

Pocket Formula Guide



combustion and energy systems

The SAACKE Group: Quality and Progress in Combustion Engineering

At SAACKE we combine series production and customised engineering to design and manufacture firing plants to customer specifications for industrial and marine applications. SAACKE products satisfy not only the demands of the industry but strict ecological standards as well.

The SAACKE Group encompasses affiliates, production facilities, after-sales service centres and associated companies worldwide.

Day by day, about a thousand employees devote themselves to making the best possible use of the world's energy and protecting our environment in the process.

This SAACKE Pocket Formula Guide is a collection of indispensable formulas, calculation bases and standards from the field of combustion engineering.

It cannot substitute individual, customer-specific calculations – but it does offer a basic tool for making rough calculations and collecting the key data to start with. The current issue has been reviewed thoroughly and new material has been added. We welcome any suggestions for improving the quality of our Pocket Formula Guide. Please feel free to contact us at the address on the back.

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General Formulae and Conversions

1.1 Decimal Powers

Prefix	Decimal Power	Symbol
peta	10^{15}	P
tera	10^{12}	T
giga	10^9	G
mega	10^6	M
kilo	10^3	k
hecto	10^2	h
deca	10	da
deci	10^{-1}	d
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ
nano	10^{-9}	n
pico	10^{-12}	p
femto	10^{-15}	f
atto	10^{-18}	a

1.2 Conversion Formulae

1.2.1 Heating Values

$$1 \frac{\text{kWh}}{\text{kg}} = 3600 \cdot \frac{\text{kJ}}{\text{kg}}$$

$$1 \frac{\text{kcal}}{\text{kg}} = 4.187 \cdot \frac{\text{kJ}}{\text{kg}}$$

$$1 \frac{\text{kcal}}{\text{kg}} = 0.001163 \cdot \frac{\text{kWh}}{\text{kg}}$$

Also applies for heating values given per normal cubic meter.

1.2.2 Temperatures

Conversion of temperature scales to Celsius (°C) and Fahrenheit (°F)

$$^{\circ}\text{C} \leftarrow \frac{5}{9} \cdot (^{\circ}\text{F} - 32)$$

$$^{\circ}\text{F} \leftarrow 1.8 \cdot ^{\circ}\text{C} + 32$$

$$0^{\circ}\text{C} = 32^{\circ}\text{F}$$

$$100^{\circ}\text{C} = 212^{\circ}\text{F}$$

1.3 Conversion Tables

1.3.1 Mass

		out				
		kg	mg	t	lb	tn l.
in	kg	1	$1 \cdot 10^6$	$1 \cdot 10^{-3}$	2.2	$9.84 \cdot 10^{-4}$
	mg	$1 \cdot 10^{-6}$	1	$1 \cdot 10^{-9}$	$2.2 \cdot 10^{-6}$	$9.84 \cdot 10^{-10}$
	t	1,000	$1 \cdot 10^9$	1	2,204.6	0.984
	lb	0.454	$4.53 \cdot 10^5$	$4.53 \cdot 10^{-4}$	1	$4.46 \cdot 10^{-4}$
	tn l.	1,016.05	$1.016 \cdot 10^9$	1.016	2,240	1

lb = pound
tn l. = long ton

t = metric ton

1.3.2 Force

		out				
		N	kN	daN	kp	lbf
in	N	1	$1 \cdot 10^{-3}$	0.1	0.102	0.225
	kN	1,000	1	100	102	225
	daN	10	0.01	1	1.02	2.25
	kp	9.81	$9.81 \cdot 10^{-3}$	0.981	1	2.205
	lbf	4.448	$4.45 \cdot 10^{-3}$	0.445	0.456	1

lbf = pound-force

1.3.3 Pressure

		out				
		Pa	bar	mbar	mm WC	psi
in	Pa	1	$1 \cdot 10^{-5}$	0.01	0.102	$1.45 \cdot 10^{-4}$
	bar	$1 \cdot 10^5$	1	$1 \cdot 10^3$	$1.02 \cdot 10^4$	14.5
	mbar	100	$1 \cdot 10^{-3}$	1	10.2	$1.45 \cdot 10^{-2}$
	mm WC	9.81	$9.81 \cdot 10^{-5}$	$9.81 \cdot 10^{-2}$	1	$1.45 \cdot 10^{-3}$
	psi	6,894	$6.89 \cdot 10^{-2}$	68.9	703.5	1

psi = pound-force per square inch

1.3.4 Energy, work

		out				
		kJ	kWh	kcal	PSh	BTU
in	kJ	1	$2.778 \cdot 10^{-4}$	0.239	$3.776 \cdot 10^{-4}$	0.948
	kWh	3,600	1	860	1.36	$3.412 \cdot 10^3$
	kcal	4.184	$1.163 \cdot 10^{-3}$	1	$1.58 \cdot 10^{-3}$	3.97
	PSh	$2.65 \cdot 10^3$	0.74	632	1	$2.51 \cdot 10^3$
	BTU	1.055	$0.293 \cdot 10^{-3}$	0.252	$0.398 \cdot 10^{-3}$	1

BTU = British Thermal Unit 1 PSh = 1 hph (metric) = 0.986 hph (mechanical)

1.3.5 Capacity

		out				
		kW	MW	kcal/h	PS	BTU/h
in	kW	1	$1 \cdot 10^{-3}$	860	1.36	$3.412 \cdot 10^3$
	MW	1,000	1	$8.6 \cdot 10^5$	1,360	$3.412 \cdot 10^6$
	kcal/h	$1.16 \cdot 10^{-3}$	$1.16 \cdot 10^{-6}$	1	$1.57 \cdot 10^{-3}$	3.97
	PS	0.736	$7.36 \cdot 10^{-4}$	632	1	$2.51 \cdot 10^3$
	BTU/h	$0.293 \cdot 10^{-3}$	$0.293 \cdot 10^{-6}$	0.252	$0.398 \cdot 10^{-3}$	1

1 PS = 1 hp (metric) = 0.986 hp (mechanical)

1.3.6 Energy Units

		out			
		MWh	GJ	Gcal	tce
in	MWh	1	3.6	0.8598	0.1228
	GJ	0.2778	1	0.2388	0.03411
	Gcal	1.163	4.187	1	0.1429
	tce	8.141	29.31	7	1

tce = tons of coal equivalent

1.3.7 Specific Energy Costs

		out				
		€ ct/kWh	€/MWh	€/GJ	€/Gcal	€/tce
in	€ ct/kWh	1	10	2.778	11.63	81.41
	€/MWh	0.1	1	0.2778	1.163	8.141
	€/GJ	0.36	3.6	1	4.187	29.31
	€/Gcal	0.08598	0.8598	0.2388	1	7
	€/tce	0.01228	0.1228	0.03411	0.1429	1

1.4 Air Pressure, Density and Temperature (Standard Atmosphere) Based on the International Altitude Formula

Values of the Standard Atmosphere			
Altitude m amsl	Pressure mbar	Density kg/m ³	Temperature °C
0	1,013	1.226	15.0
250	983	1.196	13.4
500	955	1.168	11.8
1,000	899	1.112	8.5
1,500	846	1.058	5.3

Values at Definite Temperatures				
Altitude m amsl	Pressure mbar	Density		
		at 10 °C kg/m ³	at 25 °C kg/m ³	at 40 °C kg/m ³
0	1,013	1.25	1.18	1.13
250	983	1.21	1.15	1.09
500	955	1.17	1.11	1.06
1,000	899	1.1	1.05	1
1,500	846	1.03	0.98	0.93

Standard density of air / non-standard calculation basis

$\rho_{\text{std}} = 1.293 \text{ kg/m}^3$ is the **standard density** at 0 °C and 1013 mbar abs.

$\rho = 1.15 \text{ kg/m}^3$ is the air density that SAACKE uses for selection charts and capacity data for industrial plants. It is based on 250 m amsl at 25 °C.

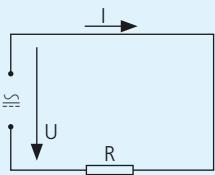
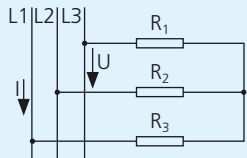
$\rho = 1.2 \text{ kg/m}^3$ is the air density fan manufacturers usually base their ratings on. It is based on 0 m amsl at 20 °C.

1.5 Conversion Table of Anglo-American Units

Length	1 inch, in = 25.4 mm 1 foot, ft = 12 in = 0.3048 m 1 yard (yd) = 3 ft = 0.9144 m	1 mm = 0.03937 in 1 m = 3.281 ft 1 m = 1.094 yd
Area	1 square inch (sq.in, in ²) = 6.452 cm ² 1 square foot (sq.ft, ft ²) = 144 in ² = 0.0929 m ² 1 square yard (sq.yd, yd ²) = 9 ft ² = 0.8361 m ² 1 square mile (sq.mile, mile ²) = 640 acres = 2.59 km ²	1 cm ² = 0.155 in ² 1 m ² = 10.764 ft ² 1 m ² = 1.196 yd ² 1 km ² = 0.386 mile ²
Volume flow rate	1 ft ³ /s = 102 m ³ /h 1 ft ³ /min. = 1.699 m ³ /h United Kingdom 1 Imp.gal/min (Imp.gpm) = 0.0758 l/s = 0.273 m ³ /h U.S. 1 U.S.gal/min (U.S.gpm) = 0.063 l/s = 0.227 m ³ /h	1 m ³ /h = 0.00981 ft ³ /s 1 m ³ /h = 0.5886 ft ³ /min 1 m ³ /h = 3.66 Imp.gal/min 1 m ³ /h = 4.40 U.S.gal/min
Mass flow rate	1 lb/s = 0.4536 kg/s = 1.633 t/h 1 short ton/h (tn.sh./h) = 907.2 kg/h 1 long ton/h (tn.l./h) = 1,016 kg/h	1 t/h = 0.6124 lb/s 1 kg/s = 2.2046 lb/s 1 kg/h = 1.102 · 10 ⁻³ tn.sh./h 1 kg/h = 0.984 · 10 ⁻³ tn.l./h
Force	1 pound-force (lbf) = 4.4482 N 1 ton-force (long) = 2,240 lbf = 9.964 kN	1 N = 0.2248 lbf 1 kN = 224.8 lbf 1 MN = 100.4 ton-force (long)
Pressure	1 lbf/in ² (psi) = 6,895 Pa = 0.06895 bar 1 lbf/ft ² (psf) = 47.88 Pa = 0.04788 kPa 1 inch of mercury (in. Hg) = 3,386 Pa 1 inch of water (in. H ₂ O) = 249.1 Pa	1 bar = 14.5 lbf/in ² 1 kPa = 20.89 lbf/ft ² 1 kPa = 0.2953 in. Hg 1 kPa = 4.015 in. H ₂ O

1.6 Electric Power

1.6.1 Direct Current and Non-Inductive Alternating or Three-Phase Current

Direct or alternating current 	Power with direct or alternating current <table border="1"><tr><td>$P = U \cdot I$</td></tr><tr><td>$P = I^2 \cdot R$</td></tr><tr><td>$P = \frac{U^2}{R}$</td></tr></table>	$P = U \cdot I$	$P = I^2 \cdot R$	$P = \frac{U^2}{R}$
$P = U \cdot I$				
$P = I^2 \cdot R$				
$P = \frac{U^2}{R}$				
Three-phase current 	Power with three-phase current <table border="1"><tr><td>$P = \sqrt{3} \cdot U \cdot I$</td></tr></table>	$P = \sqrt{3} \cdot U \cdot I$		
$P = \sqrt{3} \cdot U \cdot I$				

