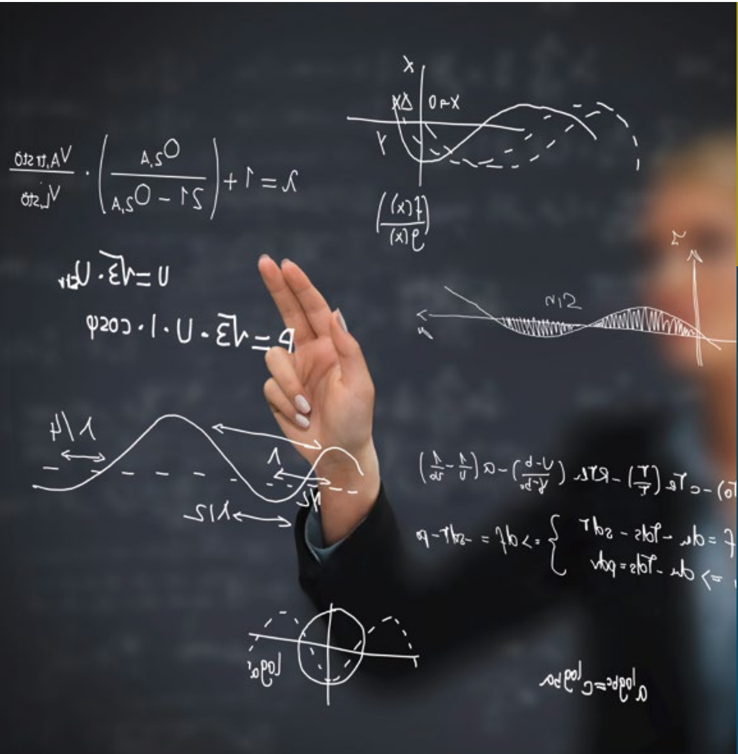
SAACKE

Pocket Formula Guide.



The SAACKE Group.

Quality and Progress in Combustion Engineering.

At SAACKE we combine series production and customised engineering to design and manufacture combustion 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 essential 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.

Although we have checked the content carefully at SAACKE, it is impossible for us to rule out all chance of error. Since it is possible that we might have overlooked a printing error or that there are errors in the content of the formulae we have provided, SAACKE does not accept any liability or responsibility for the validity of the data that appear in this publication. Nor shall SAACKE be held liable for any property damage, personal injuries or pecuniary losses resulting from the use of these data.

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

$1\,\frac{kWh}{kg} = 3600 \cdot \frac{kJ}{kg}$
$1\,\frac{kcal}{kg} = 4.187 \cdot \frac{kJ}{kg}$
$1\,\frac{kcal}{kg} = 0.001163 \cdot \frac{kWh}{kg}$

Also applies for heating values given per normal cubic meter.

1.2.2 Temperatures

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

$°C \leftarrow \frac{5}{9} . (°F - 32)$
$°F \leftarrow 1.8 \cdot °C + 32$

0 °C = 32 °F
100 °C = 212 °F

1.3 Conversion Tables

1.3.1 Mass

in \ out	kg	mg	t	lb	tn l.
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 *t = metric ton*
tn l. = long ton

1.3.2 Force

in \ out	N	kN	daN	kp	lbf
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

in \ out	Pa	bar	mbar	mm WC	psi
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

in \ out	kJ	kWh	kcal	PSh	BTU
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	Pressure	Density		
m amsl	mbar	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

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

ρ = **1.15 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.

ρ = **1.2 kg/m^3** is the air density fan manufacturers usually base their ratings on.
It is based on 0 m amsl at 20 °C.

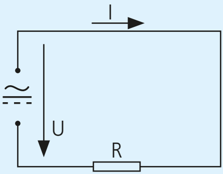
1.5 Conversion Table of Anglo-American Units

Length	1 inch, in = 25.4 mm	1 mm = 0.03937 in
	1 foot, ft = 12 in = 0.3048 m	1 m = 3.281 ft
	1 yard (yd) = 3 ft = 0.9144 m	1 m = 1.094 yd
Area	1 square inch (sq.in, in^2) = 6.452 cm^2	1 cm^2 = 0.155 in^2
	1 square foot (sq.ft, ft^2) = 144 in^2 = 0.0929 m^2	1 m^2 = 10.764 ft^2
	1 square yard (sq.yd, yd^2) = 9 ft^2 = 0.8361 m^2	1 m^2 = 1.196 yd^2
	1 square mile (sq.mile, $mile^2$) = 640 acres = 2.59 km^2	1 km^2 = 0.386 $mile^2$
Volume flow rate	1 ft^3 /s = 102 m^3 /h	1 m^3 /h= 0.00981 ft^3 /s
	1 ft^3 /min. = 1.699 m^3 /h	1 m^3 /h= 0.5886 ft^3 /min
	United Kingdom 1 Imp.gal/min (Imp.gpm) = 0.0758 l/s = 0.273 m^3 /h	1 m^3 /h= 3.66 Imp.gal/min
	U.S. 1 U.S.gal/min (U.S.gpm) = 0.063 l/s = 0.227 m^3 /h	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 t/h = 0.6124 lb/s
		1 kg/s = 2.2046 lb/s
	1 short ton/h (tn.sh./h) = 907.2 kg/h	1 kg/h = $1.102 \cdot 10^{-3}$ tn.sh./h
	1 long ton/h (tn.l./h) = 1,016 kg/h	1 kg/h = $0.984 \cdot 10^{-3}$ tn.l./h
Force	1 pound-force (lbf) = 4.4482 N	1 N = 0.2248 lbf
	1 ton-force (long) = 2,240 lbf = 9.964 kN	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 bar = 14.5 lbf/in^2
	1 lbf/ft^2 (psf) = 47.88 Pa = 0.04788 kPa	1 kPa = 20.89 lbf/ft^2
	1 inch of mercury (in. Hg) = 3,386 Pa	1 kPa = 0.2953 in. Hg
	1 inch of water (in. H_2O) = 249.1 Pa	1 kPa = 4.015 in. H_2O

1.6 Electric Power

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

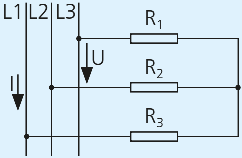
Direct or alternating current



Power with direct or alternating current

$P = U \cdot I$
$P = I^2 \cdot R$
$P = \frac{U^2}{R}$

Three-phase current



Power with three-phase current

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

P = power
U = voltage (line-to-line voltage)
I = amperage
R = resistance

1. Example:

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

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

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

2. Example:

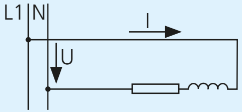
annealing Furnace, three-phase current, U = 400 V; P = 12 kW; I = ?

