} is the recharged electric energy from the mains determined in accordance with paragraph 3.2.4.6. of this Sub-Annex, Wh;

In case the considered period is a given test cycle, $\mathrm{EC}_{\mathrm{DC,j}}$ can be expressed as $\mathrm{EC}_{\mathrm{DC,test}}$, $\mathrm{EC}_{\mathrm{DC\_total,j}}$ can be expressed as $\mathrm{EC}_{\mathrm{DC\_total,test}}$ and $\mathrm{EC}_{\mathrm{total,j}}$ can be expressed as $\mathrm{EC}_{\mathrm{total,test}}$,where the index “test” is the identification of the considered test.

Sub-Annex 8 - Appendix 1

REESS state of charge profile

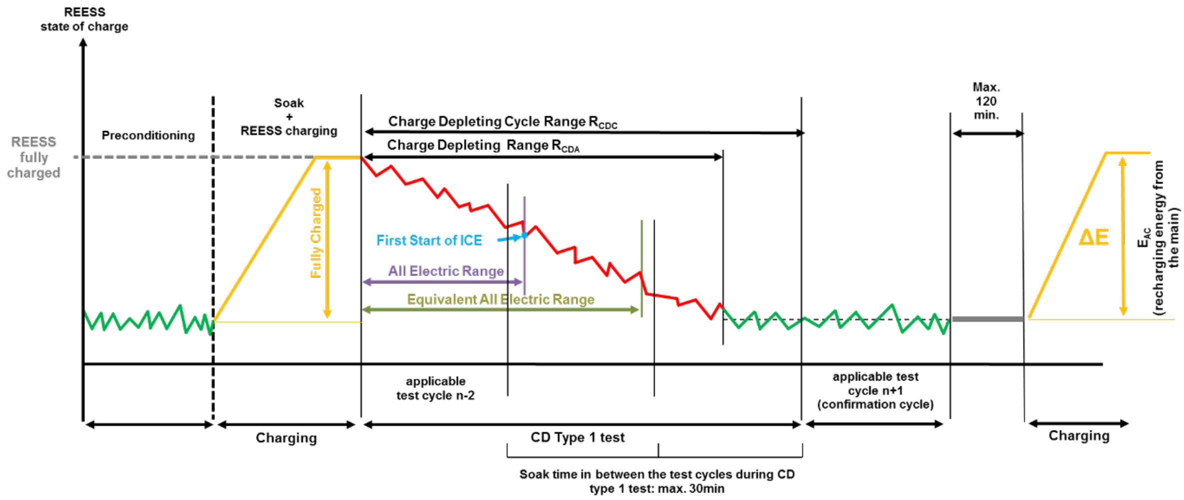
1. Test sequences and REESS profiles: OVC-HEVs, charge-depleting and charge-sustaining test

1.1. Test sequence OVC-HEVs according to option 1:

Charge-depleting type 1 test with no subsequent charge-sustaining Type 1 test (A8.App1/1)

Figure A8.App1/1

OVC-HEVs, charge-depleting Type 1 test

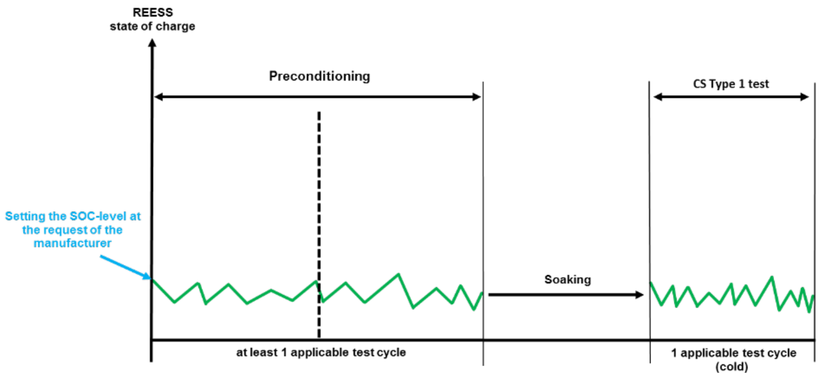


1.2. Test sequence OVC-HEVs according to option 2:

Charge-sustaining Type 1 test with no subsequent charge-depleting Type 1 test (A8.App1/2)

Figure A8.App1/2

OVC-HEVs, charge-sustaining Type 1 test

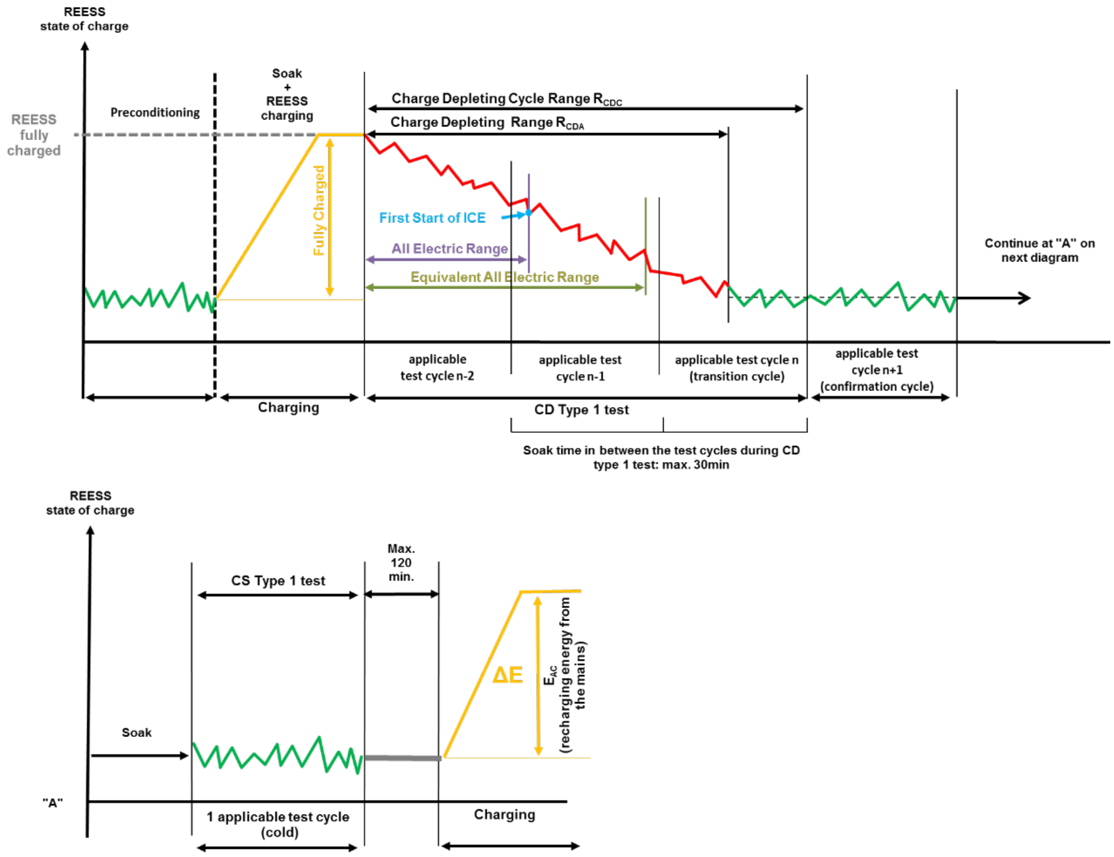


1.3. Test sequence OVC-HEVs according to option 3:

Charge-depleting Type 1 test with subsequent charge-sustaining Type 1 test (A8.App1/3)

Figure A8.App1/3

OVC-HEVs, charge-depleting type 1 test with subsequent charge-sustaining Type 1 test

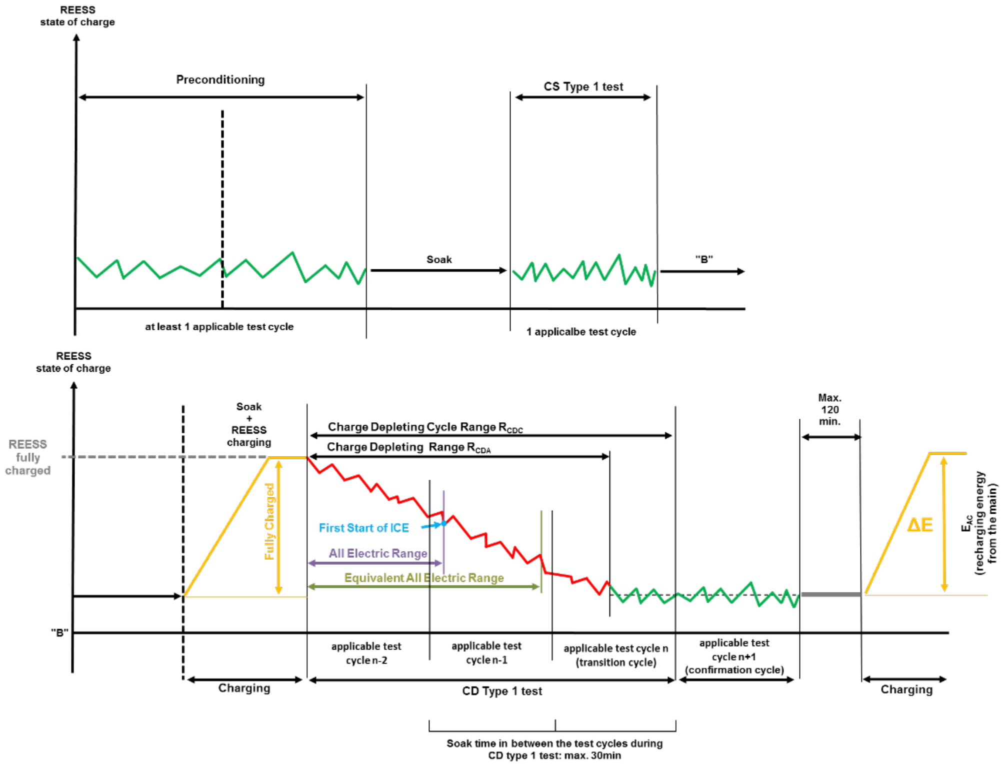


1.4. Test sequence OVC-HEVs according to option 4:

Charge-sustaining Type 1 test with subsequent charge-depleting Type 1 test (Figure A8.App1/4)