P = power

U = voltage (line-to-line voltage)

I = amperage

R = resistance

1. Example:

light bulb, U = 6 V; I = 5 A; P = ?; R = ?

$$P = U \cdot I = 6 \text{ V} \cdot 5 \text{ A} = \mathbf{30 \text{ W}}$$

$$R = \frac{U}{I} = \frac{6 \text{ V}}{5 \text{ A}} = \mathbf{1.2 \Omega}$$

2. Example:

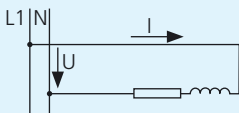
annealing Furnace, three-phase current, U = 400 V; P = 12 kW; I = ?

$$I = \frac{P}{\sqrt{3} \cdot U} = \frac{12,000 \text{ W}}{\sqrt{3} \cdot 400 \text{ V}} = \mathbf{17.3 \text{ A}}$$

Calculation of the star delta connection on page 14

1.6.2 Alternating and Three-Phase Current with Inductive Load

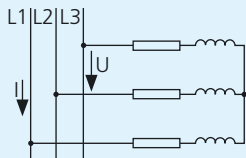
Alternating current



Active power with alternating current

$$P = U \cdot I \cdot \cos\varphi$$

Three-phase current



Active power with three-phase current

$$P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi$$

P = active power

U = voltage (line-to-line voltage)

I = amperage

$\cos\varphi$ = power factor

η = motor efficiency

P_{sh} = mechanical power of the motor (shaft power)

Example:

three-phase motor, $U = 400 \text{ V}$; $I = 21.5 \text{ A}$; $\cos\varphi = 0.85$; $P = ?$

$$\begin{aligned} P &= \sqrt{3} \cdot U \cdot I \cdot \cos\varphi = 1.732 \cdot 400 \text{ V} \cdot 21.5 \text{ A} \cdot 0.85 \\ &= 12,660 \text{ W} \approx \mathbf{12.7 \text{ kW}} \end{aligned}$$

The mechanical power delivered by the motor (shaft power) is less than the active power.

Example:

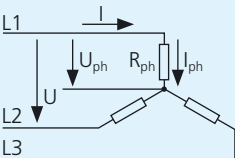
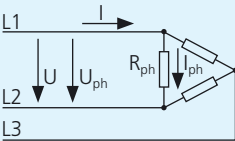
$$P_{sh} = P \cdot \eta$$

$$\eta = 87 \% ; P = 12.7 \text{ kW}$$

$$P_{sh} = 12.7 \text{ kW} \cdot 0.87 = \mathbf{11.0 \text{ kW}}$$

Calculation of the star delta connection on page 14

1.6.3 Star Delta Connection for Three-Phase Alternating Current (Rotary Current)

<p>Star connection Υ $U_{ph} = 230 \text{ V}$</p> 	<p>Star connection Υ Line-to-line current $I = I_{ph}$</p> <p>Line-to-line voltage $U = \sqrt{3} \cdot U_{ph}$</p>
<p>Delta connection Δ $U_{ph} = 400 \text{ V}$</p> 	<p>Delta connection Δ Line-to-line current $I = \sqrt{3} \cdot I_{ph}$</p> <p>Line-to-line voltage $U = U_{ph}$</p>
<p>Star or delta connection Phase current</p> $I_{ph} = \frac{U_{ph}}{R_{ph}}$	<p>Power</p> $P = \sqrt{3} \cdot U \cdot I$ $P = \sqrt{3} \cdot U \cdot I \cdot \cos\varphi$

I = line-to-line current

U = line-to-line voltage

I_{ph} = phase current

U_{ph} = phase voltage

R_{ph} = phase resistance

$\sqrt{3}$ = interlinking factor

P = active power

$\cos\varphi$ = power factor with an inductive load

Example:

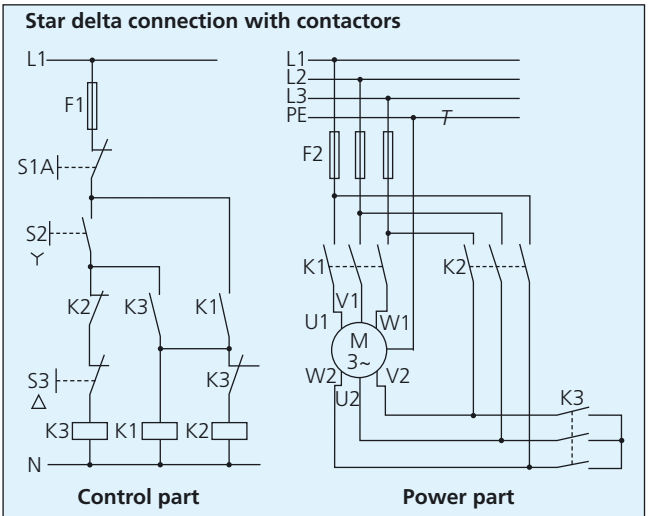
annealing furnace, $R_{ph} = 22 \Omega$; $U = 400 \text{ V}$; $P = ?$ with delta connection

$$I_{ph} = \frac{U_{ph}}{R_{ph}} = \frac{400 \text{ V}}{22 \Omega} = 18.2 \text{ A}$$

$$I = \sqrt{3} \cdot I_{ph} = \sqrt{3} \cdot 18.2 \text{ A} = 31.5 \text{ A}$$

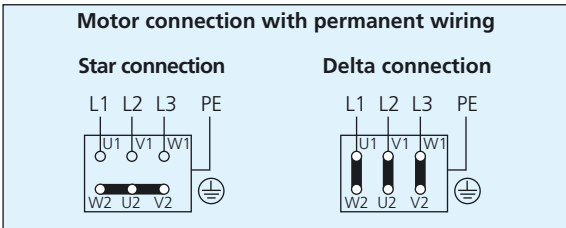
$$P = \sqrt{3} \cdot U \cdot I = \sqrt{3} \cdot 400 \text{ V} \cdot 31.5 \text{ A} = 21,824 \text{ W} = \mathbf{21.8 \text{ kW}}$$


1.6.4 Star Delta Connection of a Three-Phase Motor



K1 network contactor
 K2 delta contactor
 K3 star contactor
 S1A OFF button

S2 star connection button
 S3 delta connection button
 F1 control part fuse
 F2 power part fuse





**Capacities,
Efficiency Rates,
Steam Table**

2.1 Boiler Output - Steam Production

1 t/h saturated steam \cong 0.65 MW boiler output*

**at 12 bar and 102 °C feedwater*

1 kg oil produces approx. 16 kg steam.

1 kg oil or 1 m³ gas produces the following amount of saturated steam in kg:

heating value in kJ/kg or kJ/m³ · efficiency rate in %

234,000

The following amount of oil or gas in kg or m³ is needed to produce 1t saturated steam:

$2.34 \cdot 10^8$

heating value in kJ/kg or kJ/m³ · efficiency rate in %

2.2 Boiler Output, Burner Output and Fuel Consumption Dependent on the Boiler Efficiency Rate

Boiler output, amount of saturated steam produced		Boiler efficiency rate	Burner output	HFO flow rate	EL fuel oil flow rate
t/h	MW	%	MW	kg/h	kg/h
1	0.65	85	0.77	67.5	64.5
1	0.65	88	0.74	65.5	62.5
1	0.65	90	0.72	64.0	61.0
1	0.65	92	0.71	62.5	59.5

2.3 Exact Calculation of the Fuel Consumption Given the Steam Output and the State of the Steam

$$\dot{m}_F \text{ or } \dot{V}_F = \frac{\dot{m}_s \cdot (h - h_{fw}) \cdot 100\%}{\text{LHV} \cdot \eta_b}$$

\dot{m}_F or \dot{V}_F = fuel consumption in kg/h or m³/h

\dot{m}_s = steam output in kg/h

h = enthalpy of the steam in kJ/kg

h_{fw} = enthalpy of the feedwater in kJ/kg

LHV = lower heating value in kJ/kg or kJ/m³

η_b = boiler efficiency rate in %

If the steam output \dot{m}_s cannot be determined, it can be calculated from:

$$\dot{m}_s = \dot{m}_{fw} - \dot{m}_{bd}$$

\dot{m}_{fw} = feedwater flow rate in kg/h

\dot{m}_{bd} = blow-down rate in kg/h

2.4 Boiler Efficiency Rate

$$\eta_b = \frac{(\dot{m}_{fw} - \dot{m}_{bd}) \cdot (h - h_{fw})}{\dot{m}_f \cdot \text{LHV}} \cdot 100 \quad \text{in \%}$$

2.5 Determination of the Boiler Efficiency Rate from the Flue Gas Measurements*

$$\eta_b = 100\% - X_f\% - 2\%_{(\text{max})} \quad \text{in \%}$$

$$X_f = \left(\frac{A}{21 - O_{2,\text{dry}}} + B \right) \cdot (\vartheta_f - \vartheta_a) \quad \text{in \%}$$

X_f = flue gas loss

ϑ_f = flue gas temperature in °C

ϑ_a = combustion air temperature in °C

$O_{2,\text{dry}}$ = O_2 value measured in the dry flue gas in vol. %

A and B: constants

	EL fuel oil	HFO	Nat. gas	Liquid gas	Town gas
A	0.68	0.69	0.66	0.63	0.63
B	0.007	0.007	0.009	0.008	0.011

* Calculation basis: 1st German Immission Control Act (1. BImSchV)

2.6 Parameters of Water and Steam at Saturation Conditions depending on Pressure

Abs. pressure p bar	Temperature ϑ_{sat} °C	Spec. volume		Density steam ρ'' kg/m ³	Spec. enthalpy		Heat of vaporisation r kJ/kg
		water v' m ³ /t	steam v'' m ³ /kg		water h' kJ/kg	steam h'' kJ/kg	
0.2	60.07	1.0172	7.650	0.1307	251.45	2,609.9	2,373.2
0.5	81.35	1.0301	3.240	0.3086	340.56	2,646.0	2,305.4
1.0	99.63	1.0434	1.694	0.5904	417.51	2,675.4	2,257.9
1.5	111.37	1.0530	1.159	0.8628	467.13	2,693.4	2,226.2
2	120.23	1.0608	0.8854	1.129	504.70	2,706.3	2,201.6
3	133.54	1.0712	0.6056	1.651	561.43	2,724.7	2,163.2
4	143.62	1.0839	0.4622	2.163	604.67	2,737.6	2,133.0
5	151.84	1.0928	0.3747	2.669	640.12	2,747.5	2,107.4
6	158.84	1.1001	0.3155	3.170	670.42	2,755.5	2,085.0
7	164.94	1.1082	0.2727	3.667	697.06	2,762.0	2,064.9
8	170.41	1.1150	0.2403	4.162	720.94	2,767.5	2,046.5
9	175.36	1.1213	0.2148	4.655	742.64	2,772.1	2,029.5
10	179.88	1.1274	0.1943	5.147	762.61	2,776.2	2,013.6
12	187.96	1.1386	0.1632	6.127	798.43	2,782.7	1,984.3
14	195.04	1.1489	0.1407	7.106	830.08	2,787.8	1,957.7
16	201.37	1.1586	0.1237	8.085	858.56	2,791.7	1,933.2
18	207.11	1.1678	0.1103	9.065	884.58	2,794.8	1,910.3
20	212.37	1.1766	0.0995	10.05	908.59	2,797.1	1,888.6
22	217.24	1.1850	0.0907	11.03	930.95	2,799.1	1,868.1
24	221.78	1.1932	0.0832	12.02	951.93	2,800.4	1,848.5
26	226.04	1.2011	0.0769	13.01	971.72	2,801.4	1,829.6
28	230.05	1.2088	0.0714	14.01	990.48	2,802.0	1,811.5
30	233.84	1.2136	0.0666	15.03	1,108.4	2,802.2	1,793.9
32	237.45	1.2237	0.0624	16.02	1,025.4	2,802.3	1,776.9
35	242.52	1.2346	0.0571	17.54	1,049.7	2,801.9	1,752.5
40	250.33	1.2521	0.0498	20.10	1,087.4	2,800.3	1,712.9
50	263.91	1.2858	0.0394	25.36	1,154.5	2,794.2	1,639.7
60	275.55	1.3187	0.0324	30.83	1,213.7	2,785.0	1,571.3
80	294.97	1.3842	0.0235	42.51	1,317.1	2,759.9	1,442.8
100	310.96	1.4526	0.0180	55.43	1,408.0	2,727.7	1,319.7