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

Calculation of the star delta connection on page 14

1.6.2 Alternating and Three-Phase Current with Inductive Load

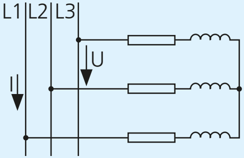
Alternating current



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 V; I = 21.5 A; $\cos\varphi$ = 0.85; P = ?

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

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

Example:

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

η = 87 %; P = 12.7 kW

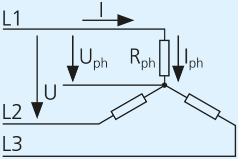
$\mathbf{P_{sh}} = 12.7\ kW \cdot 0.87 = \mathbf{11.0\ kW}$

Calculation of the star delta connection on page 14

1.6.3 Star Delta Connection for Three-Phase Alternating Current

Star connection ⋎

$U_{ph} = 230\ V$



Star connection ⋎

Line-to-line current

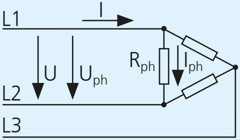
$$I = I_{ph}$$

Line-to-line voltage

$$U = \sqrt{3} \cdot U_{ph}$$

Delta connection △

$U_{ph} = 400\ V$



Delta connection △

Line-to-line current

$$I = \sqrt{3} \cdot I_{ph}$$

Line-to-line voltage

$$U = U_{ph}$$

Star or delta connection

Phase current

$$I_{ph} = \frac{U_{ph}}{R_{ph}}$$

Power

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

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

I	=	line-to-line current	$\sqrt{3}$	=	interlinking factor
U	=	line-to-line voltage	P	=	active power
I_{ph}	=	phase current	$\cos\varphi$	=	power factor with an inductive load
U_{ph}	=	phase voltage			
R_{ph}	=	phase resistance			

Example:

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

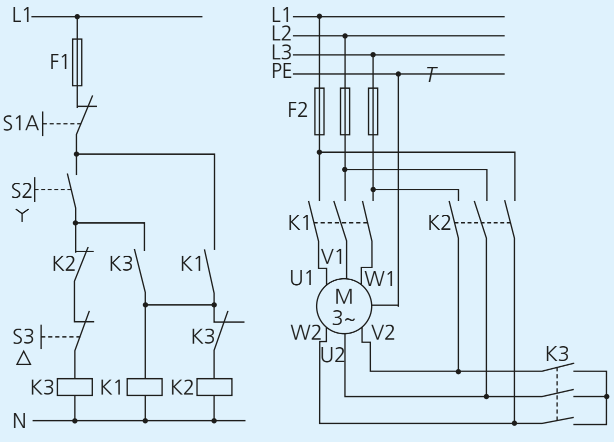
$$I_{ph} = \frac{U_{ph}}{R_{ph}} = \frac{400\ V}{22\ \Omega} = 18.2\ A$$

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

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

1.6.4 Star Delta Connection of a Three-Phase Motor

Star delta connection with contactors

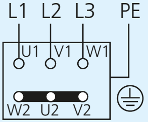


Control part **Power part**

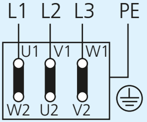
K1	network contactor	S2	star connection button
K2	delta contactor	S3	delta connection button
K3	star contactor	F1	control part fuse
S1A	OFF button	F2	power part fuse

Motor connection with permanent wiring

Star connection



Delta connection



Capacities, Efficiency Rates, Steam Table

2.1 Boiler Output - Steam Production

1 t/h of saturated steam ≙ 0.65 MW boiler output*

**at 12 bar and 102 °C feedwater*

1 kg of oil produces approx. 16 kg of steam.

1 kg of oil or 1 m^3 of gas produce the following amount of saturated steam in kg:

$$\frac{\text{heating value in kJ/kg or kJ/m}^3 \cdot \text{efficiency rate in \%}}{2{,}340}$$

The following amount of oil or gas in kg or m^3 is needed to produce 1t of saturated steam:

$$\frac{2.34 \cdot 10^6}{\text{heating value in kJ/kg or kJ/m}^3 \cdot \text{efficiency rate in \%}}$$

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	LFO 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

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

$\dot{m}_F$ or $\dot{V}_F$ = fuel consumption in kg/h or m^3 /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/m^3
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

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

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

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

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

X_f = flue gas loss
ϑ_f = flue gas temperature in °C
ϑ_a = combustion air temperature in °C
$O_{2,dry}$ = O_2 value measured in the dry flue gas in vol. %

A and B: constants

	LFO	HFO	Nat. gas	Liquid gas
A	0.68	0.69	0.66	0.63
B	0.007	0.007	0.009	0.008

* *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 water v′ m^3 /t	Spec. volume steam v″ m^3 /kg	Density steam ρ″ kg/m^3	Spec. enthalpy water h′ kJ/kg	Spec. enthalpy steam h″ kJ/kg	Heat of vaporisation r 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 water v′ m^3/t	Spec. volume steam v″ m^3/kg	Density steam ρ″ kg/m^3	Spec. enthalpy water h′ kJ/kg	Spec. enthalpy steam h″ kJ/kg	Heat of vaporisation r 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 of Water and Superheated Steam in kJ/kg