Figure A8.App1/4

OVC-HEVs, charge-sustaining Type 1 test with subsequent charge-depleting Type 1 test'

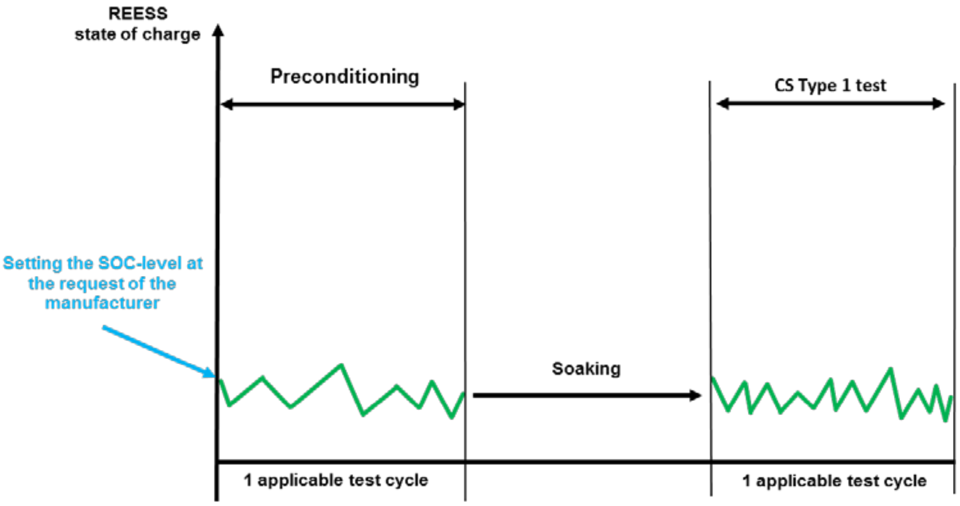


2. Test sequence NOVC-HEVs and NOVC-FCHVs

Charge-sustaining Type 1 test

Figure A8.App1/5

NOVC-HEVs and NOVC-FCHVs, charge-sustaining Type 1 test



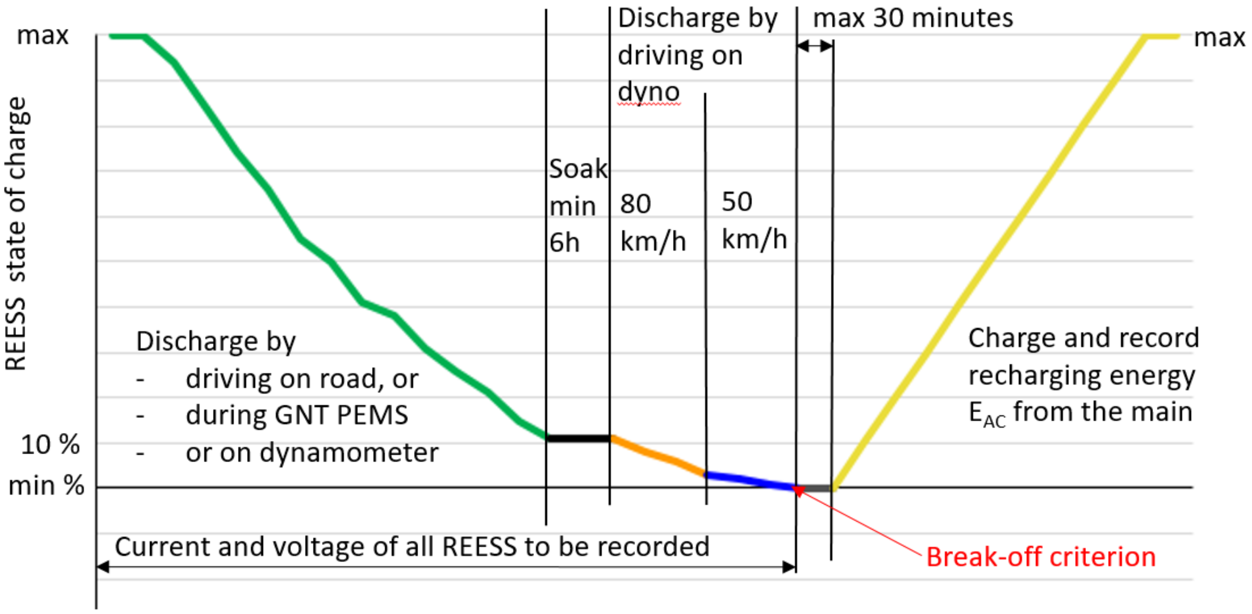
3. Test sequences PEV

According to GNT_Overall_GNCAP_Test_Procedure_WG and GNT_Real World Driving Range Test Procedure.

3.1 [reserved]

3.2 [reserved]

3.3 Charge depletion and recharge sequence to determine the “Nominal range”, “Real world range” and “Worst case range” when testing PEVs according to the Document *GNT-Real_World_Driving_Range_Test_WG.docx*



Sub-Annex 8 -Appendix 2

REESS energy change-based correction procedure

This Appendix describes the procedure to correct the charge-sustaining Type 1 test CO_2 mass emission for NOVC-HEVs and OVC-HEVs, and the fuel consumption for NOVC-FCHVs as a function of the electric energy change of all REESSs.

1. General requirements

1.1. Applicability of this Appendix

1.1.1. The phase-specific fuel consumption for NOVC-FCHVs, and the CO_2 mass emission for NOVC-HEVs and OVC-HEVs shall be corrected.

1.1.2. In the case that a correction of fuel consumption for NOVC-FCHVs or a correction of CO_2 mass emission for NOVC-HEVs and OVC-HEVs measured over the whole cycle according to paragraph 1.1.3. or paragraph 1.1.4. of this Appendix is applied, paragraph 4.3. of this Sub-Annex shall be used to calculate the charge-sustaining REESS energy change $\Delta \mathrm{E}_{\mathrm{REESS,CS}}$ of the charge-sustaining Type 1 test. The considered period j used in paragraph 4.3. of this Sub-Annex is defined by the charge-sustaining Type 1 test.

1.1.3. The correction shall be applied if $\Delta \mathrm{E}_{\mathrm{REESS,CS}}$ is negative which corresponds to REESS discharging and the correction criterion c calculated in paragraph 1.2. of this Appendix is greater than the applicable threshold in accordance with Table A8.App2/1.

1.1.4. The correction may be omitted and uncorrected values may be used if:

(a) $\Delta \mathrm{E}_{\mathrm{REESS,CS}}$ is positive which corresponds to REESS charging and the correction criterion c calculated in paragraph 1.2. of this Appendix is greater than the applicable threshold in accordance with Table A8.App2/1;

(b) The correction criterion c calculated in paragraph 1.2. of this Appendix is smaller than the applicable threshold in accordance with Table A8.App2/1;

(c) The manufacturer can prove to the GNT by measurement that there is no relation between $\Delta \mathrm{b}_{\mathrm{REESS,CS}}$ and charge-sustaining CO_2 mass emission and $\Delta \mathrm{m}_{\mathrm{REESS,CS}}$ and fuel consumption respectively.

1.2. The correction criterion c is the ratio between the absolute value of the REESS electric energy change $\Delta \mathrm{E}_{\mathrm{REESS,CS}}$ and the fuel energy and shall be calculated as follows:

$$\mathrm{c} = \frac{|\Delta \mathrm{E}_{\mathrm{REESS,CS}}|}{\mathrm{E}_{\mathrm{fuel,CS}}}$$

where:

$\Delta \mathrm{E}_{\mathrm{REESS,CS}}$ is the charge-sustaining REESS energy change according to paragraph 1.1.2. of this Appendix, Wh;

$\mathrm{E}_{\mathrm{fuel,CS}}$ is the charge-sustaining energy content of the consumed fuel in accordance with paragraph 1.2.1. of this Appendix in the case of NOVC-HEVs and OVC-HEVs, and in accordance with paragraph 1.2.2. of this Appendix in the case of NOVC-FCHVs, Wh.