2.7 Parameters of Water and Steam at Saturation Conditions depending on Temperature

Temperature ϑ °C	Abs. pressure p bar	Spec. volume		Density steam ρ'' kg/m ³	Spec. enthalpy		Heat of vapourisation r kJ/kg
		water v' m ³ /t	steam v'' m ³ /kg		water h' kJ/kg	steam h'' kJ/kg	
60	0.1992	1.0171	7.679	0.1302	251.09	2,609.7	2,358.6
65	0.2501	1.0199	6.202	0.1612	272.02	2,618.4	2,346.3
70	0.3116	1.0228	5.046	0.1982	292.97	2,626.9	2,334.0
75	0.3855	1.0259	4,134	0.2419	313.94	2,635.4	2,321.5
80	0.4736	1.0292	3.409	0.2933	334.92	2,643.8	2,308.8
85	0.5780	1.0326	2.829	0.3535	355.92	2,652.0	2,296.5
90	0.7011	1.0361	2.361	0.4235	376.94	2,660.1	2,283.2
95	0.8453	1.0399	1.982	0.5045	397.99	2,668.1	2,270.2
100	1.0133	1.0437	1.673	0.5977	419.06	2,676.0	2,256.9
110	1.4327	1.0519	1.210	0.8265	461.32	2,691.3	2,230.0
120	1.9854	1.0606	0.8915	1.122	503.72	2,706.0	2,202.2
130	2.7013	1.0700	0.6681	1.497	546.31	2,719.9	2,173.6
140	3.614	1.0801	0.5085	1.967	589.10	2,733.1	2,144.0
150	4.760	1.0908	0.3924	2.548	632.15	2,745.4	2,113.2
160	6.181	1.1022	0.3068	3.260	675.47	2,756.7	2,081.3
170	7.920	1.1145	0.2426	4.123	719.12	2,767.1	2,047.9
180	10.027	1.1275	0.1938	5.160	763.12	2,776.3	2,013.1
190	12.551	1.1415	0.1563	6.397	807.52	2,784.3	1,976.7
200	15.549	1.1565	0.1272	7.864	852.37	2,790.9	1,938.6
210	19.077	1.1726	0.1042	9.593	897.74	2,796.2	1,898.5
220	23.198	1.1900	0.0860	11.62	943.67	2,799.9	1,856.2
230	27.976	1.2087	0.0715	14.00	990.26	2,802.0	1,811.7
240	33.478	1.2291	0.0597	16.76	1,037.2	2,802.2	1,764.6
250	39.776	1.2513	0.0500	19.99	1,085.8	2,800.4	1,714.6
260	46.943	1.2756	0.0421	23.73	1,134.9	2,796.4	1,661.5
270	55.058	1.3025	0.0356	28.10	1,185.2	2,789.9	1,604.6
280	64.202	1.3324	0.0301	33.19	1,236.8	2,780.4	1,543.6
290	74.461	1.3659	0.0255	39.16	1,290.0	2,767.6	1,477.6
300	85.927	1.4041	0.02165	46.19	1,345.0	2,751.0	1,406.0
310	98.700	1.4480	0.0183	54.54	1,402.4	2,730.0	1,327.6

2.8 Enthalpy in kJ/kg of Water and Superheated Steam

Abs. pressure bar	Temperature °C						
	200	250	300	350	400	450	500
1	2,875.4	2,974.5	3,074.5	3,175.6	3,278.2	3,382.4	3,488.1
5	2,855.1	2,961.1	3,064.8	3,168.1	3,272.1	3,377.2	3,483.8
10	2,826.8	2,943.0	3,052.1	3,158.5	3,264.4	3,370.8	3,478.3
15	2,791.3	2,921.5	3,037.6	3,147.7	3,255.8	3,363.7	3,472.2
20	852.6	2,902.4	3,025.0	3,138.6	3,248.7	3,357.8	3,467.3
25	852.8	2,879.5	3,010.4	3,128.2	3,240.7	3,351.3	3,461.7
30	853.0	2,854.8	2,995.1	3,117.5	3,232.5	3,344.6	3,456.2
35	853.2	2,828.1	2,979.0	3,106.5	3,224.2	3,338.0	3,450.6
40	853.4	1,085.8	2,962.0	3,095.1	3,215.7	3,331.2	3,445.0
45	853.6	1,085.8	2,944.2	3,083.3	3,207.1	3,324.4	3,439.3
50	853.8	1,085.8	2,925.5	3,071.2	3,198.3	3,317.5	3,433.7
60	854.2	1,085.8	2,885.0	3,045.8	3,180.1	3,303.5	3,422.2
70	854.6	1,085.8	2,839.4	3,018.7	3,161.2	3,289.1	3,410.6
80	855.1	1,085.8	2,786.8	2,989.9	3,141.6	3,274.3	3,398.8
90	855.5	1,085.8	1,344.5	2,959.0	3,121.2	3,259.2	3,386.8
100	855.9	1,085.8	1,343.4	2,925.8	3,099.9	3,243.6	3,374.6
120	856.8	1,085.9	1,341.2	2,849.7	3,054.8	3,211.4	3,349.6
140	857.7	1,086.1	1,339.2	2,754.2	3,005.6	3,177.4	3,323.8
160	858.6	1,086.3	1,337.4	2,620.8	2,951.3	3,141.6	3,297.1
180	859.5	1,086.5	1,335.7	1,659.8	2,890.3	3,104.0	3,269.6
200	860.4	1,086.7	1,334.3	1,647.2	2,820.5	3,064.3	3,241.1
250	862.8	1,087.5	1,331,1	1,625,1	2,582.0	2,954.3	3,165.9
300	865.2	1,088.4	1,328,7	1,610,0	2,161.8	2,825.6	3,085.0
350	867.7	1,089.5	1,326,8	1,598,7	1,993.1	2,676.4	2,998.3
400	870.2	1,090.8	1,325,4	1,589,7	1,934.1	2,515.6	2,906.8
500	875.4	1,093.6	1,323,7	1,576,4	1,877.7	2,293.2	2,723.0
600	880.8	1,096.9	1,323,2	1,567,1	1,847.3	2,187.1	2,570.6
800	891.9	1,104.4	1,324,7	1,555,9	1,814.2	2,094.1	2,397.4

2.9 Enthalpy of Water Below the Boiling State in kJ/kg

Abs. press. bar	Temperature °C													
	100	120	140	160	180	200	220	240	260	280	300	320	340	360
2	419.1	503.7												
5	419.4	503.9	589.2											
10	419.7	504.3	589.5	675.7										
20	420.5	505.0	590.2	676.3	763.6	852.6								
40	422.0	506.4	591.5	677.5	764.6	853.4	944.1	1,037.7						
60	423.5	507.8	592.8	678.6	765.7	854.2	944.7	1,037.9	1,134.7					
80	425.0	509.2	594.1	679.8	766.7	855.1	945.3	1,038.1	1,134.5	1,236.0				
100	426.5	510.6	595.4	681.0	767.8	855.9	945.9	1,038.4	1,134.2	1,235.0	1,343.4			
120	428.0	512.1	596.7	682.2	768.8	856.8	946.6	1,038.7	1,134.1	1,234.1	1,341.2	1,460.8		
140	429.5	513.5	598.0	683.4	769.9	857.7	947.2	1,039.1	1,134.0	1,233.3	1,339.2	1,456.3		
160	431.0	514.9	599.4	684.6	771.0	858.6	947.9	1,039.4	1,133.9	1,232.6	1,337.4	1,452.4	1,588.3	
180	432.5	516.3	600.7	685.9	772.0	859.5	948.6	1,039.8	1,133.9	1,232.0	1,335.7	1,448.8	1,579.7	
200	434.0	517.7	602.0	687.1	773.1	860.4	949.3	1,040.3	1,134.0	1,231.4	1,334.3	1,445.6	1,572.5	1,742.9
220	435.6	519.2	603.4	688.2	774.2	861.4	950.0	1,040.7	1,134.0	1,230.9	1,332.9	1,442.7	1,566.2	1,722.0
240	437.1	520.6	604.7	689.5	775.3	862.3	950.8	1,041.2	1,134.1	1,230.5	1,331.7	1,440.1	1,560.8	1,707.2
260	438.6	522.0	606.0	690.8	776.4	863.3	951.5	1,041.7	1,134.3	1,230.2	1,330.6	1,437.8	1,555.9	1,695.6
280	440.1	523.5	607.4	692.0	777.6	864.2	952.3	1,042.2	1,134.5	1,229.9	1,329.6	1,435.6	1,551.6	1,686.1
300	441.6	524.9	608.7	693.3	778.7	865.2	953.1	1,042.8	1,134.7	1,229.7	1,328.7	1,433.6	1,547.7	1,678.0
400	449.2	532.1	615.5	699.6	784.4	870.2	957.2	1,045.8	1,136.3	1,229.2	1,325.4	1,425.9	1,532.9	1,650.5



Fuels, Combustion- Calculation

3.1 Density of Selected Fuels

1 litre EL fuel oil	≈ 0.84 kg at 15 °C
1 litre HFO	≈ 0.94 kg at 90 °C
1 m ³ type L nat. gas	= 0.83 kg
1 m ³ type H nat. gas	= 0.78 kg
1 m ³ pulverised lignite	= 560 kg*
1 m ³ pulverised bituminous coal	= 600-650 kg*
1 m ³ pulverised wood	= 270-300 kg*
1 m ³ propane (at STP)	= 2.01 kg
1 m ³ butane (at STP)	= 2.71 kg
1 liter animal fat	= 0.91 kg at 15 °C
1 m ³ blast-furnace gas	= 1.36 kg

* bulk density

3.2 Heating Values of Selected Fuels

Fuel	Lower heating value (LHV)					
	kJ/kg	kJ/m ³	kcal/kg	kcal/m ³	kWh/kg	kWh/m ³
EL fuel oil	42,700	–	10,200	–	11.9	–
HFO	40,700	–	9,700	–	11.3	–
Type L natural gas	–	31,800	–	7,600	–	8.83
Type H natural gas	–	36,000	–	8,600	–	10
Pulverised lignite	21,200	–	5,050	–	5.9	–
Pulverised bituminous coal	30,000	–	7,150	–	8.3	–
Pulverised wood	17,500	–	4,180	–	4.8	–
Propane	46,350	93,200	–	22,250	12.9	25.9
Butane	45,700	123,800	–	29,560	12.7	34.4
Animal fat (example)	36,000	–	8,600	–	10.0	–
Blast-furnace gas	–	3,000	–	720	–	0.83

3.3 Wobbe Index

At a constant gas pressure, the Wobbe index is proportional to the amount of heat released at the burner orifice. At the same pressure at the burner, gases with different compositions and the same Wobbe index produce almost the same heat release rate.