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	1331,1	1625,1	2,582.0	2,954.3	3,165.9
300	865.2	1,088.4	1328,7	1610,0	2,161.8	2,825.6	3,085.0
350	867.7	1,089.5	1326,8	1598,7	1,993.1	2,676.4	2,998.3
400	870.2	1,090.8	1325,4	1589,7	1,934.1	2,515.6	2,906.8
500	875.4	1,093.6	1323,7	1576,4	1,877.7	2,293.2	2,723.0
600	880.8	1,096.9	1323,2	1567,1	1,847.3	2,187.1	2,570.6
800	891.9	1,104.4	1324,7	1555,9	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	1555.9	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

3 Fuels, Combustion Calculation

3.1 Density of Selected Fuels

1 litre LFO	≙	0.84 kg at 15 °C
1 litre HFO	≙	0.94 kg at 90 °C
1 m³ type L nat. gas	≙	0.83 kg
1 m³ type H nat. gas	≙	0.78 kg
1 m³ pulverised lignite	≙	560 kg*
1 m³ pulverised bituminous coal	≙	600-650 kg*
1 m³ pulverised wood	≙	190-300 kg*
1 m³ propane (at STP)	=	2.01 kg
1 m³ butane (at STP)	=	2.71 kg
1 liter animal fat	≙	0.91 kg at 15 °C
1 m³ blast-furnace gas	≙	1.36 kg

** bulk density*

3.2 Heating Values of Selected Fuels

Fuel	Lower heating value (LHV)					
	kJ/kg	kJ/m³	kcal/kg	kcal/m³	kWh/kg	kWh/m³
LFO	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	22,200	–	5,300	–	6.2	–
Pulverised bituminous coal	29,700	–	7,100	–	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 Characteristics of Various Gases
(All values given for the standard physical state)

Characteristic	Symbol	Unit	Type L nat. gas	Type H nat. gas / LNG	Methane CH_4	Propane C_3H_8	Butane C_4H_{10}	Hydro-gen H_2
Lower heating value	LHV	MJ/m^3	31.8	36.0	35.9	93.2	123.8	10.8
Higher heating value	HHV	MJ/m^3	35.2	40.0	39.8	101.2	134.0	12.7
Densitiy	ρ	kg/m^3	0.829	0.784	0.718	2.011	2.708	0.090
Relative Density	d	-	0.641	0.606	0.555	1.555	2.094	0.069
Explosion limits (Vol. % gas in air, at 20 °C)								
Lower flammability limit	LFL	Vol.-%	5	4	4.4	1.7	1.4	4.0
Upper flammability limit	UFL	Vol.-%	15	16	17.0	10.8	9.4	77.0
Combustion values per m³ fuel gas at $\lambda = 1$								
Air demand	$v_{a,st}$	m^3/m^3	8.36	9.47	9.56	24.37	32.37	2.38
Flue gas volume (dry)	$v_{f,dry,st}$	m^3/m^3	7.64	8.53	8.55	22.81	29.74	1.88
Flue gas volume (wet)	$v_{f,wet,st}$	m^3/m^3	9.36	10.47	10.44	26.16	34.66	2.83
Steam content in flue gas	$v_{H_2O,f}$	m^3/m^3	1.72	1.94	1.89	3.35	4.92	0.95
Max. carbon dioxide	$CO_{2,f,dry,max}$	Vol.-%	11.8	12.0	11.7	13.7	14.0	-
Spec. carbon dioxide		g/kWh	201	201	198	239	239	-
Dew point flue gas	ϑ_d	°C	58	58	58	54	53	71
Composition								
Nitrogen	N_2	Vol.-%	14.0	3.1	–	–	–	–
Oxygen	O_2	Vol.-%	–	–	–	–	–	–
Carbon dioxide	CO_2	Vol.-%	0.8	1.0	–	–	–	–
Hydrogen	H_2	Vol.-%	–	–	–	–	–	100
Carbon monoxide	CO	Vol.-%	–	–	–	–	–	–
Methane	CH_4	Vol.-%	81.8	92.3	100	–	–	–
Ethane	C_2H_6	Vol.-%	2.8	2.0	–	–	–	–
Propane	C_3H_8	Vol.-%	0.4	1.0	–	100	–	–
Butane	C_4H_{10}	Vol.-%	0.2	0.6	–	–	100	–
Total	Σ	Vol.-%	100	100	100	100	100	100

3.3 Characteristics of Various Gases

(All values given for the standard physical state)

Characteristic	Symbol	Unit	Carbon monoxide CO	Blast-furnace gas *(Example)*	Biogas *(Range)*	Refinery gas *(Range)*	Refinery gas *(Example)*
Lower heating value	LHV	MJ/m^3	12.6	3.03	17 - 30	15 - 65	41.1
Higher heating value	HHV	MJ/m^3	12.6	2.99	20 - 34	17 - 75	37.2
Density	ρ	kg/m^3	1.250	1.355	0.9 - 1.2	0.2 - 1.8	0.705
Relative Density	d	–	0.967	1.048	0.7 - 0.9	0.2 - 1.5	0.545
Explosion limits (Vol. % gas in air, at 20 °C)							
Lower flammability limit	LFL	Vol.-%	11.3	40	4 - 5	3 - 6	4
Upper flammability limit	UFL	Vol.-%	76.0	65	16 - 10	70 - 55	29
Combustion values per m³ fuel gas at λ = 1							
Air demand	$v_{a,st}$	m^3/m^3	2.39	0.57	4.8 - 8.1	2.5 - 20	9.43
Flue gas volume (dry)	$v_{f,dry,st}$	m^3/m^3	2.88	1.43	4.8 - 7.4	2 - 25	8.44
Flue gas volume (wet)	$v_{f,wet,st}$	m^3/m^3	2.88	1.45	5.8 - 9.1	3 - 30	10.42
Steam content in flue gas	$v_{H_2O,f}$	m^3/m^3	–	0.02	-*	-*	1.98
Max. carbon dioxide	$CO_{2,f,dry,max}$	Vol.-%	34.7	27.5	-*	-*	11.6
Spec. carbon dioxide		g/kWh	564	944	-*	-*	187
Dew point flue gas	ϑ_d	°C	–	30	-*	-*	59
Composition							
Nitrogen	N_2	Vol.-%	–	58.0	0 - 30	0 - 20	0.1
Oxygen	O_2	Vol.-%	–	–	0 - 5	0 - 5	–
Carbon dioxide	CO_2	Vol.-%	–	18.0	15 - 40	0 - 20	–
Hydrogen	H_2	Vol.-%	–	2.0	–	5 - 90	50.5
Carbon monoxide	CO	Vol.-%	100	22.0	–	0 - 40	–
Methane	CH_4	Vol.-%	–	–	50 - 85	0 - 80	20.0
Ethane	C_2H_6	Vol.-%	–	–	–	0 - 30	15.7
Propane	C_3H_8	Vol.-%	–	–	–	0 - 50	8.1
Butane	C_4H_{10}	Vol.-%	–	–	–	0 - 30	5.6
Total	Σ	Vol.-%	100	100	100	100	100