1.2.1. Charge-sustaining fuel energy for NOVC-HEVs and OVC-HEVs

The charge-sustaining energy content of the consumed fuel for NOVC-HEVs and OVC-HEVs shall be calculated using the following equation:

$$E_{fuel,CS} = 10 \times HV \times FC_{CS,nb} \times d_{CS}$$

where:

$E_{fuel,CS}$ is the charge-sustaining energy content of the consumed fuel of the applicable WLTP test cycle of the charge-sustaining Type 1 test, Wh;

HV is the heating value according to Table A6.App2/1, kWh/l;

$FC_{CS,nb}$ is the non-balanced charge-sustaining fuel consumption of the charge-sustaining Type 1 test, not corrected for the energy balance, determined according to paragraph 6. of Sub-Annex 7, using the gaseous emission compound values according to Table A8/5, step no. 2, l/100 km;

d_{CS} is the distance driven over the corresponding applicable WLTP test cycle, km;

10 conversion factor to Wh.

1.2.2. Charge-sustaining fuel energy for NOVC-FCHVs

The charge-sustaining energy content of the consumed fuel for NOVC-FCHVs shall be calculated using the following equation:

$$E_{fuel,CS} = \frac{1}{0.36} \times 121 \times FC_{CS,nb} \times d_{CS}$$

$E_{fuel,CS}$ is the charge-sustaining energy content of the consumed fuel of the applicable WLTP test cycle of the charge-sustaining Type 1 test, Wh;

121 is the lower heating value of hydrogen, MJ/kg;

$FC_{CS,nb}$ is the non-balanced charge-sustaining fuel consumption of the charge-sustaining Type 1 test, not corrected for the energy balance, determined according to Table A8/7, step no.1, kg/100 km;

d_{CS} is the distance driven over the corresponding applicable WLTP test cycle, km;

$\frac{1}{0.36}$ conversion factor to Wh.

Table A8.App2/1

RCB correction criteria thresholds

Applicable Type 1 test cycle	*Low + Medium*	*Low + Medium + High*	*Low + Medium + High + Extra High*
Thresholds for correction criterion c	0,015	0,01	0,005 ';

2. Calculation of correction coefficients

2.1. The CO_2 mass emission correction coefficient K_{CO2}, the fuel consumption correction coefficients $K_{fuel,FCHV}$, as well as, the phase-specific correction coefficients $K_{CO2,p}$ and $K_{fuel,FCHV,p}$ shall be developed based on the applicable charge-sustaining Type 1 test cycles.

2.2. The correction coefficients shall be determined from a set of charge-sustaining Type 1 tests according to paragraph 3. of this Appendix. The number of tests performed by the laboratory shall be equal to or greater than five.

The laboratory may request to set the state of charge of the REESS prior to the test according to the manufacturer's recommendation and as described in paragraph 3. of this Appendix. This practice shall only be used for the purpose of achieving a charge-sustaining Type 1 test with opposite sign of the $\Delta E_{REESS,CS}$ and with approval of the GNT.

The set of measurements shall fulfil the following criteria:

(a) The set shall contain at least one test with $\Delta E_{REESS,CS,n} \leq 0$ and at least one test with $\Delta E_{REESS,CS,n} > 0$. $\Delta E_{REESS,CS,n}$ is the sum of electric energy changes of all REESSs of test n calculated in accordance with paragraph 4.3. of this Sub-Annex.

(b) The difference in $M_{CO2,CS}$ between the test with the highest negative electric energy change and the test with the highest positive electric energy change shall be greater than or equal to 5 g/km. This criterion shall not be applied for the determination of $K_{fuel,FCHV}$.

In the case of the determination of K_{CO2}, the required number of tests may be reduced to three tests if all of the following criteria are fulfilled in addition to (a) and (b):

(c) the difference in $M_{CO2,CS}$ between any two adjacent measurements, related to the electric energy change during the test, shall be less than or equal to 10 g/km.

(d) in addition to (b), the test with the highest negative electric energy change and the test with the highest positive electric energy change shall not be within the region that is defined by:

$-0.01 \leq \frac{\Delta E_{REESS}}{E_{fuel}} \leq +0.01$,

where:

E_{fuel} is the energy content of the consumed fuel calculated according to paragraph 1.2. of this Appendix, Wh.

(e) The difference in $M_{CO2,CS}$ between the test with the highest negative electric energy change and the mid-point, and the difference in $M_{CO2,CS}$ between the mid-point and the test with the highest positive electric energy change shall be similar. The mid-point should preferably be within the range defined by (d). If this requirement is not feasible, the GNT shall decide if a retest is necessary

The correction coefficients determined by the manufacturer shall be reviewed and approved by the GNT prior to its application.

f the set of at least five tests does not fulfil criterion (a) or criterion (b) or both, the manufacturer shall provide evidence to the GNT as to why the vehicle is not capable of meeting either or both criteria. If the GNT is not satisfied with the evidence, it may require additional tests to be performed. If the criteria after additional tests are still not fulfilled, the GNT shall determine a conservative correction coefficient, based on the measurements.

2.3. Calculation of correction coefficients:

$K_{fuel,FCHV}$ =1

And

K_{CO2}=1 according *GNT Special Requirements for Hybrid Electric Vehicles (HEV).docx.*

2.3.1. [reserved]

2.3.2. [reserved]

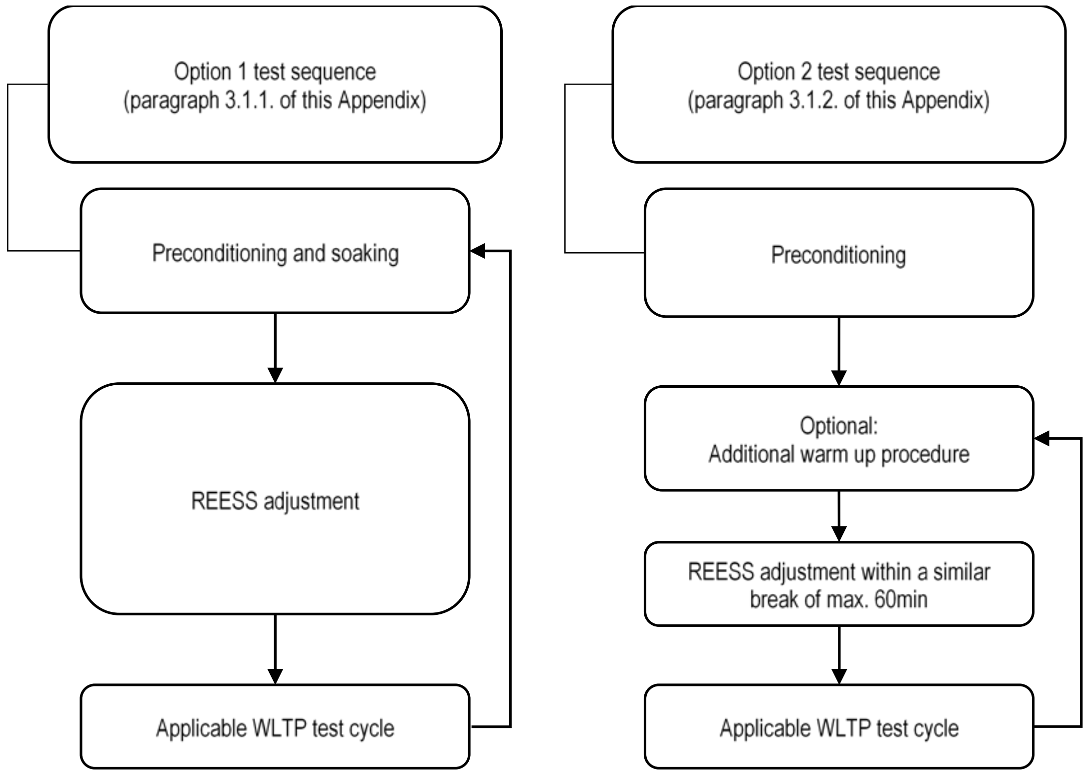
3. Test procedure for the determination of the correction coefficients

3.1. OVC-HEVs

For OVC-HEVs, one of the following test sequences according to Figure A8.App2/1 shall be used to measure all values that are necessary for the determination of the correction coefficients according to paragraph 2. of this Appendix.

Figure A8.App2/1

OVC-HEV test sequences



3.1.1. Option 1 test sequence

3.1.1.1. Preconditioning and soaking

Preconditioning and soaking shall be conducted according to paragraph 2.1. of Appendix 4. to this Sub-Annex.

3.1.1.2. REESS adjustment

Prior to the test procedure in accordance with paragraph 3.1.1.3. of this Appendix, the laboratory may adjust the REESS. The manufacturer shall provide evidence that the requirements for the beginning of the test in accordance with paragraph 3.1.1.3. of this Appendix are fulfilled.

3.1.1.3. Test procedure

3.1.1.3.1. The driver-selectable mode for the applicable WLTP test cycle shall be selected according to paragraph 3. of Appendix 6 to this Sub-Annex.

3.1.1.3.2. For testing, the applicable WLTP test cycle according to paragraph 1.4.2. of this Sub-Annex shall be driven.

3.1.1.3.3. Unless stated otherwise in this Appendix, the vehicle shall be tested according to the Type 1 test procedure described in Sub-Annex 6.

3.1.1.3.4. To obtain a set of applicable WLTP test cycles required for the determination of the correction coefficients, the test may be followed by a number of consecutive sequences required according to paragraph 2.2 of this Appendix consisting of paragraph 3.1.1.1. to paragraph 3.1.1.3. inclusive of this Appendix.

