Principle of Ship Emission Calculation based on STEAM (Jalkanen, 2009, 2012, 2014)

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November 11, 2025

1 Emission Calculation Formula

Using a bottom-up approach, the total emissions for a given pollutant i from a vessel operating at a given actual speed v_a are calculated as follows:

$$E_i = \sum_j \alpha_j \times P_j \times LF_j \times T \times EF_{i,j} \times AF_{i,j} \times 10^{-3} \tag{1}$$

where the variables are defined as:

- E_i: Total emission of pollutant i (in kg).
- i: Pollutant type, including CO_2, SO_2, NO_x, Particulate Matter (PM), and CO.
- j: Engine type, which can be Main Engine (ME) or Auxiliary Engine (AE).
- α_j: The number of engines of type j.
- P_j: The rated power of an engine of type j (in kW).
- LF_j: The load factor of an engine of type j.
- T: The travel time (in hours).
- $EF_{i,j}$: The emission factor for pollutant i from engine type j (in g/kWh), given in **Table 1**.
- $AF_{i,j}$: The low-load correction coefficient for pollutant i from engine type j.

2 Load Factor (LF_j)

The load factor is determined differently for main and auxiliary engines.

2.1 Main Engine (ME)

For the main engine, the load factor is given by the cube of the ratio of the ship's actual speed (v_a) to its maximum design speed ($v_{a,max}$):

$$LF_{ME} = \left(\frac{v_a}{v_{a,max}}\right)^3 \tag{2}$$

2.2 Auxiliary Engines (AE)

For auxiliary engines, the load factor is assumed to be a constant value based on the ship's operational mode:

$$LF_{AE} = \begin{cases} 0.13, & \text{during navigation} \\ 0.17, & \text{during docking or other operations} \end{cases} \tag{3}$$

3 Low-Load Correction Factor ($AF_{i,j}$)

Emissions can exhibit non-monotonic behavior at low engine loads. A correction factor, $AF_{i,j}$, is applied to account for this phenomenon, particularly when the engine load drops below 20%, at which point fuel consumption increases disproportionately.

- **For Main Engines (ME):** When $LF_{ME} < 20\%$, the value of $AF_{i,ME}$ for pollutants $i \in \{\mathrm{NO}_x, \mathrm{CO}, \mathrm{PM}, \mathrm{SO}_2, \mathrm{CO}_2\}$ is given in **Table 2** of the source document. Otherwise, $AF_{i,ME} = 1$.
- **For Auxiliary Engines (AE):** For simplicity, the correction factor is always set to one, i.e., $AF_{i,AE} = 1$ for all pollutants (U.S. Environmental Protection Agency, 2009).

4 Tables and References

Table 1: Baseline emissions factors (IMO, 2010)

Emission Species	Engine Speed or Type	EF Equation	Main EF (g/kWh)	Main EF (g/fuel)	Main EF (kg/tonne)	Aux EF (g/kWh)	Aux EF (g/fuel)	Aux EF (kg/tonne)	Reference
CO_2	Slow	1	195	607	3,114	N/A	N/A	N/A	MEPC 63/23, Annex 8
	Medium	1	215	670	3,114	227	707	3,114	MEPC 63/23, Annex 8
	High	1	N/A	N/A	N/A	227	707	3,114	MEPC 63/23, Annex 8
	LNG (Otto)	1	166	457	2,750	166	457	2,750	MEPC 63/23, Annex 8
	Gas Turbine	1	305	950	3,114	N/A	N/A	N/A	MEPC 63/23, Annex 8
	Steam	1	305	950	3,114	N/A	N/A	N/A	MEPC 63/23, Annex 8
NO_x	T0 Slow	N/A	195	18.1	0.093	N/A	N/A	N/A	ENTEC 2002
	T0 Medium	2	215	14.0	0.065	227	14.7	64.76	ENTEC 2002
	T0 High	N/A	N/A	N/A	N/A	227	11.6	51.10	ENTEC 2002
	TI Slow	3	195	17.0	0.09	N/A	N/A	N/A	IMO Standard
	TI Medium	3	215	13.0	0.06047	227	13.0	57.27	IMO Standard
	TI High	N/A	N/A	N/A	N/A	227	10.4	45.81	IMO Standard
	TII Slow	N/A	195	15.3	0.07846	N/A	N/A	N/A	IMO Standard
	TII Medium	N/A	215	11.2	0.05209	227	11.2	49.34	IMO Standard
	TII High	N/A	N/A	N/A	N/A	227	8.2	36.12	IMO Standard
	LNG (Otto)	N/A	166	1.3	0.00783	166	1.3	7.83	Kristensen 2012
	Gas Turbine	N/A	305	6.1	0.020	N/A	N/A	N/A	IVL 2004
	Steam	N/A	305	2.1	0.00689	N/A	N/A	N/A	IVL 2004
SO_2	Slow	4	195	10.29	0.053	N/A	N/A	N/A	Mass balance
	Medium	4	215	11.35	0.053	227	11.98	52.78	Mass balance
	High	4	N/A	N/A	N/A	227	11.98	52.78	Mass balance
	LNG (Otto)	N/A	166	0.00269	0.00002	166	0.00269	0.02	Kunz & Gosee 2013
	Gas Turbine	4	305	16.10	0.053	N/A	N/A	N/A	Mass balance
	Steam	4	305	16.10	0.053	N/A	N/A	N/A	Mass balance
PM	Slow	5	195	1.42	0.00728	N/A	N/A	N/A	USEPA 2007
	Medium	5	215	1.43	0.00665	227	1.44	6.34	USEPA 2007
	High	5	N/A	N/A	N/A	227	1.44	6.34	USEPA 2007
	LNG (Otto)	N/A	166	0.03	0.00018	166	0.03	0.180	Kristensen 2012
	Gas Turbine	N/A	305	0.06	0.00020	N/A	N/A	N/A	IVL 2004
	Steam	N/A	305	0.93	0.00305	N/A	N/A	N/A	IVL 2004