* *Values must be determined individually*

3.4 Properties of Important Organic Compounds

#	Formula	Name	Molar Mass g/mol	Lower flammability limit LFL g/m³ (at STP)	Vol.- %	Upper flammability limit UFL g/m³ (at STP)	Vol.- %	Flash point ϑ_F °C	Ign. temp. ϑ_Z °C	HHV MJ/kg	LHV MJ/kg
1	CH_2O	Methanal (formaldehyde)	30,03	87	7	910	73	32-61	424	19,0	25,1
2	CH_2O_2	Formic acid	46,03	190	10	865	45,5	45	520	6,5	5,6
3	CH_3OH	Methanol	32,04	80	6	665	50	9	440	23,8	21,1
4	CH_4	Methane	16,04	29	4,4	113	17	-	595	55,5	50,0
5	CH_5N	Methylamine	31,06	60	4,9	270	20,7	-58	430	34,5	31,8
6	CO	Carbon Monoxide	28,01	131	11,3	901	76	-191	605	10,1	10,1
7	C_2H_2	Acetylene	26,04	24	2,3	-	100	-	305	49,9	48,2
8	C_2H_4	Ethylene	28,05	29	2,4	388	32,6	-	440	50,3	47,2
9	C_2H_4O	Acetaldehyde	44,1	73	4	1040	57	<-20	155	27,1	25,1
10	C_2H_4O	Ethylene oxide	44,05	47	2,6	1820	100	-57	435	29,6	27,6
11	$C_2H_4O_2$	Acedic acid	60,05	100	4	430	17	40	485	15,4	14,0
12	C_2H_6	Ethane	30,07	31	2,4	182	14,3	-	515	51,9	47,5
13	C_2H_6O	Ethanol	46,07	-	3,1	-	19	12	400	30,6	27,7
14	C_3H_3N	Acrylnitrile	53,06	61	2,8	620	28	-5	480	-	-
15	C_3H_4O	2-Propenal (acrolein)	56,06	65	2,8	730	31	-29	215	29,4	28,3
16	$C_3H_5O_9N_3$	Nitroglycerin	227,09	-	-	-	-	-	270	6,8	6,6
17	C_3H_6O	Acetone	58,08	60	2,5	345	14,3	<-20	535	32,9	30,7
18	$C_3H_6O_2$	Ethyl methanoate (ethyl formate)	74,08	80	2,7	500	16,5	-20	455	22,2	20,9
19	$C_3H_6O_2$	Ethyl acetate (methyl ethanoate)	74,08	95	3,1	495	16	-13	505	21,9	20,1
20	C_3H_7OH	1-Propanol	60,1	52	2,1	480	19,2	15	385	33,4	33,8
21	C_3H_8	Propane	44,1	31	1,7	202	10,8	104	470	50,3	46,4
22	C_4H_6	1,3-Butadiene	54,09	31	1,4	365	16,3	-85	415	47,0	44,5
23	$C_4H_6O_2$	Vinyl acetate (ethenyl acetate)	86,09	93	2,6	480	13,4	-8	385	24,6	23,1
24	$C_4H_6O_3$	Acetic anhydride	102,09	85	2	430	10,2	49	330	18,2	16,9
25	C_4H_8O	2-Butanone (ethyl methyl ketone)	72,11	45	1,5	378	12,6	-10	475	33,8	31,3
26	C_4H_8O	Tetrahydrofuran	72,11	46	1,5	370	12,4	-20	230	35,1	32,7
27	$C_4H_8O_2$	1,4-Dioxane	88,11	70	1,9	820	22,5	11	375	27,3	25,3
28	$C_4H_8O_2$	Ethyl acetate (methyl ethanoate)	88,11	73	2	470	12,8	-4	470	25,8	23,8
29	C_4H_{10}	Butane	58,12	33	1,4	231	9,4	-60	365	49,5	45,7
30	$C_4H_{10}O$	1-Butanol	74,12	52	1,7	350	11,3	35	325	36,8	35,4
31	$C_4H_{10}O$	Diethyl ether	74,12	50	1,7	1100	36	-20	175	37,1	34,1