3.1.2. Option 2 test sequence

3.1.2.1. Preconditioning

The test vehicle shall be preconditioned according to paragraph 2.1.1. or paragraph 2.1.2. of Appendix 4 to this Sub-Annex.

3.1.2.2. REESS adjustment

After preconditioning, soaking according to paragraph 2.1.3. of Appendix 4 to this Sub-Annex shall be omitted and a break, during which the REESS is permitted to be adjusted, shall be set to a maximum duration of 60 minutes. A similar break shall be applied in advance of each test. Immediately after the end of this break, the requirements of paragraph 3.1.2.3. of this Appendix shall be applied.

Upon request of the laboratory, an additional warm-up procedure may be conducted in advance of the REESS adjustment to ensure similar starting conditions for the correction coefficient determination. If the laboratory requests this additional warm-up procedure, the identical warm-up procedure shall be applied repeatedly within the test sequence.

3.1.2.3. Test procedure

3.1.2.3.1. The driver-selectable mode for the applicable WLTP test cycle shall be selected according to paragraph 3. of Appendix 6 to this Sub-Annex.

3.1.2.3.2. For testing, the applicable WLTP test cycle according to paragraph 1.4.2. of this Sub-Annex shall be driven.

3.1.2.3.3. Unless stated otherwise in this Appendix, the vehicle shall be tested according to the Type 1 test procedure described in Sub-Annex 6.

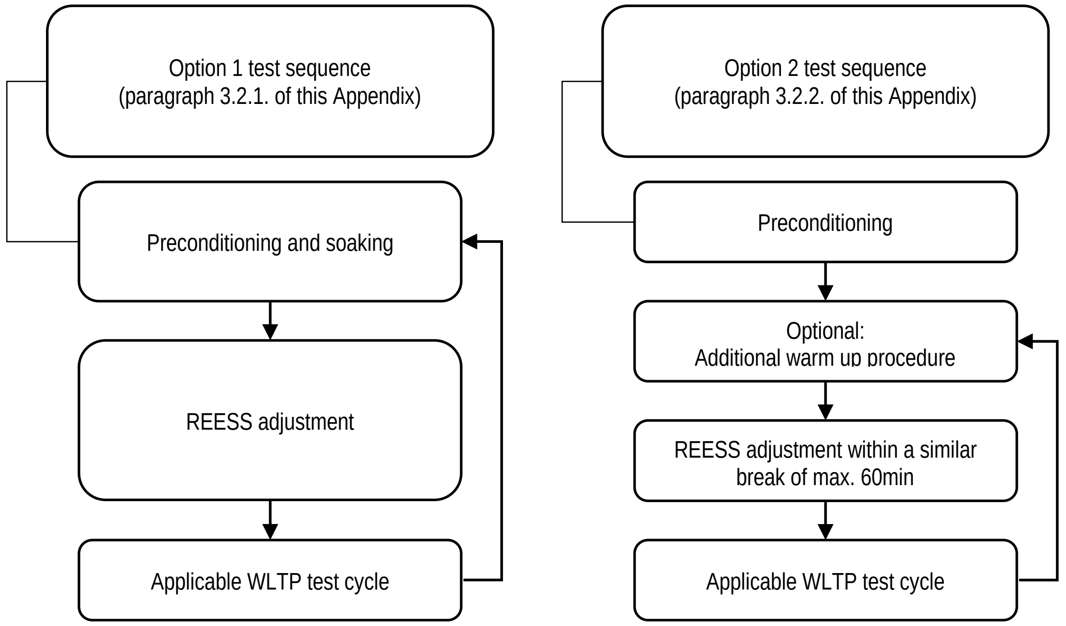
3.1.2.3.4. To obtain a set of applicable WLTP test cycles that are required for the determination of the correction coefficients, the test may be followed by a number of consecutive sequences required according to paragraph 2.2. of this Appendix consisting of paragraphs 3.1.2.2. and 3.1.2.3. of this Appendix.

3.2. NOVC-HEVs and NOVC-FCHVs

For NOVC-HEVs and NOVC-FCHVs, one of the following test sequences according to Figure A8.App2/2 shall be used to measure all values that are necessary for the determination of the correction coefficients according to paragraph 2. of this Appendix.

Figure A8.App2/2

NOVC-HEV and NOVC-FCHV test sequences



3.2.1. Option 1 test sequence

3.2.1.1. Preconditioning and soaking

The test vehicle shall be preconditioned and soaked according to paragraph 3.3.1. of this Sub-Annex.

3.2.1.2. REESS adjustment

Prior to the test procedure, according to paragraph 3.2.1.3., the laboratory may adjust the REESS. The manufacturer shall provide evidence that the requirements for the beginning of the test according to paragraph 3.2.1.3. are fulfilled.

3.2.1.3. Test procedure

3.2.1.3.1. The driver-selectable mode shall be selected according to paragraph 3. of Appendix 6 to this Sub-Annex.

3.2.1.3.2. For testing, the applicable WLTP test cycle according to paragraph 1.4.2. of this Sub-Annex shall be driven.

3.2.1.3.3. Unless stated otherwise in this Appendix, the vehicle shall be tested according to the charge-sustaining Type 1 test procedure described in Sub-Annex 6.

3.2.1.3.4. To obtain a set of applicable WLTP test cycles that are required for the determination of the correction coefficients, the test can be followed by a number of consecutive sequences required according to paragraph 2.2. of this Appendix consisting of paragraph 3.2.1.1. to paragraph 3.2.1.3. inclusive of this Appendix.

3.2.2. Option 2 test sequence

3.2.2.1. Preconditioning

The test vehicle shall be preconditioned according to paragraph 3.3.1.1. of this Sub-Annex.

3.2.2.2. REESS adjustment

After preconditioning, the soaking according to paragraph 3.3.1.2. of this Sub-Annex shall be omitted and a break, during which the REESS is permitted to be adjusted, shall be set to a maximum duration of 60 minutes. A similar break shall be applied in advance of each test. Immediately after the end of this break, the requirements of paragraph 3.2.2.3. of this Appendix shall be applied.

Upon request of the laboratory, an additional warm-up procedure may be conducted in advance of the REESS adjustment to ensure similar starting conditions for the correction coefficient determination. If the laboratory requests this additional warm-up procedure, the identical warm-up procedure shall be applied repeatedly within the test sequence.

3.2.2.3. Test procedure

3.2.2.3.1. The driver-selectable mode for the applicable WLTP test cycle shall be selected according to paragraph 3. of Appendix 6 to this Sub-Annex.

3.2.2.3.2. For testing, the applicable WLTP test cycle according to paragraph 1.4.2. of this Sub-Annex shall be driven.

3.2.2.3.3. Unless stated otherwise in this Appendix, the vehicle shall be tested according to the Type 1 test procedure described in Sub-Annex 6.

3.2.2.3.4. To get a set of applicable WLTP test cycles that are required for the determination of the correction coefficients, the test can be followed by a number of consecutive sequences required according to paragraph 2.2. of this Appendix consisting of paragraphs 3.2.2.2. and 3.2.2.3. of this Appendix.

Sub-Annex 8 -Appendix 3

Determination of REESS current and REESS voltage for NOVC-HEVs, OVC-HEVs, PEVs and NOVC-FCHVs

1. Introduction

1.1. This Appendix defines the method and required instrumentation to determine the REESS current and the REESS voltage of NOVC-HEVs, OVC-HEVs, PEVs and NOVC-FCHVs.

1.2. Measurement of REESS current and REESS voltage shall start at the same time as the test starts and shall end immediately after the vehicle has finished the test.

1.3. The REESS current and the REESS voltage of each phase shall be determined.

1.4. A list of the instrumentation used by the manufacturer to measure REESS voltage and current (including instrument manufacturer, model number, serial number, last calibration dates (where applicable)) during:

(a) the Type 1 test according to paragraph 3 of this Sub-Annex,

(b) the procedure to determine the correction coefficients according to Appendix 2 of this Sub-Annex (where applicable),

(c) the ATCT as specified in Sub-Annex 6a

shall be provided to the GNT.

2. REESS current

REESS depletion is considered as a negative current.

2.1. External REESS current measurement

2.1.1. The REESS current(s) shall be measured during the tests using a clamp-on or closed type current transducer. The current measurement system shall fulfil the requirements specified in Table A8/1 of this Sub-Annex. The current transducer(s) shall be capable of handling the peak currents at engine starts and temperature conditions at the point of measurement.

In order to have an accurate measurement, zero adjustment and degaussing shall be performed before the test in accordance with the instrument manufacturer's instructions.

2.1.2. Current transducers shall be fitted to any of the REESS on one of the cables connected directly to the REESS and shall include the total REESS current.

In case of shielded wires, appropriate methods shall be applied in accordance with the GNT.

In order to easily measure the REESS current using external measuring equipment, the manufacturer should provide appropriate, safe and accessible connection points in the vehicle. If that is not feasible, the manufacturer is obliged to support the laboratory in connecting a current transducer to one of the cables directly connected to the REESS in the manner described above in this paragraph.