Upper / lower Wobbe Index

$$W_s = \frac{HHV}{\sqrt{d}} \quad W_i = \frac{LHV}{\sqrt{d}}$$

d = relative density

ρ_G = density of the gas at standard temperature and pressure

ρ_L = density of the air at standard temperature and pressure (1.293 kg/m³)

$$d = \frac{\rho_G}{\rho_L}$$

3.4 Stoichiometric Air Demand

in m³/kg or m³/m³ (rough calculation)

$$v_{a,st} \approx \frac{2.6 \cdot LHV^*}{10,000} \quad \text{in m}^3 \text{ air / kg or m}^3 \text{ fuel}$$

* in kJ/kg or kJ/m³

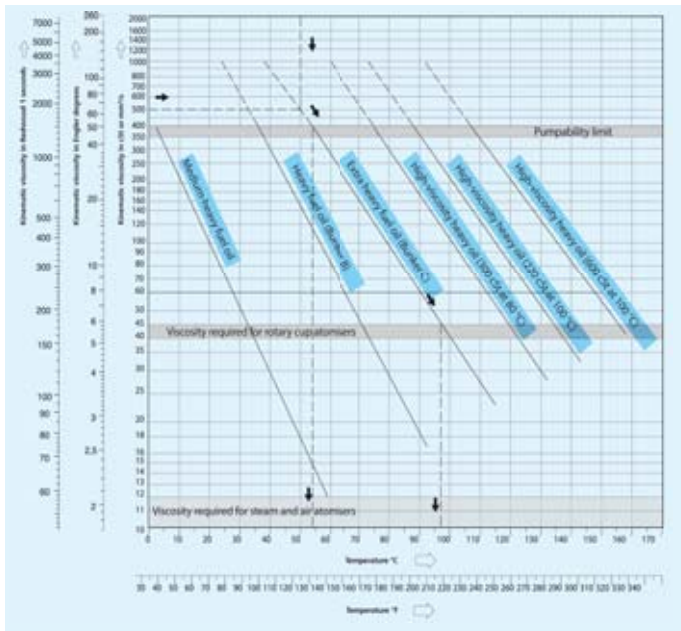
$$v_{a,st} \approx 942 \frac{\text{m}^3/\text{h}}{\text{MW}} \quad \text{or } 0.262 \frac{\text{m}^3/\text{s}}{\text{MW}}$$

3.5 Characteristics of Liquid Fuels

(All values given for the standard physical state)

Characteristic	Symbol	Unit	EL fuel oil	HFO	Methanol	Ethanol	Animal fat (example)
Lower heating value	LHV	MJ/kg	42.7	40.7	19.4	26.5	36.0
Higher heating value	HHV	MJ/kg	45.4	42.5	22.7	29.7	38.6
Density at 15 °C	ρ_{15}	kg/l	0.84	0.96	0.791	0.789	0.91
Flash point	ϑ_{fl}	°C	70	120	–	11	200
Viscosity at 20 °C	ν	mm ² /s	max. 6	–	–	–	90
at 50 °C	ν	mm ² /s	2	max. 50	–	–	max. 40
at 100 °C	ν	mm ² /s	–	30	–	–	8
Combustion values at $\lambda = 1$							
Air demand	v_a	m ³ /kg	11.0	10.7	4.93	6.85	9.56
Flue gas volume (dry)	$v_{f,dry}$	m ³ /kg	10.3	10.0	4.59	6.37	8.97
Flue gas volume (wet)	$v_{f,wet}$	m ³ /kg	11.8	11.4	5.96	7.80	10.32
Water content in the flue gas	v_{H_2O}	m ³ /kg	1.5	1.4	1.30	1.43	1.35
Max. carbon dioxide	CO _{2,max}	vol. %	15.5	15.9	15.2	15.1	15.8
Composition:							
Carbon	C	wt. %	86	84	37.5	52	76
Hydrogen	H	wt. %	13	12	12.5	13	12
Sulphur	S	wt. %	≤ 0.2	≤ 2.8	–	–	0.02
Oxygen	O	wt. %	0.4	0.5	50	35	11
Nitrogen	N	wt. %	0.02	0.3	–	–	0.05
Water	H ₂ O	wt. %	0.4	0.4	–	–	0.93
Total	Σ	wt. %	100	100	100	100	100

3.6 Viscosity-Temperature Diagram



Example:

- The given heavy fuel oil has a kinematic viscosity of 500 cSt at 50 °C
- Temperature required to pump it: >54 °C (using tank preheater)
- Temperature required for a rotary cup burner: >97 °C (using tank preheater)

Conversion of kinematic / dynamic viscosity:

$$v = \frac{\eta}{\rho}$$

Kinematic viscosity (v):

$$1\text{cSt} = \frac{1 \text{ mm}^2}{\text{s}}$$

Dynamic viscosity (η):

$$1\text{cP} = 1\text{mPa} \cdot \text{s}$$

3.7 Characteristics of Various Utility Gases

(All values given for the standard physical state)

Characteristic	Symbol	Unit	Type L nat. gas	Type H nat. gas	Town gas
Lower heating value	LHV	MJ/m ³	31.8	36.0	17.59
Higher heating value	HHV	MJ/m ³	35.2	40.0	19.82
Explosion limits (vol. % gas in air, at 20 °C)					
Lower flammability limit	LFL	vol. %	5	4	5
Upper flammability limit	UFL	vol. %	15	16	30
Density	ρ	kg/m ³	0.829	0.784	0.513
Relative density	d	–	0.641	0.606	0.397
Combustion values at $\lambda = 1$					
Air demand	v_a	m ³ /m ³	8.36	9.47	4.33
Flue gas volume (dry)	$v_{f,dry}$	m ³ /m ³	7.64	8.53	3.91
Flue gas volume (wet)	$v_{f,wet}$	m ³ /m ³	9.36	10.47	4.98
Max. carbon dioxide	CO _{2,max}	vol. %	11.80	12.00	10.03
Water content in the flue gas (in rel. to the fuel gas volume)	H ₂ O _A	m ³ /m ³	1.72	1.94	0.92
Dew point (dry combustion air)	ϑ_d	°C	58	58	62
Composition:					
Nitrogen	N ₂	vol. %	14.0	3.1	9.6
Oxygen	O ₂	vol. %	–	–	–
Carbon dioxide	CO ₂	vol. %	0.8	1.0	2.3
Hydrogen	H ₂	vol. %	–	–	54.5
Carbon monoxide	CO	vol. %	–	–	5.5
Methane	CH ₄	vol. %	81.8	92.3	24.9
Ethane	C ₂ H ₆	vol. %	2.8	2.0	2.5
Propane	C ₃ H ₈	vol. %	0.4	1.0	0.7
Butane	C ₄ H ₁₀	vol. %	0.2	0.6	–
Total	Σ	vol. %	100	100	100

Characteristics of Various Utility Gases

(All values given for the standard physical state)

Characteristic	Symbol	Unit	Sewage gas	Hydrogen H ₂	Methane CH ₄	Propane C ₃ H ₈	Butane C ₄ H ₁₀	Blast-furnace gas (example)	Carbon monoxide CO
Lower heating value	LHV	MJ/m ³	23.0	10.76	35.9	93.2	123.8	2.5 - 3.3	12.64
Higher heating value	HHV	MJ/m ³	25.5	12.74	39.8	101.2	134.0	2.5 - 3.4	12.64
Density	ρ	kg/m ³	1.158	0.090	0.718	2.011	2.708	1.36	1.25
Relative density	d	–	0.896	0.069	0.555	1.555	2.094	1.05	–
Combustion values at λ = 1									
Air demand	v _a	m ³ /m ³	6.12	2.38	9.56	24.37	32.37	0.57	2.39
Flue gas volume (dry)	v _{f,dry}	m ³ /m ³	5.84	1.88	8.55	22.81	29.74	1.43	2.88
Flue gas volume (wet)	v _{f,wet}	m ³ /m ³	7.05	2.83	10.44	26.16	34.66	1.45	–
Max. carbon dioxide	CO _{2,max}	vol. %	16.85	–	11.65	13.7	14.0	28	34.7
Water content in the flue gas (in rel. to the fuel gas volume)	H ₂ O _A	m ³ /m ³	1.28	1.00	2.00	4.09	5.22	0.02	–
Dew point (combustion air dry)	ϑ _d	°C	57	71	58	54	53	–	–
Composition:									
Nitrogen	N ₂	vol. %	1.2	–	–	–	–	58	–
Oxygen	O ₂	vol. %	–	–	–	–	–	–	–
Carbon dioxide	CO ₂	vol. %	34.6	–	–	–	–	18	–
Hydrogen	H ₂	vol. %	0.2	100	–	–	–	2	–
Carbon monoxide	CO	vol. %	–	–	–	–	–	22	100
Methane	CH ₄	vol. %	64.0	–	100	–	–	–	–
Ethane	C ₂ H ₆	vol. %	–	–	–	–	–	–	–
Propane	C ₃ H ₈	vol. %	–	–	–	100	–	–	–
Butane	C ₄ H ₁₀	vol. %	–	–	–	–	100	–	–
Total	Σ	vol. %	100	100	100	100	100	100	100

3.8 Properties of Important Organic Compounds

#	Name	Formula	Molar mass g/mol	Lower flamm. limit LFL		Upper flamm. limit UFL		Flash point ϑ_{fl} °C	Ign. temp. ϑ_{ign} °C	HHV MJ/kg	LHV MJ/kg
				g/m ³ (at STP)	Vol.-%	g/m ³ (at STP)	Vol.-%				
1	Methane	CH ₄	16.04	29	4.4	113	17	–	595	55.54	49.85
2	Ethane	C ₂ H ₆	30.07	31	2.4	182	14.3	–	515	51.91	47.48
3	Propane	C ₃ H ₈	44.1	31	1.7	202	10.8	-104	470	50.38	46.34
4	Hexane	C ₆ H ₁₄	86.18	35	1	319	8.9	-20	230	48.2	44.99
5	Dodecane	C ₁₂ H ₂₆	170.34	40	0.6	–	–	74	200	47.55	44.49
6	Cyclohexane	C ₆ H ₁₂	84.16	35	1	326	9.3	-18	260	46.58	43.83
7	Decahydronaphthalene	C ₁₀ H ₁₈	138.25	50	0.7	280	4.9	54	240	45.48	42.92
8	Ethylene	C ₂ H ₄	28.05	29	2.4	388	32.6	–	440	55.71	52.54
9	Acetylene	C ₂ H ₂	26.04	24	2.3	–	100	–	305	50.23	48.56
10	1,3-Butadiene	C ₄ H ₆	54.09	31	1.4	365	16.3	-85	415	47.87	45.44
11	1-Pentene	C ₅ H ₁₀	70.13	40	1.4	255	8.7	-51	280	48.02	45.19
12	Benzene	C ₆ H ₆	78.11	39	1.2	280	8.6	-11	555	41.93	40.68
13	Naphthalene	C ₁₀ H ₈	128.17	48	0.9	315	5.9	80	540	40.24	39.46
14	Toluene	C ₇ H ₈	92.14	42	1.1	300	7.8	6	535	42.5	41.04
15	o-Xylene	C ₈ H ₁₂	106.17	43	0.97	335	7.6	30	465	43.13	41.45
16	Styrene	C ₈ H ₈	104.1	42	1	334	7.7	32	490	42.07	40.77
17	Gasoline	(mixture)	–	32	0.8	310	8.1	-40	320	47	43.56
18	EL oil	(mixture)	–	–	0.6	–	6.5	>55	220	45.4	42.6
19	Turpentine oil	(mixture)	–	45	0.7	–	6	35	220	–	–
20	Biodiesel (rapeseed methyl ester) (EN 14214)	(C ₁₆ and C ₁₆ -C ₁₈ - unsaturated)	–	–	–	–	–	186	183	40	37.1
21	Rapeseed oil		–	–	–	–	–	317	410	39.6	36.9
22	Palm oil		–	–	–	–	–	220	>250	39.6	36.9
23	Animal fat	(mixture)	–	–	–	–	–	267	–	38.6	36
24	Methanol	CH ₃ OH	32.04	80	6	665	50	9	440	22.69	21.17
25	Ethanol	C ₂ H ₆ O	46.07	–	3.1	–	19	12	400	29.67	27.72
26	1-Propanol	C ₃ H ₇ OH	60.1	52	2.1	480	19.2	15	385	33.37	31.14
27	1-Butanol	C ₄ H ₁₀ O	74.12	52	1.7	350	11.3	35	325	36.05	33.72
28	1-Pentanol	C ₅ H ₁₂ O	88.15	47	1.3	385	10.5	43	320	48.88	45.77
29	Cyclohexanol	C ₆ H ₁₂ O	100.16	62	1.5	460	11.1	61	300	37.22	35.03
30	Phenol	C ₆ H ₆ O	94.11	50	1.3	370	9.5	82	595	32.59	31.9
31	o-Cresol	C ₇ H ₈ O	108.14	58	1.3	–	–	81	555	34.21	33.14
32	1-Naphthol (α-naphthol)	C ₁₀ H ₈ O	144.17	–	–	–	–	125	510	34.44	33.75
33	Methanal (formaldehyde)	CH ₂ O	30.03	87	7	910	73	32-61	424	18.7	17.29
34	Acetaldehyde	C ₂ H ₄ O	44.1	73	4	1040	57	<-20	155	26.5	25.09
35	2-Propenal (acrolein)	C ₃ H ₄ O	56.06	65	2.8	730	31	-29	215	29.37	28.31
36	Acetone	C ₃ H ₆ O	58.08	60	2.5	345	14.3	<-20	535	31.06	29.34