3.4 Properties of Important Organic Compounds

#	Formula	Name	Molar Mass	Lower flammability limit LFL		Upper flammability limit UFL		Flash point ϑ_F	Ign. temp. ϑ_Z	HHV	LHV
			g/mol	g/m³ (at STP)	Vol.- %	g/m³ (at STP)	Vol.- %	°C	°C	MJ/kg	MJ/kg
32	C_5H_5N	Pyridine	79,1	56	1,7	350	10,6	17	550	34,9	34,1
33	C_5H_{10}	1-Pentene	70,13	40	1,4	255	8,7	-51	280	48,1	45,0
34	$C_5H_{11}N$	Diethylamine	85,14	50	1,7	305	10,1	-23	310	41,3	38,5
35	C_5H_{12}	1-Pentene	72,15	33	1,1	260	8,7	-49	260	49,0	45,3
36	$C_5H_{12}O$	1-Pentanol	88,15	47	1,3	385	10,5	43	320	38,4	35,2
37	$C_6H_4N_2O_4$	m-Nitrobenzene	168,11	-	-	-	-	150	490	-	-
38	$C_6H_5NO_2$	Nitrobenzene	123,11	90	1,8	2048	40	88	480	25,1	24,7
39	C_6H_6	Benzene	78,11	39	1,2	280	8,6	-11	555	42,3	40,6
40	C_6H_6O	Phenol	94,11	50	1,3	370	9,5	82	595	33,2	33,2
41	C_6H_7N	Aniline	93,13	48	1,2	425	11	76	630	36,5	35,4
42	$C_6H_{10}O$	Cyclohexanone	98,15	53	1,3	380	9,4	43	430	36,3	34,1
43	C_6H_{12}	Cyclohexane	84,16	35	1	326	9,3	-18	260	47,0	43,8
44	$C_6H_{12}O$	Cyclohexanol	100,16	62	1,5	460	11,1	61	300	37,8	31,8
45	$C_6H_{12}O_2$	Butyl acetate	116,16	58	1,2	360	7,5	27	390	30,9	28,6
46	C_6H_{14}	Hexane	86,18	35	1	319	8,9	-20	230	48,7	45,1
47	C_7H_8	Toluene	92,14	42	1,1	300	7,8	6	535	42,9	40,9
48	C_7H_8O	o-Cresol	108,14	58	1,3	-	-	81	555	34,9	33,8
49	$C_8H_6O_4$	Phtalic acid	166,13	-	-	-	-	168	-	18,4	18,9
50	C_8H_8	Styrene	104,1	42	1	334	7,7	32	490	42,6	40,9
51	C_8H_{10}	Xylene	106,17	43	0,97	335	7,6	30	465	43,3	41,2
52	$C_{10}H_8$	Naphthalene	128,17	48	0,9	315	5,9	80	540	40,8	39,4
53	$C_{10}H_8O$	1-Naphthol (α-naphthol)	144,17	-	-	-	-	125	510	35,0	17,5
54	$C_{10}H_{18}$	Transdecalin	138,25	50	0,7	280	4,9	54	240	45,8	42,9
55	$C_{12}H_{26}$	Dodecane	170,34	40	0,6	-	-	74	200	47,8	44,5
56	H_2	Hydrogen	2,02	3,3	4	65	77	-	560	141,8	119,9
57	NH_3	Ammonia	17,03	108	15,4	240	33,6	-	630	22,5	18,6
58	(Mixture)	Gasoline	-	32	0,8	310	8,1	-40	320	47,0	43,6
59	(Mixture)	EL Oil	-	-	0,6	-	6,5	>55	220	45,4	42,6
60	(Mixture)	Turpentine Oil	-	45	0,7	-	6	35	220	-	-
61	(Mixture)	Tallow	-	-	-	-	-	267	-	38,6	36,0
62	(C_{16}- and C_{16}-C_{18} non-sat.)	Biodiesel (acc. to EN 14214)	-	-	-	-	-	186	183	40,0	37,1
63		Palm Oil	-	-	-	-	-	220	>250	39,6	36,9
64		Rapeseed Oil	-	-	-	-	-	317	410	39,6	36,9

3.5 Characteristics of Liquid Fuels

(All values given for the standard physical state)

Characteristic	Symbol	Unit	LFO	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	mm²/s	max. 6	**	–	–	90
at 50 °C	ν	mm²/s	2	**	–	–	max. 40
at 100 °C	ν	mm²/s	–	**	–	–	8
Combustion values at λ = 1							
Air demand	$v_{a,st}$	m³/kg	11.0	10.7	4.93	6.85	9.56
Flue gas volume (dry)	$v_{f,dry,st}$	m³/kg	10.3	10.0	4.59	6.37	8.97
Flue gas volume (wet)	$v_{f,wet,st}$	m³/kg	11.8	11.4	5.96	7.80	10.32
Steam content in flue gas	$v_{H_2O,f}$	m³/kg	1.5	1.4	1.37	1.43	1.35
Max. carbon dioxide	$CO_{2,f,dry,max}$	Vol.-%	15.5	15.9	15.2	15.1	15.8
Spec. carbon dioxide		g/kWh	264	276	254	257	278
Composition							
Carbon	C	Wt.-%	86	84	37.5	52	76
Hydrogen	H	Wt.-%	13	12	12.5	13	12
Oxygen	O	Wt.-%	0.4	0.5	50	35	11
Nitrogen	N	Wt.-%	0.02	0.3	–	–	0.05
Sulphur	S	Wt.-%	≤ 0.2	≤ 2.8	–	–	0.02
Water	H_2O	Wt.-%	0.4	0.4	–	–	0.93
Total	Σ	Wt.-%	100	100	100	100	100