2.1.3. The current transducer output shall be sampled with a minimum frequency of 20 Hz. The measured current shall be integrated over time, yielding the measured value of Q, expressed in ampere-hours Ah. The integration may be done in the current measurement system.

2.2. Vehicle on-board REESS current data

As an alternative to paragraph 2.1. of this Appendix, the laboratory may use the on-board current measurement data. The accuracy of these data shall be demonstrated to the GNT.

3. REESS voltage

3.1. External REESS voltage measurement

During the tests described in paragraph 3. of this Sub-Annex, the REESS voltage shall be measured with the equipment and accuracy requirements specified in paragraph 1.1. of this Sub-Annex. To measure the REESS voltage using external measuring equipment, the manufacturers shall support the laboratory by providing REESS voltage measurement points.

3.2. Nominal REESS voltage

For NOVC-HEVs, NOVC-FCHVs and OVC-HEVs, instead of using the measured REESS voltage in accordance with paragraph 3.1. of this Appendix, the nominal voltage of the REESS determined in accordance with IEC 60050-482 may be used.

3.3. Vehicle on-board REESS voltage data

As an alternative to paragraph 3.1. and 3.2. of this Appendix, the laboratory may use the on-board voltage measurement data. The accuracy of these data shall be demonstrated to the GNT.

Sub-Annex 8 -Appendix 4

Preconditioning, soaking and REESS charging conditions of PEVs and OVC-HEVs

1. This Appendix describes the test procedure for REESS and combustion engine preconditioning in preparation for:

(a) Electric range, charge-depleting and charge-sustaining measurements when testing OVC-HEVs; and

(b) Electric energy consumption measurements when testing PEVs.

1.1 In case of determining “Nominal range”, “Real word range” and “Worst case range” when testing PEVs discharging, soaking and REESS charging conditions shall be applied according to the Document *GNT-Real_World_Driving_Range_Test_WG.docx*.

2. OVC-HEV preconditioning and soaking

2.1. Preconditioning and soaking when the test procedure starts with a charge-sustaining test

2.1.1. For preconditioning the combustion engine, the vehicle shall be driven over at least one applicable WLTP test cycle. During each driven preconditioning cycle, the charging balance of the REESS shall be determined. The preconditioning shall be stopped at the end of the applicable WLTP test cycle during which the break-off criterion is fulfilled according to paragraph 3.2.4.5. of this Sub-Annex.

2.1.2. As an alternative to paragraph 2.1.1. of this Appendix, at the request of the laboratory and upon approval of the GNT, the state of charge of the REESS for the charge-sustaining Type 1 test may be set according to the manufacturer’s recommendation in order to achieve a test under charge-sustaining operating condition.

In such a case, a preconditioning procedure, such as that applicable to pure ICE vehicles as described in paragraph 2.6. of Sub-Annex 6, shall be applied.

2.1.3. Soaking of the vehicle shall be performed in accordance with paragraph 2.7. of Sub-Annex 6.

2.2. Preconditioning and soaking when the test procedure starts with a charge-depleting test

2.2.1. OVC-HEVs shall be driven over at least one applicable WLTP test cycle. During each driven preconditioning cycle, the charging balance of the REESS shall be determined. The preconditioning shall be stopped at the end of the applicable WLTP test cycle during which the break-off criterion is fulfilled according to paragraph 3.2.4.5. of this Sub-Annex.

2.2.2. Soaking of the vehicle shall be performed in accordance with paragraph 2.7. of Sub-Annex 6. Forced cooling down shall not be applied to vehicles preconditioned for the Type 1 test. During soak, the REESS shall be charged using the normal charging procedure as defined in paragraph 2.2.3. of this Appendix..

2.2.3. Application of a normal charge

2.2.3.1. The REESS shall be charged at an ambient temperature as specified in paragraph 4 of *GNT-Real World Driving Range Test Procedure* either with:

(a) The on-board charger if fitted; or

(b) An external charger recommended by the manufacturer using the charging pattern prescribed for normal charging.

The procedures in this paragraph exclude all types of special charges that could be automatically or manually initiated, e.g. equalization charges or servicing charges. The manufacturer shall declare that, during the test, a special charge procedure has not occurred.

2.2.3.2. End-of-charge criterion

The end-of-charge criterion is reached when the on-board or external instruments indicate that the REESS is fully charged.

3. PEV preconditioning

3.1. Initial charging of the REESS

Initial charging of the REESS consists of discharging the REESS and applying a normal charge.

3.1.1. Discharging the REESS

The discharge procedure shall be performed according to the manufacturer's recommendation. The manufacturer shall guarantee that the REESS is as fully depleted as is possible by the discharge procedure.

The discharge procedure for determination of the usable REESS capacity $E_{DC\text{-}discharge}$ sall follow the provisions of paragraph 2 of *GNT-Real World Driving Range Test Procedure* .

3.1.2. Application of a normal charge

The REESS shall be charged according to paragraph 2.2.3.1. of this Appendix.

Sub-Annex 8 -Appendix 5

[reserved]

Sub-Annex 8 - Appendix 6

Selection of driver-selectable modes

The selection of driver selectable modes has to be conducted according to the provisions made in *GNT_Special_Requirements_for_Hybrid_Electric_Vehicles_(HEV).docx.*

Sub-Annex 8 - Appendix 7

Fuel consumption measurement of compressed hydrogen fuel cell hybrid vehicles

1. General requirements

1.1. Fuel consumption shall be measured using the gravimetric method in accordance with paragraph 2. of this Appendix.

At the request of the laboratory and with approval of the GNT, fuel consumption may be measured using either the pressure method or the flow method. In this case, the manufacturer shall provide technical evidence that the method yields equivalent results. The pressure and flow methods are described in ISO 23828:2013.

2. Gravimetric method

Fuel consumption shall be calculated by measuring the mass of the fuel tank before and after the test.

2.1. Equipment and setting

2.1.1. An example of the instrumentation is shown in Figure A8.App7/1. One or more off-vehicle tanks shall be used to measure the fuel consumption. The off-vehicle tank(s) shall be connected to the vehicle fuel line between the original fuel tank and the fuel cell system.

2.1.2. For preconditioning, the originally installed tank or an external source of hydrogen may be used.

2.1.3. The refuelling pressure shall be adjusted to the manufacturer's recommended value.

2.1.4. Difference of the gas supply pressures in lines shall be minimized when the lines are switched.

In the case that influence of pressure difference is expected, the laboratory and the GNT shall agree whether correction is necessary or not.

2.1.5. Balance

2.1.5.1. The balance used for fuel consumption measurement shall meet the specification of Table A8.App7/1.

Table A8.App7/1

Analytical balance verification criteria

Measurement system	*Resolution*	*Precision*
Balance	0.1 g maximum	±0.02 maximum(1)

(1) Fuel consumption (REESS charge balance = 0) during the test, in mass, standard deviation

2.1.5.2. The balance shall be calibrated in accordance with the specifications provided by the balance manufacturer or at least as often as specified in Table A8.App7/2.

Table A8.App7/2

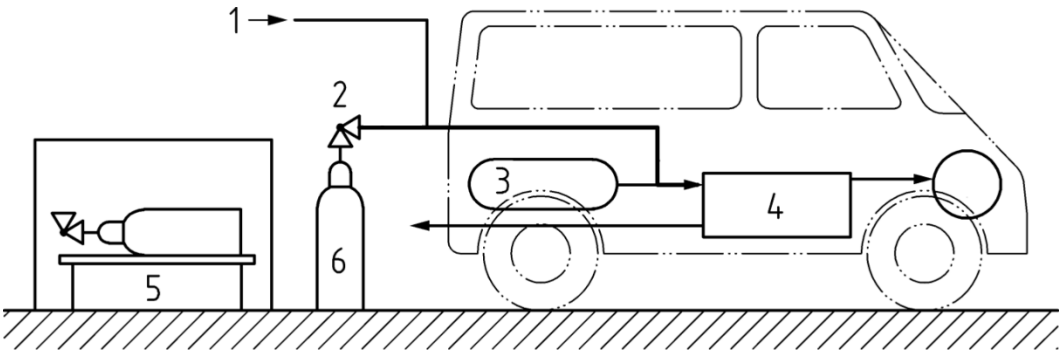
Instrument calibration intervals

Instrument checks	*Interval*
Precision	Yearly and at major maintenance

2.1.5.3. Appropriate means for reducing the effects of vibration and convection, such as a damping table or a wind barrier, shall be provided.

Figure A8.App7/1

Example of instrumentation



where:

1 is the external fuel supply for preconditioning

2 is the pressure regulator

3 is the original tank

4 is the fuel cell system

5 is the balance

6 is/are off-vehicle tank(s) for fuel consumption measurement

2.2. Test procedure

2.2.1. The mass of the off-vehicle tank shall be measured before the test.

2.2.2. The off-vehicle tank shall be connected to the vehicle fuel line as shown in Figure A8.App7/1.

2.2.3. The test shall be conducted by fuelling from the off-vehicle tank.

2.2.4. The off-vehicle tank shall be removed from the line.

2.2.5. The mass of the tank after the test shall be measured.

2.2.6. The non-balanced charge-sustaining fuel consumption $\mathrm{FC_{CS,nb}}$ from the measured mass before and after the test shall be calculated using the following equation:

$$\mathrm{FC_{CS,nb}} = \frac{\mathrm{g_1 - g_2}}{\mathrm{d}} \times 100$$

where:

$FC_{CS,nb}$ is the non-balanced charge-sustaining fuel consumption measured during the test, kg/100km;

g_1 is the mass of the tank at the start of the test, kg;
g_2 is the mass of the tank at the end of the test, kg;
d is the distance driven during the test, km.
$FC_{CS,nb,p}$

Sub-Annex 9

[reserved]

Sub-Annex 10

Additional Determination of emissions of unregulated pollutants: laughing gas (N_2O) and Ammonia (NH_3)

1. Laboratory test procedure

1.1 Scope and references

The purpose of this procedure is to describe the method of measuring the concentration of laughing gas (N_2O) and Ammonia (NH_3), performed as a part of the Green NCAP test program.