Table 1 – continued from previous page

Emission Species	Engine Speed or Type	EF Equation	Main EF (g/kWh)	Main EF (g/fuel)	Main EF (kg/tonne)	Aux EF (g/kWh)	Aux EF (g/fuel)	Aux EF (kg/tonne)	Reference
CO	Slow	N/A	195	0.54	0.0028	N/A	N/A	N/A	Sarvi et al 2008
	Medium	N/A	215	0.54	0.0025	227	0.54	2.38	Sarvi et al 2008
	High	N/A	N/A	1.3	N/A	227	0.54	2.38	Sarvi et al 2008
	LNG (Otto)	N/A	166	1.30	0.00783	166	1.30	7.83	Kristensen 2012
	Gas Turbine	N/A	305	0.10	0.00033	N/A	N/A	N/A	IVL 2004
	Steam	N/A	305	0.20	0.00066	N/A	N/A	N/A	IVL 2004
CH_4	Slow	6	195	0.012	0.00006	N/A	N/A	N/A	IVL 2004
	Medium	6	215	0.01	0.00005	227	0.008	0.04	IVL 2004
	High	6	N/A	N/A	N/A	227	0.008	0.04	IVL 2004
	LNG (Otto)	N/A	166	8.50	0.0512	166	8.50	51.2	MARINTEK 2010
	Gas Turbine	6	305	0.002	0.00001	N/A	N/A	N/A	IVL 2004
	Steam	6	305	0.002	0.00001	N/A	N/A	N/A	IVL 2004
N_2O	Slow	7	195	0.031	0.00016	N/A	N/A	N/A	USEPA 2014
	Medium	7	215	0.034	0.00016	227	0.036	0.16	USEPA 2014
	High	7	N/A	N/A	N/A	227	0.036	0.16	USEPA 2014
	LNG (Otto)	7	166	0.018	0.00011	166	0.018	0.11	Kunz & Gosee 2013
	Gas Turbine	7	305	0.049	0.00016	N/A	N/A	N/A	USEPA 2014
	Steam	7	305	0.049	0.00016	N/A	N/A	N/A	USEPA 2014
NMVOC	Slow	N/A	195	0.60	0.00308	N/A	N/A	N/A	ENTEC 2002
	Medium	N/A	215	0.50	0.00235	227	0.40	1.76	ENTEC 2002
	High	N/A	N/A	0.5	N/A	227	0.40	1.76	ENTEC 2002
	LNG (Otto)	N/A	166	0.50	0.00301	166	0.50	3.01	Kristensen 2012
	Gas Turbine	N/A	305	0.10	0.00033	N/A	N/A	N/A	ENTEC 2002
	Steam	N/A	305	0.10	0.00033	N/A	N/A	N/A	ENTEC 2002

Table 2: Calculated Low Load Multiplicative Adjustment Factors (EPA, 2009)

Load (%)	**NO_x**	**HC**	**CO**	**PM**	**SO_2**	**CO_2**
1	11.47	59.28	19.32	19.17	5.99	5.82
2	4.63	21.18	9.68	7.29	3.36	3.28
3	2.92	11.68	6.46	4.33	2.49	2.44
4	2.21	7.71	4.86	3.09	2.05	2.01
5	1.83	5.61	3.89	2.44	1.79	1.76
6	1.60	4.35	3.25	2.04	1.61	1.59
7	1.45	3.52	2.79	1.79	1.49	1.47
8	1.35	2.95	2.45	1.61	1.39	1.38
9	1.27	2.52	2.18	1.48	1.32	1.31
10	1.22	2.20	1.96	1.38	1.26	1.25
11	1.17	1.96	1.79	1.30	1.21	1.21
12	1.14	1.76	1.64	1.24	1.18	1.17
13	1.11	1.60	1.52	1.19	1.14	1.14
14	1.08	1.47	1.41	1.15	1.11	1.11
15	1.06	1.36	1.32	1.11	1.09	1.08
16	1.05	1.26	1.24	1.08	1.07	1.06
17	1.03	1.18	1.17	1.06	1.05	1.04
18	1.02	1.11	1.11	1.04	1.03	1.03
19	1.01	1.05	1.05	1.02	1.01	1.01
20	1.00	1.00	1.00	1.00	1.00	1.00

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