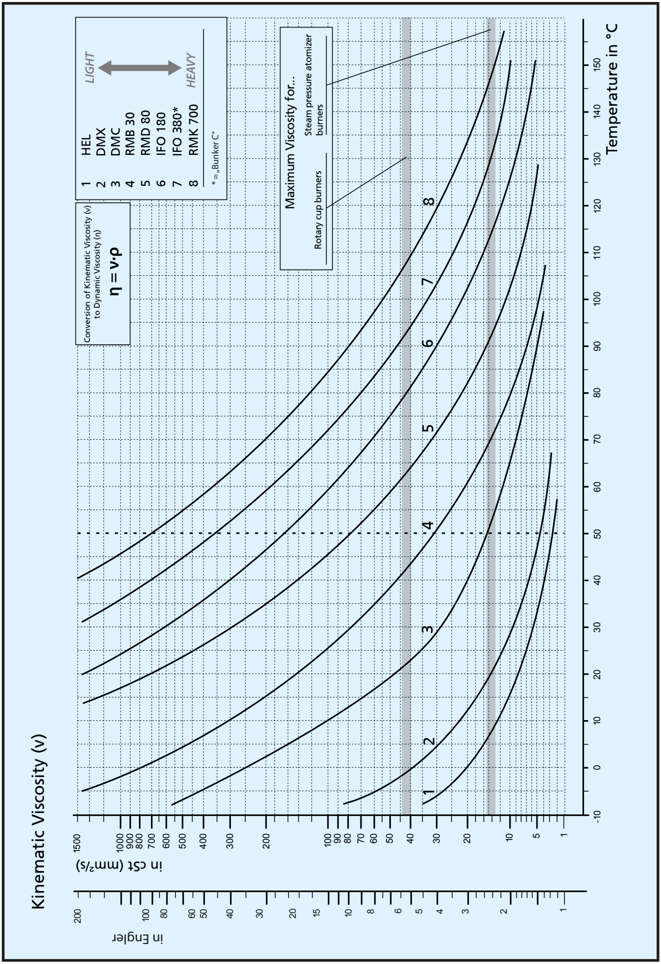
**Densities measured at different temperatures must be converted to 15 °C. To convert the densities, you can use the following formula, which is sufficiently accurate:*

$$\rho_t \approx \rho_{15} - a \cdot (\vartheta - 15°C) \quad [g/ml]$$

The cubic expansion coefficient "a" amounts to 0.00068 for LFO and to 0.00062 for heavy oil.

*** See diagram in chapter 3.6*

3.6 Viscosity-Temperature Diagram



3.7 Properties of Pulverized Fuels

Characteristic	Symbol	Unit	Petrol Coke	Hard Coal	Rheinbraun lignite	Sawdust (mean values)	Wood Pellets
Lower Heating value	LHV	MJ/kg	35.4	29.7	22.2	16.5	16.5
Higher Heating value	HHV	MJ/kg	36.7	31.2	23.8	18.2	18.2
Bulk density[1]		kg/m^3	500	550	550	300	250
Particle size distribution: x% smaller than ... µm	100%	µm	100	200	500	1,000	1,400
	85%	µm	90	90	250	500	500
	50%	µm	63	63	90	250	250
Composition							
Volatiles		Mass -%	2..10	20-30	46	60...75	65
Water	x_W	Mass -%	< 2,0	7,0	11,0	6...10	9,0
Ash	x_a	Mass -%	< 1.0	3,0-15	4.0	5...15	< 1.0
Carbon	C	Mass -%	94.5	84.0	69.1	51.4	50.3
Hydrogen	H	Mass -%	3.8	5.0	5.0	6.8	6.1
Oxygen	O	Mass -%	< 0.1	9.0	24.7	39.0	43.1
Nitrogen	N	Mass -%	0.9	1.0	0.8	2.6	0.3
Sulphur	S	Mass -%	0.8	1.0	0.4	0.2	0.2
Total	Σ	Mass -%	100	100	100	100	100
Ash Temperatures							
Ash softening	ϑ	°C	1,200	1,200	1,100	1,100	1,150
Hemisphere	ϑ	°C	1,250	1,250	1,200	1,325	1,325
Fluid	ϑ	°C	1,300	1,300	1,250	1,350	1,350
Combustion values at λ =1							
Air demand	v_a	m^3/kg	9.3	7.7	5.8	4.4	4.1
Flue gas volume (dry)	$v_{f,dry}$	m^3/kg	9.1	7.5	5.7	4.4	4.1
Flue gas volume (wet)	$v_{f,wet}$	m^3/kg	9.5	8.1	6.3	5.0	4.8
Steam content in flue gas	$v_{H_2O,f}$	m^3/kg	0.4	0.6	0.6	0.6	0.7
Max. carbon dioxide	$CO_{2,f,dry,max}$	Vol.-%	17.5	17.0	14.9	14.8	15.3
Spec. carbon dioxide		g/kWh	318	303	270	279	269

1 Bulk density of milled fuel
2 Typical values. May vary by ± 10% depending on the origin
3 Related to the LHV

3.8 Wobbe Index

Fuel gases or fuel gas mixtures with identical Wobbe indexes release the same amount of heat when fed to a combustion plant with identical pressure gradient via the burner nozzle(s) (given that the combustion is complete).

Upper / Lower Wobbe Index

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

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)

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

3.9 Stoichiometric Air Demand

in m^3/kg or m^3/m^3 (rough calculation)

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

** in kJ/kg or kJ/m³*

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

3.10 Excess Air

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

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

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

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

	Hydro-gen	Nat. gas	Propane	LFO	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

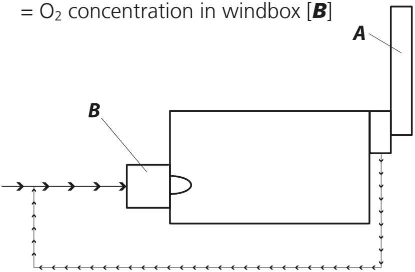
$v_{f,wet} = v_{f,wet,st} + (\lambda - 1) \cdot v_{a,st}$

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

3.11 Flue Gas Recirculation (FGR)

With SAACKE, the FGR proportion refers to the sum of wet flue gas volume and wet recirculation volume:

$v_{f,dry,st}$ = Dry flue gas volume (stoichiometric)
$v_{f,wet}$ = Wet flue gas volume (incl. excess air)
$v_{a,st}$ = Air demand of fuel (stoichiometric)
$v_{FGR,dry}$ = Dry flue gas volume of recirculation
$O_{2,f,dry}$ = O_2 concentration in flue gas [***A***]
$O_{2,a+FGR,dry}$ = O_2 concentration in windbox [***B***]



$$\Psi_{RV} \stackrel{\text{def}}{=} \frac{v_{FGR,wet}}{v_{f,wet} + v_{FGR,wet}} = \left[1 + \left(\frac{(\lambda - 1) \cdot v_{a,st} + v_{f,dry,st}}{\lambda \cdot v_{a,st}}\right) \cdot \left(\frac{O_{2,a+FGR,dry} - O_{2,f,dry}}{21\% - O_{2,a+FGR,dry}}\right)\right]^{-1}$$