This procedure is based on GTR15 and COMMISSION REGULATION (EU) No 582/2011 requirements . It is also consistent with existing materials and methods in partner laboratories.

1.2 Terms and definitions

For terms and definitions please see *GNT_Definitions_Accronyms_Symbols.*

1.3 Measurement principles and sampling prescriptions

Three measurement principles are specified for the N_2O and two for the NH_3 measurement. The analyser can be a laser infrared spectrometer defined as modulated high resolution narrow band infrared analyser (QCL). An NDIR (for N_2O) or FTIR (for N_2O and NH_3) may also be used but H_2O, CO and CO_2 interference shall be taken into consideration.

The ambient air sample shall be measured on the same analyser with the same range.

No gas drying device shall be used before the analysers unless it is shown to have no effect on the content of the compound in the gas stream.

1.3.1 N_2O and NH_3 Measurement via quantum cascade laser (QCL)

1.3.1.1 Measurement principle (QCL)

The QCL employs the single line spectroscopy principle. The N_2O absorption line is chosen in the mid-infrared spectral range. The advantage of using a QCL is the extremely narrow band width of the emitted laser light, where a very high selectivity to the desired measurement component can be achieved. When measured over a long path gas-flow cell the coupled laser light is partially absorbed. The absorption rate determined by the analyser software is a measure of the concentration of the component gas.

1.3.1.2 Installation of QCL

The analyser shall be installed either directly in the exhaust pipe (in-situ) or within an analyser cabinet using extractive sampling in accordance with the instrument manufacturer's instructions. The QCL analyser shall be used for undiluted exhaust gas measurement at end of pipe using extractive sampling in accordance with the instrument manufacturer's instructions. If the device specifications allow it to be used for accurate measurement of N_2O and NH_3 concentration in the diluted exhaust gas, the QCL may be used for continuous diluted exhaust measurement or diluted exhaust sample bag analysis.

Where applicable, sheath air used in conjunction with an in-situ measurement for protection of the instrument shall not affect the concentration of any exhaust component measured downstream of the device, or, if the sheath air affects the concentration, the sampling of other exhaust components shall be made upstream of the device.

1.3.1.3 Cross interference at N_2O and NH_3 measurement via QCL

The spectral resolution of the laser shall be within 0.5 per cm in order to minimize cross interference from other gases present in the exhaust gas.

1.3.2 N_2O and NH_3 measurement via Fourier transform infrared analyser (FTIR)

1.3.2.1 Measurement principle (FTIR)

An FTIR employs the broad waveband infrared spectroscopy principle. It allows simultaneous measurement of exhaust components whose standardised spectra are available in the instrument. The absorption spectrum (intensity/wavelength) is calculated from the measured interferogram (intensity/time) by means of the Fourier transform method.

1.3.2.2 Installation of FTIR analyser

The analyser shall be used for raw exhaust gas measurement at end of pipe using extractive sampling in accordance with the instrument manufacturer's instructions.

1.3.2.2.1 The internal analyser sample stream up to the measurement cell and the cell itself shall be heated.

1.3.2.2.2 Extractive sampling

The sample path upstream of the analyser (sampling line, prefilter(s), pumps and valves) shall be made of stainless steel or PTFE, and shall be heated to set points between 110 °C and 190 °C in order to minimise losses and sampling artefacts. In addition, the sampling line shall be as short as possible. At the request of the manufacturer, temperatures between 110 °C and 133 °C may be chosen.

1.3.2.3 Cross interference at N_2O and NH_3 measurement via FTIR analyser

1.3.2.3.1 The spectral resolution of the target wavelength shall be within 0.5 per cm in order to minimize cross interference from other gases present in the exhaust gas.

1.3.2.3.2 Analyser response shall not exceed ± 2 ppm at the maximum CO_2 and H_2O concentration expected during the vehicle test.

1.3.3 N_2O measurement via nondispersive infrared analyser (NDIR)

1.3.3.1 Measurement principle (NDIR)

A nondispersive infrared sensor (or NDIR sensor) is a simple spectroscopic sensor often used as a gas detector. The infrared light is directed through the sample chamber towards the detector. The gas in the sample chamber causes absorption of specific wavelengths and the attenuation of these wavelengths is measured by the detector to determine the gas concentration. The detector has an optical filter in front of it that eliminates all light except the wavelength that the selected gas molecules can absorb.

1.3.3.2 Installation of NDIR analyser

1.3.3.2.1 The NDIR analyser may be used for undiluted exhaust gas measurement at end of pipe using extractive sampling in accordance with the instrument manufacturer's instructions. The extracted sample shall be non-condensing and cooled down to a temperature specified by the instrument's manufacturer. If a gas drying device is used, it must be shown to have no effect on the content of the compound in the gas stream.

1.3.3.2.2 If the NDIR specifications allow it to be used for accurate measurement of N_2O concentration in the diluted exhaust gas, the NDIR may be used for continuous diluted exhaust measurement or diluted exhaust sample bag analysis.

1.3.4 Cross interference at N_2O measurement via NDIR analyser

Cross sensitivities to H_2O, CO_2 or other exhaust gas components are to be considered by the manufacturer through compensation methods.

If the analyser shows interference to compounds present in the sample, this interference shall be corrected. Analysers shall have combined interference within 0 ± 2 ppm.

1.3.5

In order not to influence the results of the downstream measurements in the CVS system, the amount of raw exhaust extracted for the N_2O measurement shall be limited. This may be achieved by in-situ measurement, a low sample flow analyser, or the return of the N_2O sample flow back to the CVS.

The maximum allowable N_2O sample flow not returned to the CVS shall be calculated by:

$$\mathrm{Flow\_lost\_max} = \frac{0.005 * V_{\mathrm{mix}}}{\mathrm{DF}} \qquad \textit{Equation 1}$$

where:

Flow_lost_max is the volume of sample not returned to the CVS, m^3;

V_{mix} is the volume of diluted exhaust per phase, m^3;

DF is the dilution factor.

If the unreturned volume of the N_2O sample flow exceeds the maximum allowable for any phase of the test, the downstream measurements of the CVS are to be corrected by considering the lost flow volume.

If the extracted flow is returned to the CVS, an upper limit of 10 standard l/min shall apply. If this limit is exceeded, an additional test is therefore necessary without the N_2O measurement.

1.4 Calibration

1.4.1 Calibration gases

- N_2O in nitrogen (tolerance: ± 2 per cent or 0.25 ppm, whichever is greater)
- NH_3 in nitrogen (tolerance: ± 3 per cent).
- Nitrogen for purge and zero calibration (Purity: ≤ 1 ppm C1, ≤ 1 ppm CO, ≤ 400 ppm CO_2, ≤ 0.1 ppm NO, ≤ 0.1 ppm N_2O, ≤ 0.1 ppm NH_3)

1.4.2 Calibration frequency

- A sequence of gas calibration (gas concentration and zero) shall be done daily
- An annual maintenance of the test equipment shall be done, including:
    - Linearity check
    - Preventive (and curative if necessary) maintenance of equipment
- Instrument calibration intervals according to Table 1

Table 1: Instrument calibration intervals

Instrument checks	*Interval*	*Criterion*
N_2O NDIR:	Monthly	-2 to 2 ppm

CO_2/H_2O interference		
QCL	Yearly or at major maintenance	According to the instrument manufacturer
FTIR: linearity verification	Within 370 days before testing and after major maintenance	See section 3.2.3

1.5 Analyser specifications

1.5.1 The sensitivity of the analysers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible.

1.5.2 The analysers shall have a measuring range compatible with the accuracy required to measure the concentrations of the exhaust gas sample compounds. A typical measuring low range may be 0 – 100 ppm for N_2O and 0 – 50 ppm for NH_3. The resolution shall be ≤ 1 ppm and the lower detection limit ≤ 2 ppm. Prior to the emissions test, the analyser range shall be selected. Emission analysers with automatic or manual range switching shall be permitted. During the test cycle, the range of the analysers shall not be switched.

1.5.3 The accuracy, defined as the deviation of the analyser reading from the reference value, shall not exceed ± 2 % of reading or ± 2 ppm, whichever is larger.

1.5.4 The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1 % of the full scale concentration for a measurement range equal or above 155 ppm and 2 % of the full scale concentration for a measurement range of below 155 ppm.

1.5.5 The rise time, defined as the time between the 10 % and 90 % response of the final reading (t_{90} – t_{10}), shall not exceed 5 seconds.