3.8 Properties of Important Organic Compounds

# Name	Formula	Molar mass g/mol	Lower flamm. limit LFL		Upper flamm. limit UFL		Flash point ϑ_{fl} °C	Ign. temp. ϑ_{ign} °C	HHV MJ/kg	LHV MJ/kg
			g/m ³ (at STP)	Vol.-%	g/m ³ (at STP)	Vol.-%				
37 2-Butanone (ethylmethylketone)	C ₄ H ₈ O	72.11	45	1.5	378	12.6	-10	475	33.82	31.94
38 Cyclohexanone	C ₆ H ₁₀ O	98.15	53	1.3	380	9.4	43	430	-	-
39 Diethyl ether	C ₄ H ₁₀ O	74.12	50	1.7	1,100	36	-20	175	36.85	34.23
40 Ethylene oxide	C ₂ H ₄ O	44.05	47	2.6	1,820	100	-57	435	28.71	27.47
41 Tetrahydrofuran	C ₄ H ₈ O	72.11	46	1.5	370	12.4	-20	230	-	-
42 1,4-Dioxane	C ₄ H ₈ O ₂	88.11	70	1.9	820	22.5	11	375	26.68	25.04
43 Ethyl methanoate (ethyl formate)	C ₃ H ₆ O ₂	74.08	80	2.7	500	16.5	-20	455	22.16	20.85
44 Methyl acetate (methyl ethanoate)	C ₃ H ₆ O ₂	74.08	95	3.1	495	16	-13	505	21.54	20.23
45 Ethyl acetate (ethyl ester)	C ₄ H ₈ O ₂	88.11	73	2	470	12.8	-4	470	25.61	24
46 Butyl acetate (n-butyl ester)	C ₆ H ₁₂ O ₂	116.16	58	1,2	360	7,5	27	390	-	-
47 Vinyl acetate (ethenyl acetate)	C ₄ H ₆ O ₂	86.09	93	2,6	480	13,4	-8	385	-	-
48 Formic acid	CH ₂ O ₂	46.03	190	10	865	45,5	45	520	5.72	5.4
49 Acetic acid	C ₂ H ₄ O ₂	60.05	100	4	430	17	40	485	14.4	13.53
50 Acetic anhydride	C ₄ H ₆ O ₃	102.09	85	2	430	10,2	49	330	17.68	16.9
51 Phthalic acid	C ₈ H ₆ O ₄	166.13	-	-	-	-	168	-	18.41	18.93
52 Methylamine	CH ₅ N	31.06	60	4,9	270	20,7	-58	430	34.48	31.81
53 Diethylamine	C ₅ H ₁₁ N	73.14	50	1,7	305	10,1	-23	310	41.32	38.47
54 Aniline	C ₆ H ₇ N	93.13	48	1,2	425	11	76	630	36.5	35.38
55 Acrylonitrile	C ₃ H ₃ N	53.06	61	2,8	620	28	-5	480	-	-
56 Pyridine	C ₅ H ₅ N	79.1	56	1,7	350	10,6	17	550	34.94	34.08
57 Nitrobenzene	C ₆ H ₅ NO ₂	123.11	90	1,8	2,048	40	88	480	25.14	24.72
58 m-Dinitrobenzene	C ₆ H ₄ N ₂ O ₄	168.11	-	-	-	-	150	490	-	-
59 Nitroglycerin	C ₃ H ₅ O ₉ N ₃	227.09	-	-	-	-	-	270	6.77	6.55
60 Hydrogen	H ₂	2.02	3.3	4	65	77	-	560	141.87	120.04
61 Carbon monoxide	CO	28.01	131	11,3	901	76	-191	605	10.1	10.1
62 Ammonia	NH ₃	17.03	108	15,4	240	33,6	-	630	22.5	18.56

3.9 Excess Air

$$\lambda = \frac{v_a}{v_{a,st}} \approx \frac{CO_{2,f,max}}{CO_{2,f,meas}} \approx \frac{21\%}{21\% - O_{2,f,meas}}$$

$$\lambda = 1 + \left(\frac{CO_{2,f,max}}{CO_{2,f,meas}} - 1 \right) \cdot \frac{v_{f,dry,st}}{v_{a,st}}$$

$$\lambda = 1 + \left(\frac{O_{2,f}}{21 - O_{2,f}} \right) \cdot \frac{v_{f,dry,st}}{v_{a,st}}$$

Approximate values for $v_{f,dry,st} / v_{a,st}$

	Hydro- gen	Nat. gas	Propane	EL fuel oil	HFO	Coke
$\frac{v_{f,dry,st}}{v_{a,st}}$	0.79	0.91	0.93	0.93	0.94	1.0

Actual volume of dry flue gas

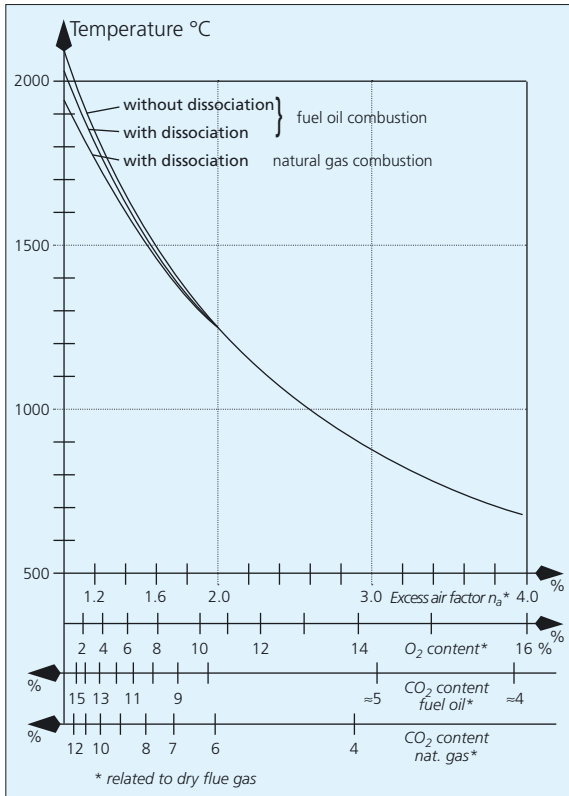
$$v_{f,dry} = v_{f,dry,st} + (\lambda - 1) \cdot v_{a,st}$$

Actual volume of wet flue gas

$$v_{f,wet} = v_{f,wet,st} + (\lambda - 1) \cdot v_{a,st}$$

- λ = excess air ratio
- v_a = actual volume of air in m^3 (at STP)/kg
- $v_{a,st}$ = stoichiometric volume of air in m^3 (at STP)/kg or m^3 (at STP)/ m^3 (at STP)
- $v_{f,wet}$ = actual volume of wet flue gas in m^3 (at STP)/kg
- $CO_{2,f,max}$ = max. CO_2 content during stoichiometric combustion in vol. %
- $CO_{2,f,meas}$ = CO_2 content in vol. %
- $v_{f,dry,st}$ = volume of dry flue gas during stoichiometric combustion in m^3 (at STP)/kg
- O_2 = O_2 content in vol. %

3.10 Theoretical Adiabatic Flame Temperature



Overview of SAACKE Burners



4 SAACKE Burners

Burner	Fuel	Capacity range approx. MW (guide values)													
		up to 2	up to 4	up to 6	up to 8	up to 10	up to 15	up to 20	up to 25	up to 30	up to 40	up to 50	up to 100	up to 134	
SKV	HFO	•	•	•	•	•	•	•	•	•	•	•			
SKV-A	HFO			•	•	•	•	•	•	•	•	•			
SKV	EL fuel oil	•	•	•	•	•	•	•	•	•	•	•			
SKV-A	EL fuel oil			•	•	•	•	•	•	•	•	•			
SG	Gas	•	•	•	•	•	•	•	•	•	•	•			
SG-A	Gas			•	•	•	•	•	•	•	•	•			
SKVG	HFO / gas	•	•	•	•	•	•	•	•	•	•	•			
SKVG-A	HFO / gas			•	•	•	•	•	•	•	•	•			
SKVG	EL fuel oil / gas	•	•	•	•	•	•	•	•	•	•	•			
SKVG-A	EL fuel oil / gas			•	•	•	•	•	•	•	•	•			
SGD	2 gases		•	•	•	•	•	•	•	•	•	•			
SKVGD	HFO / 2 gases		•	•	•	•	•	•	•	•	•	•			
SKVGD	EL fuel oil / 2 gases		•	•	•	•	•	•	•	•	•	•			
SKVJ	HFO	•	•	•	•										
SKVJG	HFO / gas		•	•	•										
JL	EL fuel oil		•	•	•										
JG	Gas		•	•	•										
JGL	EL fuel oil / gas		•	•	•										
EUROTHERM HG	Natural gas	•	•	•											
EUROTHERM HL	EL fuel oil	•	•	•											
EUROTHERM HLG	EL fuel oil / natural gas		•	•											
TEMINOX LS Mono	EL fuel oil		•	•	•	•	•	•							
TEMINOX GS Mono	Gas		•	•	•	•	•	•							
TEMINOX GLS Mono	EL fuel oil / gas		•	•	•	•	•	•							
TEMINOX LS Duo	EL fuel oil		•	•	•	•	•	•							
TEMINOX GS Duo	Gas		•	•	•	•	•	•							
TEMINOX GLS Duo	EL fuel oil / gas		•	•	•	•	•	•							
TEMINOX TL	EL fuel oil		•	•	•	•	•	•							
TEMINOX TG	Gas		•	•	•	•	•	•							
TEMINOX TGL	EL fuel oil / gas		•	•	•	•	•	•							
TF-DDZ	EL fuel oil				•	•	•	•	•	•	•	•			
TF-DDG	Gas				•	•	•	•	•	•	•	•			
TF-DDZG	EL fuel oil / gas				•	•	•	•	•	•	•	•			
DDZ	HFO				•	•	•	•	•	•	•	•	•	•	
DDZ	EL fuel oil				•	•	•	•	•	•	•	•	•	•	
DDG	Gas				•	•	•	•	•	•	•	•	•	•	
DDZG	HFO / gas				•	•	•	•	•	•	•	•	•	•	
DDZG	EL fuel oil / gas				•	•	•	•	•	•	•	•	•	•	
SSBS	HFO		•	•	•	•	•	•	•	•	•	•	•		
SSBG	Gas		•	•	•	•	•	•	•	•	•	•	•		
SSBGS	HFO / gas		•	•	•	•	•	•	•	•	•	•	•		
SSBGL	EL fuel oil / gas		•	•	•	•	•	•	•	•	•	•	•		
SSKV	Sulphur	•	•	•	•	•									
SSK	Sulphur				•	•	•	•	•	•	•	•	•		
SSB-D	Pulverised coal		•	•	•	•	•	•	•	•	•	•	•		
SSBS-D	Pulverised coal / HFO		•	•	•	•	•	•	•	•	•	•	•		
SSBL-D	Pulverised coal / EL fuel oil		•	•	•	•	•	•	•	•	•	•	•		
SSBG-D	Pulverised coal / gas		•	•	•	•	•	•	•	•	•	•	•		
SSB-LCG	Low calorific gas		•	•	•	•	•	•	•	•	•	•	•		