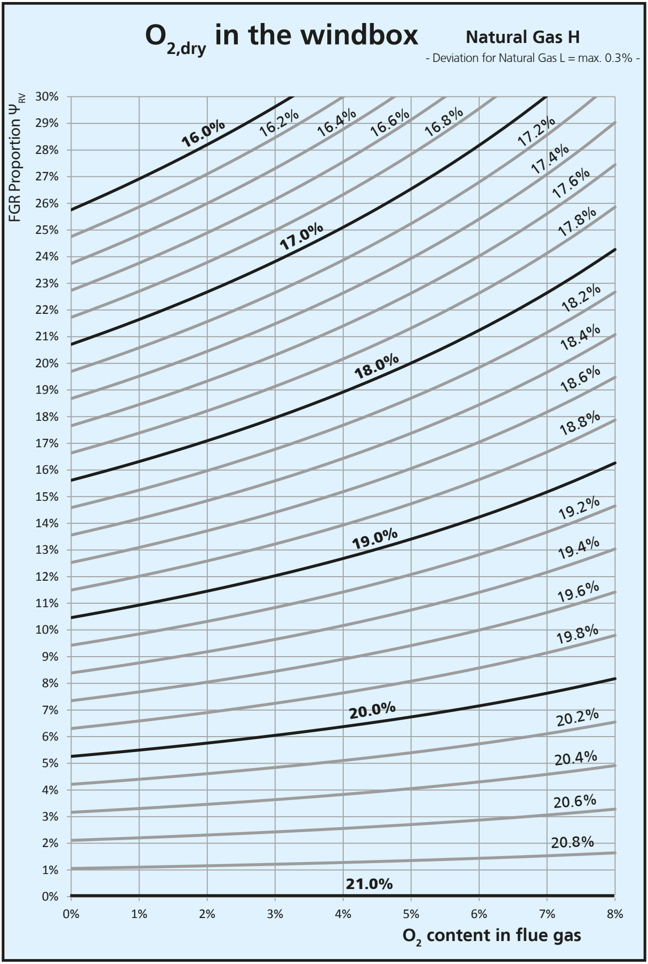
Example

In natural gas operation the the O_2 concentration in the flue gas is 3.1 % which corresponds to an excess air ratio $\lambda = 1.15$. The O_2-concentration in the windbox is 19.6%.

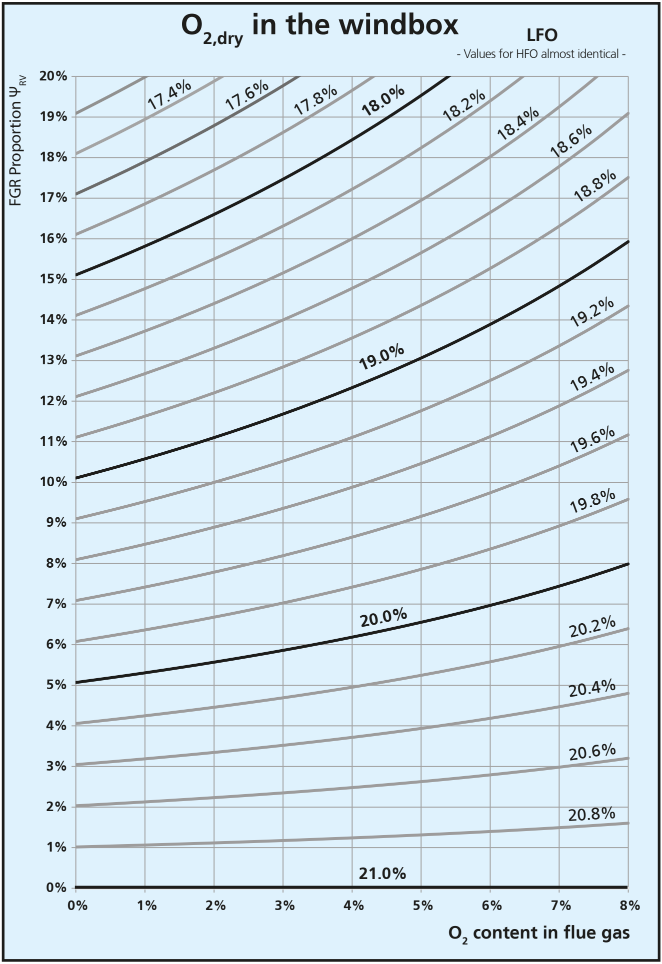
$\lambda = 1.15$; $v_{a,st} = 9.47$ m³/m³; $v_{f,dry,st} = 8.53$ m³/m³;
$O_{2,f,dry} = 3.0\%$; $O_{2,a+FGR,dry} = 19.6\%$

$$\Psi_{RV} = \left[1 + \left(\frac{(1.15 - 1) \cdot 9.47 + 8.53}{1.15 \cdot 9.47}\right) \cdot \left(\frac{19.6\% - 3.0\%}{21\% - 19.6\%}\right)\right]^{-1} \approx 8.5\%$$

3.11.1 Flue Gas Recirculation in Natural Gas Operation



3.11.2 Flue Gas Recirculation in LFO Operation



3.12 Dry / Wet O_2 Content

$$O_{2,wet} = O_{2,dry} \cdot \left(1 - \frac{v_{H_2O}}{v_{f,wet,st} + (\lambda - 1) \cdot v_{a,st}}\right)$$

O_2 in flue gas: calculate λ with O_2 in the flue gas
O_2 in wind box: calculate λ with O_2 in the windbox