1.5.6 The system response time shall be ≤ 20 seconds.

1.5.7 The sampling rate should be 1 Hz at least.

1.5.7.1 Analyser drift

As soon as practical but no later than 30 minutes after the test cycle is complete or during the soak period, the zero and span responses of the analyser shall be determined. The difference between the pre-test and post-test results shall be less than 2 % of full scale. For the span response, a N_2O and NH_3 gases that meets the specifications of point 1.4.1. shall be used. The use of reference cells that contain N_2O or NH_3 span gas is permitted.

1.5.7.2 Response time check of the analytical system

For the response time check, the settings of the analytical system shall be the same as during the emissions test (i.e. pressure, flow rates, filter settings in the analysers and all other parameters influencing the response time). The response time shall be determined with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0.1 second. The gases used for the test shall cause a concentration change of at least 60 % full scale of the analyser.

The concentration trace of each single gas component shall be recorded. The delay time is defined as the time from the gas switching (t_0) until the response is 10 % of the final reading (t_{10}). The rise time is defined as the time between 10 % and 90 % response of the final reading (t_{90} – t_{10}). The system response time (t_{90}) consists of the delay time to the measuring detector and the rise time of the detector.

For time alignment of the analyser and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 % of the final reading (t_{50}).

1.5.8 N_2O and NH_3 concentration recording

Sampling, measurement and recording of parameters shall begin prior to the start of the engine. The N_2O and NH_3 concentration shall be measured continuously and stored with at least 1 Hz on a computer system.

1.5.8.1 Units for N_2O and NH_3 results

The results must be expressed in a time resolved manner as [mg/s] for every second of the test duration and as cumulative emissions in [mg/km] for each test phase and for the whole test. Additionally, the [ppm] concentration values of the raw exhaust measurement are to be stored for engineering purposes.

1.5.8.2 Time alignment of N_2O and NH_3 measurement

To facilitate time alignment, it is recommended to record the parameters that are subject to time alignment either by a single data recording device or with a synchronised time stamp. Before and directly after engine start, it shall be confirmed that all necessary parameters are recorded by the data logger.

The continuous N_2O and NH_3 concentration measurements must be time aligned with a reference fictive diluted exhaust in-situ emission measuring point at end of pipe for both undiluted and diluted exhaust emission measurement types. For that purpose, the analyser's transformation time must be considered.

The recorded traces of all component concentrations shall be time corrected by reverse shifting according to the transformation times of the respective analysers.

$$c_{i,c}\left(t - \Delta t_{t,i}\right) = c_{i,r}(t) \qquad \textit{Equation 2}$$

where:

$c_{i,c}$ is the time-corrected concentration of component *i* as function of time *t*

$c_{i,r}$ is the raw concentration of component *i* as function of time *t*

$\Delta t_{t,i}$ is the transformation time *t* of the analyser measuring component *i*

1.6 Exhaust flow

Sampling, measurement and recording of parameters shall begin prior to the start of the engine. The exhaust flow shall be measured continuously and stored with at least 1 Hz on a computer system.

1.6.1 Application and units

The knowledge of the exhaust mass is needed for the calculation of gravimetric emission values, i.e. the conversion of [ppm] values into gram [g] values. The undiluted exhaust flow values may be used:

- For multiplying undiluted exhaust flow rate with continuously sampled concentrations.
- For multiplying total undiluted exhaust flow with batch-sampled concentrations.

Within the cases, where the N_2O or NH_3 concentration is being analysed in the undiluted exhaust, the undiluted exhaust gas mass is needed. Within the cases, where the N_2O or NH_3 concentration is being analysed in the diluted exhaust gas, the diluted exhaust mass in needed.

For some applications it may be more convenient to work with the exhaust volume rather than with the exhaust mass. In these cases, special attention should be paid to the used reference conditions. It is strongly recommended to use standard conditions for temperature and pressure (0 °C and 101.325

kPa) for volume calculations.

1.6.2 Determination of undiluted exhaust flow

Instruments, sensors or signals for measuring the exhaust mass flow rate shall have a measuring range and response time appropriate for the accuracy required to measure the exhaust mass flow rate under transient and steady state conditions. The sensitivity of instruments, sensors and signals to shocks, vibration, aging, variability in temperature, ambient air pressure, electromagnetic interferences and other impacts related to vehicle and instrument operation shall be on a level as to minimize additional errors.

Intake-air-flow measurement devices may include a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer.

Intake-air flow meters and fuel flow meters should meet the linearity requirements stated in "Specifications and calibration of PEMS components and signals” of GNT_PEMS+ procedure and the accuracy requirements stated in “Sensors and auxiliary equipment” in the GNT_PEMS+ procedure.

For any type of intake-air flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. This may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

1.6.2.1 Calculation method using air mass flow rate and fuel mass flow rate

As set out in “Determination of exhaust mass flow rate” in the GNT_PEMS+ procedure.

1.6.2.2 Calculation method using air mass flow and air-to-fuel ratio

As set out in “Determination of exhaust mass flow rate” in the GNT_PEMS+ procedure.

1.6.2.3 Calculation method using fuel mass flow and air-to-fuel ratio

As set out in “Determination of exhaust mass flow rate” in the GNT_PEMS+ procedure.

1.6.2.4 The ECU intake-air signal may be used instead of a calibrated intake-air flow meter only if the ECU intake air signal is validated towards a calibrated intake-air flow meter.

If the air mass flow rate, the fuel mass flow rate, the air-to-fuel ratio and the exhaust mass flow rate are determined from ECU recording, the calculated instantaneous exhaust mass flow rate shall meet the linearity requirements specified for the exhaust mass flow rate "Specifications and calibration of PEMS components and signals” of the GNT_PEMS+ procedure and the validation requirements specified in “Validation procedure for the exhaust mass flow rate determined by non-traceable instruments and sensors” in the GNT_PEMS+ procedure.

1.6.3 Measurement of undiluted exhaust flow

The undiluted exhaust flow may be measured with an exhaust flow measuring device. Each individual exhaust mass flow meter shall fulfil the linearity requirements set out for “Specifications and calibration of PEMS components and signals” in the GNT_PEMS+ procedure.

Exhaust flow measurement devices may involve using an ultrasonic flow meter, a subsonic venturi, an averaging Pitot tube, a hot-wire anemometer, or other measurement principle. This would generally not involve a laminar flow element or a thermal-mass meter. Any raw-exhaust meter must be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states.

For any type of intake-air flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. This may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

The undiluted exhaust may be cooled upstream of the raw-exhaust flow meter, as long as all the following provisions are observed:

- PM should not be sampled downstream of the cooling.
- If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, NMHC should not be sampled downstream of the cooling for compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW.
- The cooling must not cause aqueous condensation.

1.6.3.1 Calibration and verification standards

The measurement performance of exhaust mass flow meters shall be verified with air or exhaust gas against a traceable standard such as, e.g. a calibrated exhaust mass flow meter or a full flow dilution tunnel.

1.6.3.2 Frequency of verification

The compliance of exhaust mass flow meters with points 1.6.3.3 to 1.6.3.9 shall be verified no longer than one year before the actual test.

1.6.3.3 Accuracy

The accuracy, defined as the deviation of the EFM reading from the reference flow value, shall not exceed ± 2.5 % of the reading, 1.5 % of full scale or ± 2.0 % of the maximum flow at which the EFM has been calibrated, whichever is larger.

1.6.3.4 Precision

The precision, defined as 2.5 times the standard deviation of 10 repetitive responses to a given nominal flow, approximately in the middle of the calibration range, shall not exceed 1 % of the maximum flow at which the EFM has been calibrated.

1.6.3.5 Noise

The noise, defined as two times the root mean square of ten standard deviations, each calculated from the zero responses measured at a constant recording frequency of at least 1.0 Hz during a period of 30 seconds, shall not exceed 2 % of the maximum calibrated flow value. Each of the 10 measurement periods shall be interspersed with an interval of 30 seconds in which the EFM is exposed to the maximum calibrated flow.

1.6.3.6 Zero response drift

The zero response drift is defined as the mean response to zero flow during a time interval of at least 30 seconds. The zero response drift can be verified based on the reported primary signals, e.g., pressure. The drift of the primary signals over a period of 4 hours shall be less than ± 2 % of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

1.6.3.7 Span response drift

The span response drift is defined as the mean response to a span flow during a time interval of at least 30 seconds. The span response drift can be verified based on the reported primary signals, e.g., pressure. The drift of the primary signals over a period of 4 hours shall be less than ± 2 % of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

1.6.3.8 Rise time

The rise time of the exhaust flow instruments and methods should match as far as possible the rise time of the gas analysers but shall not exceed 1 second.

1.6.3.9 Response time check

The response time of exhaust mass flow meters shall be determined by applying similar parameters as those applied for the emissions test (i.e., pressure, flow rates, filter settings and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the exhaust mass flow meter. The gas flow switching shall be done as fast as possible, but highly recommended in less than 0.1 second. The gas flow rate used for the test shall cause a flow rate change of at least 60 % full scale of the exhaust mass flow meter. The gas flow shall be recorded. The delay time is defined as the time from the gas flow switching (t_0) until the response is 10 % (t_{10}) of the final reading. The rise time is defined as the time between 10 % and 90 % response ($t_{90} – t_{10}$) of the final reading. The response time (t_{90}) is defined as the sum of the delay time and the rise time. The exhaust mass flow meter response time (t_{90}) shall be ≤ 3 seconds with a rise time ($t_{90} – t_{10}$) of ≤ 1 second in accordance with point 1.6.3.8.