Dimensioning a Plant

5.1 Power Consumption of Fans

5.1.1 Shaft Power in kW*

$$P_{sh} \approx \frac{\dot{V}_{std} \cdot (p_{sta} + 3) \cdot 4}{10^5} \quad \text{in kW}$$

*Valid for approx. 20° C air temperature and 75% fan efficiency rate

P_{sh} = shaft power in kW

p_{sta} = static pressure increase in mbar

\dot{V}_{std} = volume flow rate in m³ (STP)/h

Note: The drive motor should be dimensioned with an adequate power margin.

5.1.2 Influence of the Fan Speed

$$\frac{\dot{V}_2}{\dot{V}_1} = \frac{n_2}{n_1}$$

$$\frac{\Delta p_2}{\Delta p_1} = \left(\frac{n_2}{n_1} \right)^2$$

$$\frac{P_2}{P_1} = \left(\frac{n_2}{n_1} \right)^3$$

5.2 Output Series for Electric Motors

Output series for electric motors (standard motor) to EN 50347		
0.18 kW	4.0 kW	45 kW
0.25 kW	5.5 kW	55 kW
0.37 kW	7.5 kW	75 kW
0.55 kW	11.0 kW	90 kW
0.75 kW	15.0 kW	110 kW
1.1 kW	18.5 kW	132 kW
1.5 kW	22.0 kW	160 kW
2.2 kW	30.0 kW	200 kW
3.0 kW	37.0 kW	

5.3 International Protection Classes according to EN 60529 (IEC 529 / VDE 047 T1)

IP x y

x	Protected against...	y	Protected against...
0	No protection	0	No protection
1	Protected against solid objects over 50mm e.g. accidental touch by hands	1	Protected against vertically falling drops of water
2	Protected against solid objects over 12mm e.g. fingers	2	Protected against direct sprays of water up to 15° from the vertical
3	Protected against solid objects over 2.5mm (tools and wires)	3	Protected against sprays up to 60° from the vertical
4	Protected against solid objects over 1mm (tools, wires and small wires)	4	Protected against water sprayed from all directions – limited ingress permitted
5	Protected against dust – limited ingress (no harmful deposit)	5	Protected against low pressure jets of water from all directions – limited ingress permitted
6	Totally protected against dust	6	Protected against strong jets of water e.g. for use on ship decks – limited ingress protected
		7	Protected against the effects of temporary immersion between 15cm and 1m. Duration of test 30 minutes
		8	Protected against long periods of immersion under pressure

5.4 Power Consumption of Electric Preheaters

$$P \approx \frac{\dot{m}_F \cdot (\vartheta_2 - \vartheta_1)}{1,585} \quad \text{in kW}$$

P = power consumption in kW ϑ_2 = outlet temperature in °C
 ϑ_1 = inlet temperature in °C \dot{m}_F = oil flow rate in kg/h

5.5 Calculation of the Furnace Heat Release Rate

$$\dot{q}_{ft} \approx \frac{\dot{m}_F \text{ (or } \dot{V}_F) \cdot \text{LHV} \cdot 3.53}{D_{ft}^2 \cdot L_{ft} \cdot 10^7} \quad \text{in MW/m}^3$$

\dot{m}_F or \dot{V}_F = fuel consumption in kg/h or m³/h
LHV = heating value in kJ/kg or kJ/m³
 D_{ft} = inner flame tube diameter in m
 L_{ft} = flame tube length without reversal chamber in m

5.6 Flue Gas Temperature for Boilers without Economisers

$$\vartheta_f \approx \text{saturated steam or hot water temperature} + 40 \text{ }^\circ\text{C}$$

5.7 Conversion of an Air or Gas Flow Rate from Standard Conditions to Operating Conditions

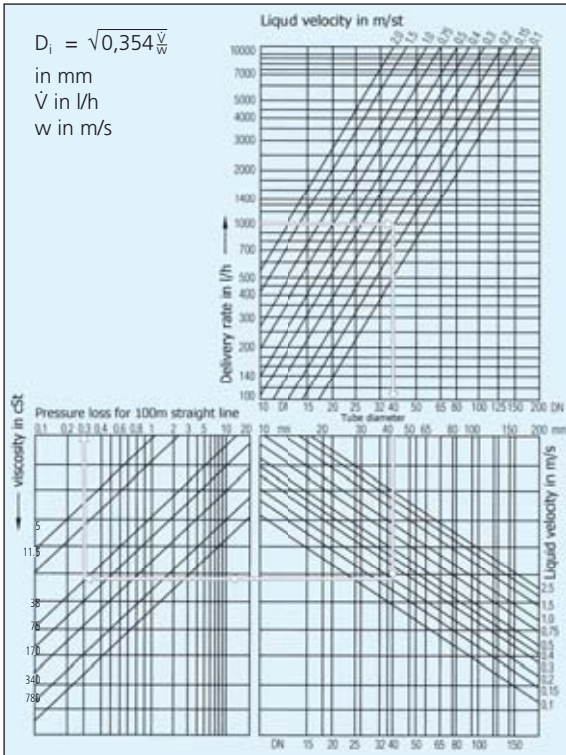
$$\dot{V}_{(\text{at OTP})} = \dot{V}_{(\text{at STP})} \cdot \frac{1,013}{1,013 + p} \cdot \frac{273 + \vartheta}{273} \quad \begin{array}{l} \dot{V} \text{ in m}^3/\text{h} \\ p \text{ in mbar} \\ \vartheta \text{ in }^\circ\text{C} \end{array}$$

5.8 Pressure Loss of a Liquid or Gas Flow

$$\Delta p = \zeta \cdot \frac{\rho}{2} \cdot w^2 \cdot \frac{1}{100} \quad \text{in mbar}$$

Δp = pressure loss
 ζ = resistance coefficient (if unknown: use 1)
 ρ = density
 w = flow rate

5.9 Fuel Oil Lines Tube Diameters and Pressure Losses



Example:

delivery rate:	1,000 l/h
tube:	DN 40
liquid velocity:	0.2 m/s
viscosity:	38 cSt
pressure loss:	0.3 bar per 100 m straight line

5.10 Velocity of Flow in Pipelines

Fluid (medium)	Type of pipeline	m/s
Water	Potable and non-potable water - main lines	1 – 2
	” ” – long distance lines	up to 3
	” ” – local lines	0.6 – 0.7
	” ” – house lines	2
	Pressure water lines (depending on the length)	15 – 30
	Feedwater – suction lines	0.5 – 1
	Feedwater – pressure lines	1.5 – 2.5
	Condensate lines upstream of the steam trap	1 – 2
Steam	Steam lines < 10 bar	15 – 20
	” 10 – 40 bar	20 – 40
	” 40 – 125 bar	30 – 60
	Exhaust steam lines	15 – 25
Air	Pressure lines	15 – 25
Gas	Long-distance gas lines up to 2 bar	4 – 20
	” up to 5 bar	11 – 35
	” above 5 bar	15 – 40
EL fuel oil	Suction lines	1
	Pressure lines	1.5 – 2
HFO	Suction lines	0.1 – 0.5
	Pressure lines	0.5 – 1

5.11 Seamless Steel Tubes to EN 10220, Series 1

Nominal bore	Suitable for BSPT pipe thread	Outer diameter	Wall thickness	Inner diameter	Inner cross-section	Tube weight	Volume flow rate at 1 m/s
DN in mm	R in inches	D _O in mm	d in mm	D _i in mm	A in cm ²	G ₁ in kg/m	\dot{V} in m ³ /h
10	3/8	17.2	1.8	13.6	1.45	0.684	0.52
15	1/2	21.3	2.0	17.3	2.35	0.952	0.85
20	3/4	26.9	2.3	22.3	3.90	1.40	1.40
25	1	33.7	2.6	28.5	6.37	1.99	2.30
32	1 1/4	42.4	2.6	37.2	10.9	2.55	3.92
40	1 1/2	48.3	2.6	43.1	14.6	2.93	5.25
50	2	60.3	2.9	54.5	23.3	4.11	8.40
65	2 1/2	76.1	2.9	70.3	38.8	5.24	14.0
80	3	88.9	3.2	82.5	53.5	6.76	19.3
100	4	114.3	3.6	107.1	90.0	9.83	32.4
125	5	139.7	4.0	131.7	136.0	13.4	49.0
150	–	168.3	4.5	159.3	199.0	18.2	71.8
200	–	219.1	6.3	206.5	334.0	33.1	122.0
250	–	273.0	6.3	260.4	532.0	41.4	192.0
300	–	323.9	7.1	309.7	753.0	55.5	270.0
350	–	355.6	8.0	339.6	906.0	68.6	327.0
400	–	406.4	8.8	388.8	1,180.0	86.3	426.0

\dot{V} = volume flow rate in l/h

w = velocity in m/s

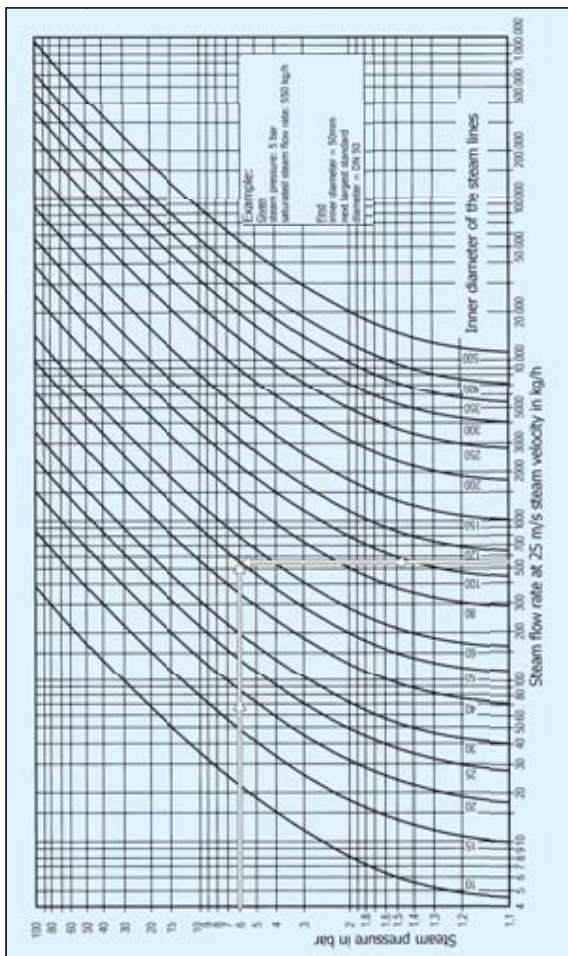
Example:

$$\dot{V} = 5.25 \text{ m}^3 / \text{h} = 5,250 \text{ l/h}$$

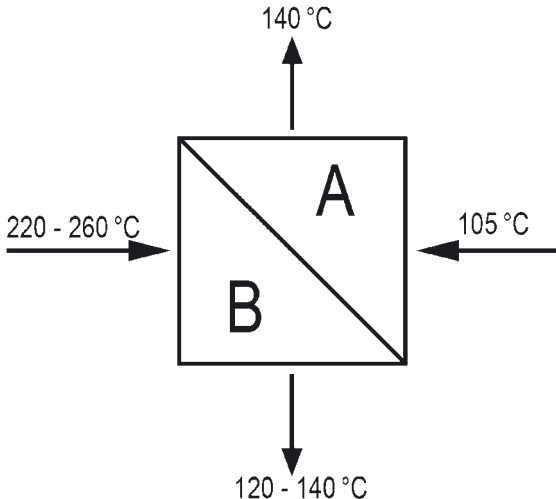
$$w = 1 \text{ m/s}$$

$$D_i = \sqrt{0.354 \frac{\dot{V}}{w}} = 43.1 \text{ mm} \triangleq \text{DN 40}$$

5.12 Dimensioning Saturated Steam Lines



5.13 Guide Values for Economisers



A = return flow / feedwater

B = flue gas

Guide value

Lowering the flue gas temperature by 30 K improves the efficiency rate by approx. 1%. Using an economiser increases the boiler efficiency rate by approx. 4 - 5%.

Flue gas temperature limits

Hot water boilers:

minimum return flow temperature operating on gas > 60 °C

minimum return flow temperature operating on oil > 65 °C

With steam boilers the flue gas temperature must be approx. 60 - 80 K higher than the steam temperature.

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Emissions, Limits for Flue Gas and Noise

6.1 Emissions Limits for Firing Plants*

* The following tables provide an overview of the emission values of standard fuels. Please note the separate SAACKE publications on this issue and the recent versions of the BImSchV. (The German Federal Immission Control Acts („BImSchV“) are among the worlds strictest. The limits given in this table are valid in Germany at the time of printing. They are subject to ongoing revision.)

EL fuel oil / liquid standard fuels							
		NO _x mg/m ³	CO mg/m ³	SO ₂ mg/m ³	Dust mg/m ³	Soot no.	Remarks
1 st BImSchV 2010-03-22	≤ 120 kW	110 ¹⁾	–	–	–	1	
	≤ 400 kW	120 ¹⁾	–	–	–	1	
	< 10 MW	185 ¹⁾	–	–	–	1	
	< 20 MW	180 ^{1) 7)}	80	–	–	–	1
200 ^{1) 7)}		80	–	–	–	1	operating temp. ≤ 210 °C
250 ^{1) 7)}		80	–	–	–	1	operating temp. > 210 °C
4 th BImSchV 2003-08-14 ("TA Luft")	< 50 MW	180 ¹⁾	80	–	–	1	operating temp. < 110 °C
		200 ¹⁾	80	–	–	1	operating temp. ≤ 210 °C
	≥ 1 (5) – < 50 MW	250 ¹⁾	80	–	–	1	operating temp. > 210 °C
		350 ¹⁾	80	850 ²⁾	–	1	fuel oils except EL fuel oil
13 th BImSchV 2004-07-206)	< 100 MW	180 ¹⁾	80	850	–	1	operating temp. < 110 °C
		200 ¹⁾	80	850	–	1	operating temp. ≤ 210 °C
		250 ¹⁾	80	850	–	1	operating temp. > 210 °C
	< 300 MW	200 ⁴⁾	80	400-200 ³⁾	–	1	
	< 100 MW	350 ⁵⁾	80	850	20	–	fuel oils except EL fuel oil
	< 300 MW	200 ⁴⁾	80	400-200 ³⁾	20	–	
	> 300 MW	150 ⁴⁾	80	200	10	1	all fuel oils

1) The NO_x emissions for EL fuel oil are based on a fuel nitrogen content of 140 mg/kg acc. to EN 267. They may be corrected according to Annex A.

2) The SO₂ emissions for a burner output of up to 5 MW must not be any higher than those from EL fuel oil.

3) linear decrease

4) Annual average must not exceed 100 mg/m³.

5) Annual average must not exceed 250 mg/m³.

6) Daily average. Half-hour averages must not exceed twice this value.

7) Dual-fuel burners that are operated with liquid fuels for less than 300 h/a: 250 mg/m³.

The emissions limits given are based on a residual oxygen content in the flue gas of 3% O_{2,dry}

Natural gas / other gaseous fuels								
		NO _x mg/m ³	CO mg/m ³	SO ₂ mg/m ³	Dust mg/m ³		Remarks	
1 st BImSchV 2010-03-22	≤ 120 kW	60	–	–	–			
	≤ 400 kW	80	–	–	–			
	< 10 MW	120	–	–	–			
	< 20 MW	100	80	–	–	–		operating temp. < 110 °C
		110	80	–	–	–		operating temp. 110 – 210 °C
		150	80	–	–	–		operating temp. > 210 °C
< 20 MW	200	80	–	–	–		other standard fuels	
4 th BImSchV 2003-08-14 ("TA Luft")	< 50 MW	100	50	10	5		operating temp. < 110 °C	
		110	50	10	5		operating temp. 110 – 210 °C	
		150	50	10	5		operating temp. > 210 °C	
< 50 MW	200	80	various	5 - 10		other standard fuels		
13 th BImSchV 2004-07-20	< 300 MW	100	50	35	5		operating temp. < 110 °C	
		110	50	35	5		operating temp. 110 – 210 °C	
		150	50	35	5		operating temp. > 210 °C	
	< 300 MW	200	80 - 100	various	5 - 10		other standard fuels	
	> 300 MW	100	50	35	5			
	> 300 MW	100	80 - 100	various	5 - 10		other standard fuels	

The emissions limits given are based on a residual oxygen content in the flue gas of 3% O_{2,dry}

Solid or liquid waste								
		NO _x mg/m ³	NO _x mg/kWh	CO mg/m ³	SO ₂ mg/m ³	Dust mg/m ³	C _x H _y	Remarks
17 th BImSchV 2003-08-14		200	–	50	50	10	10	daily average
		400	–	100	200	30	20	half-hour average

The emissions limits given are based on a residual oxygen content in the flue gas of 11% O_{2,dry}

6.2 Continuous Monitoring acc. to "TA Luft"*

	Liquid fuels ¹⁾	Gaseous fuels ¹⁾
Flue-gas opacity	5 up to 25 MW ≥ 5 MW EL fuel oil	
Dust	> 25 MW except for EL fuel oil	
CO	> 25 MW	> 50 MW
SO ₂	2)	
NO _x		
1) Performance data: burner output of the individual firing plants 2) When fuels other than EL fuel oil are fired, a record must be kept of the sulphur content.		

* The German Clean Air Act goes beyond EU requirements and is among the strictest in the world.

6.3 Estimation of the Solid Content in the Flue Gas of Liquid Fuels

$$\text{solid content} = \text{ash content} \cdot 830 + X \quad \text{in mg/m}^3$$

solid content in mg/m³ dry flue gas

ash content in %

X = depending on the plant : from 10 to 40

6.4 Estimation of the SO_x Content in the Flue Gas

$$\text{SO}_x \text{ content in mg/m}^3 = \text{fuel sulphur content in wt. \%} \cdot 1700$$

fuel sulphur content:

HFO approx. 1.0 wt. % \triangleq 10000 mg/kg

EL fuel oil approx. 0.015 wt. % \triangleq 150 mg/kg

6.5 Conversion of Emissions Values

Depending on the fuel and the type of firing plant, the emissions values are based on a defined oxygen concentration in the dry flue gas ($O_{2, \text{dry}}$ in vol. %).

The conversion of ppm to mg/m^3 , based on the prescribed O_2 value, is done in two steps:

6.5.1 Equation for Correction to the O_2 Reference Value

$$E = \frac{21 - X}{21 - O_{2, \text{meas}}} \cdot E_{\text{meas}}$$

$E \triangleq$ emission, based on X% O_2 e.g. NO, SO_2 , CO

X = O_2 reference value in volume percent

6.5.2 Factors for Conversion from ppm to mg/m^3

$$\begin{aligned} 1 \text{ ppm CO} &= 1.25 \text{ mg CO}/\text{m}^3 \\ 1 \text{ ppm NO} &\Downarrow 2.05 \text{ mg NO}_2/\text{m}^3 * \\ 1 \text{ ppm NO} &= 1.34 \text{ mg NO}/\text{m}^3 \\ 1 \text{ ppm SO}_2 &= 2.93 \text{ mg SO}_2/\text{m}^3 \end{aligned}$$

*Nitrogen oxides (NO_x) are understood as the mixture of nitrogen monoxide (NO) and nitrogen dioxide (NO_2). The NO_x concentration is calculated in $\text{mg NO}_2/\text{m}^3$

6.5.3 Correction of the Influence of the Temperature and Humidity of the Combustion Air on the NO_x Emissions*

$$NO_{x,ref} = NO_{x,meas} + \left[\frac{0.02 \cdot NO_{x,meas} - 0.34}{1 - 0.02 \cdot (h_{meas} - 10)} \right] (h_{meas} - 10) + [0.85 \cdot (20 - \vartheta_{meas})]$$

NO_{x,meas} = NO_x value in mg/kWh, measured at h_{meas} and ϑ_{meas} in the 50 mg/kWh to 300 mg/kWh range

h_{meas} = humidity during measurement of NO_{x,meas} in g/kg in the 5 g/kg to 15 g/kg range

ϑ_{meas} = temperature in °C during measurement of NO_{x,meas}

NO_{x,ref} = corrected NO_x value in mg/kWh at a humidity of 10g/kg and a temperature of 20 °C (reference conditions).