1.6.4 Measurement of dilution air and diluted exhaust

A diluted exhaust flow meter may be used to determine instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval. The difference between a diluted exhaust flow meter and a dilution air meter may be used to calculate undiluted exhaust flow rates or total undiluted exhaust flow over a test interval.

For any type of diluted exhaust flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

The diluted exhaust may be cooled upstream of a dilute-exhaust flow meter, as long as all the following provisions are observed:

- PM should not be sampled downstream of the cooling.
- If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, NMHC should not be sampled downstream of the cooling for compression-ignition engines, two-stroke spark-ignition engines, or four-stroke spark-ignition engines at or below 19 kW.
- The cooling must not cause aqueous condensation.

1.6.4.1 For constant-volume sampling (CVS) of the total flow of diluted exhaust, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM) may be used. Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller in a CVS system. However, any flow meter with any active flow control system may be combined to maintain proportional sampling of exhaust constituents. The total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls may be controlled to maintain proportional sampling.

CVS flow meter should be calibrated using a reference flow meter such as a subsonic venturi flow meter, a long-radius ASME/NIST flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow meter. This reference flow meter's response to flow should be used as the reference value for CVS flow-meter calibration.

For any other dilution system, a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer may be used.

1.6.5 Time alignment of exhaust flow recordings

To facilitate time alignment, it is recommended to record the parameters that are subject to time alignment either by a single data recording device or with a synchronised time stamp. Before and directly after engine start, it shall be confirmed that all necessary parameters are recorded by the data logger.

The exhaust flow values must be time aligned with a reference fictive raw exhaust in-situ emission measuring point at end of pipe for both diluted and undiluted exhaust emission measurement types. This reference point should be the same as for N_2O or NH_3 measurement alignment. For that purpose, the exhaust flow meter's transformation time must be considered. Good engineering judgment should be used to time align flow and concentration data to match transformation time, t_{50}, to within ±1 s. Special attention is to be paid to time alignment, when the undiluted exhaust flow is determined from the diluted exhaust flow and dilution air flow. The usage of a tracing method for time alignment is advisable.

The exhaust mass flow rate measured with an exhaust flow meter shall be time corrected by reverse shifting according to the transformation time of the exhaust mass flow meter.

$$q_{m,c}\left(t - \Delta t_{t,m}\right) = q_{m,r}(t) \qquad \textit{Equation 3}$$

where:

$q_{m,c}$ is the time-corrected exhaust mass flow rate as function of time t

$q_{m,r}$ is the raw exhaust mass flow rate as function of time t

$\Delta t_{t,m}$ is the transformation time t of the exhaust mass flow meter

1.7 Calculating the mass emissions of gaseous components

1.7.1 Calculation method with the exhaust flow in mass per time unit

The instantaneous mass emissions [mg/s] shall be determined by multiplying the instantaneous concentration of the pollutant under consideration [ppm] with the instantaneous exhaust mass flow rate [kg/s], both corrected and aligned for the transformation time, and the respective u value of *Table 2*. If measured on a dry basis, the dry-wet correction according to point "Dry-wet correction" of the GNT_PEMS+ procedure shall be applied to the instantaneous component concentrations before executing any further calculations. If occurring, negative instantaneous emission values shall enter all subsequent data evaluations. Parameter values shall enter the calculation of instantaneous emissions [mg/s] as reported by the analyser, flow-measuring instrument, sensor or the ECU.

The following equation shall be applied when the exhaust flow is known in mass units:

$$m_{gas,i} = u_{gas} * c_{gas,i} * q_{mew,i} \qquad \textit{Equation 4}$$

where:

$m_{gas,i}$ is the mass of the exhaust component 'gas', [g/s]

u_{gas} is the ratio of the density of the exhaust component 'gas' and the overall density of the exhaust as listed in *Table 2*

$c_{gas,i}$ is the measured concentration of the exhaust component 'gas' in the exhaust, [ppm]

$q_{mew,i}$ is the measured exhaust mass flow rate, [kg/s]

gas is the respective component

i number of the measurement

Table 2: Raw exhaust gas u values depicting the ratio between the densities of exhaust component or pollutant i [kg/m^3] and the density of the exhaust gas [kg/m^3](6)

Fuel	ρ_e [kg/m^3]	Component or pollutant i	Component or pollutant i
		N_2O	NH_3
		ρ_{gas} [kg/m^3]	ρ_{gas} [kg/m^3]
		1.964	0.772
		u_{gas} (2,6)	u_{gas} (2,6)
Diesel (B7)	1.2943	0.001517	0.000596
Ethanol (ED95)	1.2768	0.001538	0.000605
CNG(3)	1.2661	0.001551	0.000610
Propane	1.2805	0.001533	0.000603
Butane	1.2832	0.001533	0.000602
LPG(5)	1.2811	0.001533	0.000603
Petrol (E10)	1.2931	0.001518	0.000597
Ethanol (E85)	1.2797	0.001534	0.000603

(2) at $\lambda = 2$, dry air, 273 K, 101.3 kPa

(3) u values accurate within 0.2 % for mass composition of: C=66-76 %; H=22-25 %; N=0-12 %

(5) u accurate within 0.2 % for mass composition of: C 3 =70-90 %; C 4 =10-30 %

(6) u_{gas} is a unitless parameter; the u_{gas} values include unit conversions to ensure that the instantaneous emissions are obtained in the specified physical unit, i.e., g/s

1.7.2 Calculation method with the exhaust flow in volume per time unit

In the cases where the exhaust flow is expressed in volume units per time unit (e.g. [l/s] or [m^3/h]), it is recommended to convert the measured exhaust volume flow to standard conditions by using following equation:

$$\dot{V}_n = \frac{p}{p_0} * \frac{T_0}{T} * \dot{V}_B \qquad \text{Equation 5}$$

where:

V_n	volumetric flow under standard conditions (0 °C and 101.325 kPa)
V_B	measured volumetric flow
p	measured pressure
p_0	standard pressure
T	measured temperature
T_0	standard temperature

The mass emissions of the N_2O or NH_3 pollutant are then to be calculated as follows:

$$\dot{m}_{gas}\left[\frac{g}{s}\right] = c_{gas}[ppm] * \frac{\dot{V}_n}{3600}\left[\frac{m^3}{h}\right] * \rho_{gas,N}\left[\frac{g}{m^3}\right] \qquad \textit{Equation 6}$$

where:

$\dot{m}_{gas}$	mass flow of N_2O or NH_3
c_{gas}	measured N_2O or NH_3concentration
$\rho_{gas,N}$	N_2O or NH_3 density at standard conditions

1.8 Determination of average N_2O or NH_3 concentration in ppm/test$_{phase}$ and ppm/test

Besides the determination of emissions as shown in *Point 1.7*, the N_2O or NH_3 emissions are also to be expressed in average N_2O or NH_3 emission concentration per test phase in ppm/test$_{phase}$.

The average concentration of N_2O or NH_3 (ppm/test$_{phase}$) shall be calculated using one of the following equations, depending on the character of the measurement:

$$C_{\text{gas mean phase}} = \frac{1}{n_{phase}} \sum_{i=n_{phase\_start}}^{i=n_{phase\_end}} C_{\text{gas}_i} \qquad \textit{Equation 7}$$

where:

C_{gas}	is the instantaneous N_2O or NH_3 concentration, ppm;
n	is the number of measurements in the respective test phase.
n_{phase_start}	is the measurement number at the start of the respective phase
$n_{phase\ end}$	is the measurement number at the end of the respective phase

or

$$C_{gas\ mean\ phase} = \frac{\int_{t_{1_{phase}}}^{t_{2_{phase}}} C_{\text{gas}}\, dt}{t_{2_{phase}} - t_{1_{phase}}} \qquad \textit{Equation 8}$$

where:

$\int_{t_{1_{\text{phase}}}}^{t_{2_{\text{phase}}}} C_{gas}\, dt$ is the integral of the recording of the continuous N_2O and NH_3 analyser over the test phase duration (t_{2phase} - t_{1phase})

C_{gas} is the instantaneous N_2O or NH_3 concentration [ppm]

The test average N_2O or NH_3 emissions in ppm/test are calculated as follows:

$$C_{gas\ mean\ test} = \frac{1}{n}\sum_{i=1}^{i=n} C_{\mathrm{gas}_i} \qquad \textit{Equation 9}$$

where:

C_{gas} is the instantaneous N_2O or NH_3 concentration [ppm]

n is the number of measurements during the entire test.

or

$$C_{\mathrm{gas\ mean\ test}} = \frac{\int_{t_1}^{t_2} C_{gas}\, dt}{t_2 - t_1} \qquad \textit{Equation 10}$$

where:

$\int_{t_1}^{t_2} C_{gas}\, dt$ is the integral of the recording of the continuous N_2O and NH_3 analyser over the entire test duration (t_2 - t_1)

C_{gas} is the instantaneous N_2O or NH_3 concentration [ppm]