For this calculation the temperature ϑ_{meas} must be within a tight range:

- for EL fuel oil between 15 and 30 °C

- for public utility gases between 15 and 25 °C

6.5.4. Correction of the Influence of the Nitrogen Content in the Oil on the NO_x Emissions*

To correct the NO_x value, the actual nitrogen content N_{meas} of the oil must be known (e.g. from an analysis).

$$NO_{x(EN267)} = NO_{x,ref} - (N_{meas} - N_{ref}) \cdot 0.2$$

NO_{x(EN267)} = NO_x value in mg/kWh corrected to the reference value for nitrogen in the oil

NO_{x,ref} = NO_x value calculated according to [6.5.3]

N_{meas} = measured nitrogen content of the oil

N_{ref} = reference value for the nitrogen content in the oil (140 mg/kg)

*According to EN267, symbols harmonised

6.6 Acid Dew Points and Minimum Flue Gas Temperatures

	Acid dew point	Min. flue gas temperature
Natural gas	approx. 55 °C	> 100 °C
EL fuel oil	approx. 120 °C	> 150 °C
HFO*	approx. 155 °C	> 180 °C

*1% sulphur content

6.7 Emissions Conversion

	ppmv 0% O ₂ , dry	ppmv 3% O ₂ , dry	mg NO _x /kg fuel	mg NO _x /m ³ (at STP) fuel	mg NO _x /m ³ (at STP) dry flue gas, 3% O ₂	mg NO _x /MJ (LHV)	mg NO _x /kWh or g NO _x /MWh
ppmv 0% O ₂ , dry	1	0.87	23.39	19.84	1.78	0.49	1.76
ppmv 3% O ₂ , dry	1.15	1	27.29	23.15	2.05	0.57	2.05
mg NO _x /kg fu- el	0.043	0.037	1	0.85	13.29	0.021	0.075
mg NO _x /m ³ (at STP) fuel	0.050	0.043	1.18	1	0.089	0.025	0.089
mg NO _x /m ³ (at STP) dry flue gas 3% O ₂	0.562	0.488	0.075	11.24	1	0.28	1.0
mg NO _x /MJ (LHV)	2.045	1.754	47.62	40.00	3.6	1	3.6
mg NO _x /kWh or g NO _x /MWh	0.568	0.487	13.30	11.20	1	0.28	1

Basic Business Formulae

7.1 Pre-Investment Analysis, Static Method

There are a number of key figures you can calculate in order to estimate the costs of an investment (e.g. a plant modernisation). The following calculation is simplified but it is close enough for a rough estimate. Proceed step by step:

1. Collect the basic data.
 - 1a. Determine the fuel costs per year up to now.
 - 1b. Determine the expected fuel costs per year.
 - 1c. Calculate the fuel savings [F] per year.
 - 1d. Estimate roughly the plant investments [C].
2. Calculation of the debt service [CD] of the investment [C]* - (assumed interest rate: 10%)

**simplified calculation of the average capital expenditure*

$$CD = \frac{C}{2} \cdot \frac{10\%}{100\%}$$

3. Calculation of the write-off for depreciation [W] of the investment [C] for the service life (example: 10 years)

$$W = \frac{C}{10}$$

4. Calculation of the annual cost savings [S]

$$S = F + CD + W$$

5. Calculation of the annual cash return [CR]

$$CR = S + W$$

6. Calculation of the amortisation / pay-off period / pay-back period [PB]

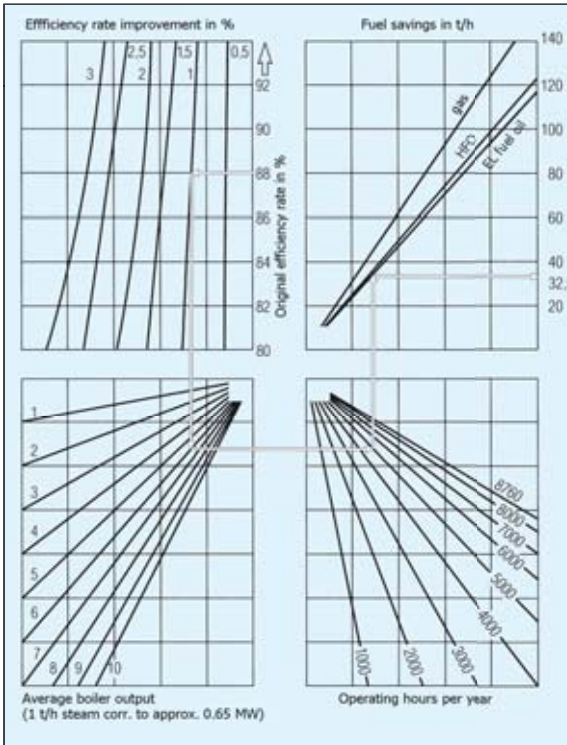
$$PB = \frac{C}{CR}$$

7. Calculation of the return on investment [ROI] / yield*

**You can also use $\frac{C}{S}$ instead of C.*

$$ROI = \frac{S}{C}$$

7.2 Profitability Diagram for Firing Plants with Oxygen Control



Example:

original efficiency rate	88 %
efficiency rate improvement from O ₂ control	1 %
average boiler output	6 MW
operating hours per year	5,000

Savings of 32.5 metric tons of EL fuel oil per year.

7.3 Calculation of the Gross and Net Price of heat

gross heat price [€/GJ]	$= \frac{\text{price of the mass (volume) unit of fuel} \\ [\text{€ /100 l}] \text{ or } [\text{€ /m}^3]}{\text{lower heating value of the mass (volume) unit of fuel (LHV)} \\ [\text{kJ/kg}] \text{ or } [\text{kJ/m}^3]}$
net heat price [€/GJ]	$= \frac{\text{gross heat price [€/GJ]} \cdot 100\%}{\text{annual operating efficiency rate \%}}$

Average annual operating efficiency rates*

with EL fuel oil	82%
with HFO	81%
with natural gas and liquid gas	83%

*assuming an optimum combustion efficiency rate

Example calculation:

fuel: EL fuel oil, LHV = 42,700 kJ/kg
price: 85 €/100 l
density: 0.83 kg/l

$$\text{gross heat price} = \frac{85 \text{ € /100 l} \cdot 10^6 \text{ kJ/GJ}}{42,700 \text{ kJ/kg} \cdot 83 \text{ kg/100 l}} = 23.98 \text{ € /GJ}$$

$$\text{net heat price} = \frac{23.98 \text{ € /GJ}}{0.82} = 29.37 \text{ € /GJ}$$

A large, white, stylized number '8' is centered on a light blue background. The number is composed of two thick, rounded loops that meet at a central point. The text is positioned in the upper loop of the '8'.

Overview of Important Standards and Directives

8.1 Overview of Important Standards and Directives*

EN 267	Automatic forced draught burners for liquid fuels
EN 676	Automatic forced draught burners for gaseous fuels
EN 230	Automatic burner control systems for oil burners
EN 298	Automatic gas burner control systems for gas burners and gas burning appliances with or without fans
EN 50156	Electrical equipment for furnaces and ancillary equipment. Requirements for application, design and installation
EN 12952	Water-tube boilers and auxiliary installations
EN 12953	Shell boilers
EN 746-2	Industrial thermoprocessing equipment. Safety requirements for combustion and fuel handling systems
EN 60529	(IEC 529 / VDE 047 T1) Specifications for degrees of protection provided by enclosures (IP Code)

Directive 94/9/EC	of the European Parliament concerning equipment and protective systems intended for use in potentially explosive atmospheres
Directive 1999/92 EC	of the European Parliament on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres
Directive 2006/42/EG	of the European Parliament on Machinery (" Machinery Directive ")
Directive 97/23/EG	of the European Parliament on the approximation of the laws of the Member States concerning pressure equipment (" Pressure Equipment Directive ")
Directive 90/396/EWG	of the Council on the approximation of the laws of the Member States relating to appliances burning gaseous fuels (" Gas Appliance Directive ")
Directive 2006/95/EG	of the European Parliament on the harmonisation of the laws of the Member States relating to electrical equipment designed for use within certain voltage limits (" Low Voltage Directive ")

**The Technical Rules for Steam Boilers (TRD) rulebook is obsolete and is no longer listed here.*

8.2 Explosion Protection – Selecting and Marking Equipment *

*Based on ATEX Directive 94/9/EC for the EU. Although international harmonisation is in progress (IEC), certain country-specific standards apply elsewhere.

8.2.1 Definition of the Explosion Protection Zones


Explosive mixture present	Zone for gases	Zone for dusts
continuously, for long periods or frequently	zone 0	zone 20
in normal operation occasionally	zone 1	zone 21
in normal operation unlikely or only briefly	zone 2	zone 22

8.2.2 Selecting the Equipment Category

Explosion protection for gases		Explosion protection for dusts	
Zone	Category	Zone	Category
0	1G	20	1D
1	1G or 2G	21	1D or 2D
2	1G, 2G or 3G	22	1D, 2D or 3D

8.2.3 Equipment Marking

(minimum requirements acc. to 94/9/EC)

General information on the manufacturer	Name, address of the manufacturer, series, model, serial number, year of manufacture
CE mark	CE with the number of the notified body
EX mark	
Equipment group	I mines (methane, dusts) II all other potentially explosive areas
Category	1G, 2G, 3G or 1D, 2D, 3D for zones 0, 1, 2 respectively or for zones 20, 21, 22

8.2.4 Ignition Protection Class

Identifier*	Ignition protection class	Example application
Ex p	pressurized enclosure	ventilated control cabinet
Ex c	constructional safety	new, for non-electrical components
Ex d	pressure-tight enclosure	in particular for motors
Ex de	pressure-tight enclosure with increased connection safety	local control boxes
Ex ia	intrinsically safe for zone 0	instrumentation
Ex ib	intrinsically safe for zones 1 and 2	instrumentation
Ex em	increased safety / encapsulation	pilot valves
Ex b	protection by control of ignition sources	new, for non-electric components
Ex k	liquid immersion	transformers
Ex nA	non-sparking	electric motors

* As of 2008-10-01; 'EEx' on equipment marked according to the previous standard

8.2.5 Explosion Group Classification

Explosion Group	Example material	Maximum experimental safe gap
I	methane	> 1,1 mm
IIA	propane	> 0,9 mm
IIB	ethylene	> 0,5 mm
IIC	hydrogen	< 0,5 mm

8.2.6 Temperature Class

T1	surface temperature < 450°C	CH ₄ , H ₂ , C ₃ H ₈
T2	surface temperature < 300°C	Cyclohexanone
T3	surface temperature < 200°C	H _x S _y
T4	surface temperature < 135°C	Acetaldehyd
T5	surface temperature < 100°C	-
T6	surface temperature < 85°C	C _x S _y

8.2.7 Complete Designation (Example)

	II 2G EEx d IIC T4
---	---------------------------

Nomenclature

Conventions

EL fuel oil	light fuel oil to DIN 51603-1
HFO	heavy fuel oil to DIN 51603-3

Abbreviations and Symbols

A	area
$\cos \varphi$	electric power factor
d	relative density
d	wall thickness
D	diameter
DN	nominal diameter
E	emission
G	weight
h	enthalpy
h	humidity
HHV	higher heating value
I	electric amperage
L	length
LFL	lower flammability limit
LHV	lower heating value
\dot{m}	mass flow rate, consumption
MSL	mean sea level
n	number, quantity
n	rate of revolution
OTP	operating temperature and pressure
p	pressure
P	power / wattage
q	heat release rate
Q	burner output
r	latent heat of vaporisation
R	pipe thread
R	electric resistance
STP	standard temperature and pressure
U	voltage
UFL	upper flammability limit
V	volume
v	specific volume
\dot{V}	volume flow rate, consumption
w	speed, flow rate
X	an arbitrary value, result of a calculation

Greek Letters

η	dynamic viscosity
η	efficiency rate
Δ	difference
λ	excess air factor
ν	kinematic viscosity
ρ	density
ϑ	temperature in °C
ζ	resistance coefficient

Subscripts

a	air
abs	absolute
b	boiler
bd	blow-down
d	dew point
dry	dry
dyn	dynamic
eff	effective
f	flue gas
F	fuel
fl	flash
ft	flame tube
fw	feedwater
g	gas
i	inner
ign	ignition
L	sound level (volume)
max	maximum value
meas	measured
min	minimum value
o	outer
ph	phase
ref	reference
s	steam
sat	saturation
sh	shaft
st	stoichiometric
sta	static
std	standard
wet	wet

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