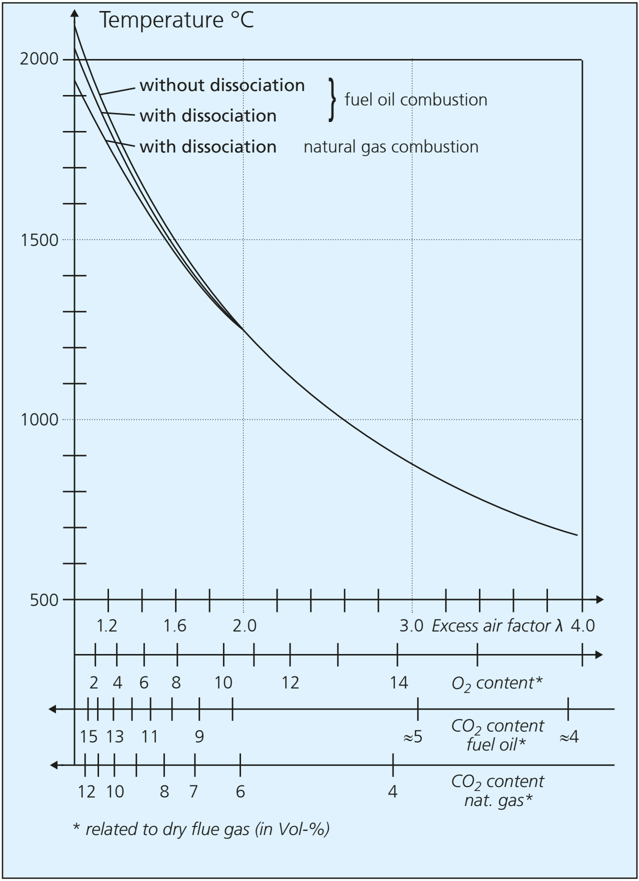
3.12.1 O_2 measured in the Flue Gas

$O_{2,f,dry}$	$O_{2,f,wet}$	
	Nat. gas H/L	**LFO/HFO**
0.0	0.0	0.0
0.5	0.4	0.9
1.2	1.0	1.1
1.4	1.2	1.2
1.6	1.3	1.4
1.8	1.5	1.6
2.0	1.7	1.8
2.2	1.8	1.9
2.4	2.0	2.1
2.6	2.2	2.3
2.8	2.3	2.5
3.0	2.5	2.7
3.2	2.7	2.8
3.4	2.9	3.0
3.6	3.0	3.2
3.8	3.2	3.4
4.0	3.4	3.6
4.2	3.6	3.8
4.4	3.7	3.9
4.6	3.9	4.1
4.8	4.1	4.3
5.0	4.3	4.5
6.0	5.2	5.4
7.0	6.1	6.4
8.0	7.0	7.3

3.12.2 O_2 measured in the Windbox (Air+FGR)

$O_{2,a+FGR,dry}$	$O_{2,a+FGR,wet}$	
	Nat. gas H/L	**LFO/HFO**
21.0	21.0	21.0
20.8	20.8	20.8
20.6	20.5	20.5
20.4	20.3	20.3
20.2	20.0	20.1
20.0	19.8	19.9
19.8	19.5	19.6
19.6	19.3	19.4
19.4	19.1	19.2
19.2	18.8	19.0
19.0	18.6	18.7
18.8	18.4	18.5
18.6	18.1	18.3
18.4	17.9	18.1
18.2	17.7	17.9
18.0	17.4	17.6
17.8	17.2	17.4
17.6	17.0	17.2
17.4	16.7	17.0
17.2	16.5	16.8
17.0	16.3	16.5
16.8	16.1	16.3
16.6	15.8	16.1
16.4	15.6	15.9
16.2	15.4	15.7
16.0	15.2	15.5

3.13 Theoretical Adiabatic Flame Temperature



4

Overview of SAACKE Burners

4 SAACKE Burners

saacke.com/products

	Burner Series	SSB-LCL	SSB-LCG	SSB-D	SSB	GDG	DDZG-GTM (CHP)	DDZG-GTA (CHP)	DDZG	SKVG-A	SKVG	SKVJG	TEMINOX GL	Tx
Fuels	Light fuel oil	•	•	•	•		•	•	•	•	•	•	•	•
	Heavy fuel oil	•	•	•	•			•	•	•	•	•		
	Natural gas	•	•	•	•	•	•	•	•	•	•	•	•	•
	Propane gas	•	•	•	•	•	•	•	•	•	•	•	•	•
	Biogas	•	•	•	•	•	•	•	•	•	•	•	•	
	Special gaseous fuel, high calorific value	•	•	•	•	•	•	•	•	•	•	•	•	
	Special gaseous fuel, low calorific value		•						•		•		•	
	Special liquid fuel, high calorific value	•	•	•	•			•	•		•	•		
	Special liquid fuel, low calorific value	•							•		•			
	Pulverized fuel			•										
Capacity range of single burners (approx. values)	< 2.5 MW	•	•	•	•		•				•	•		•
	< 3.5 MW	•	•	•	•		•				•	•	•	
	< 5 MW	•	•	•	•	•	•			•	•	•	•	
	< 7 MW	•	•	•	•	•	•	•		•	•	•	•	
	<10 MW	•	•	•	•	•	•	•	•	•	•		•	
	< 14 MW	•	•	•	•	•	•	•	•	•	•		•	
	< 20 MW	•	•	•	•	•	•	•	•	•	•		•	
	< 28 MW	•	•	•	•	•		•	•		•		•	
	< 40 MW	•	•	•	•	•		•	•		•			
	< 56 MW	•	•	•	•	•		•	•		•			
	< 80 MW		•	•	•	•		•	•					
	> 80 MW		•		•	•		•	•					

5

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 m^3 (at STP)/h

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

5.1.2 Influence of the Fan Speed

$$\frac{\dot{V}_2}{\dot{V}_1} = \frac{n_2}{n_1} \qquad \frac{\Delta p_2}{\Delta p_1} = \left(\frac{n_2}{n_1}\right)^2 \qquad \frac{P_2}{P_1} = \left(\frac{n_2}{n_1}\right)^3$$

5.1.3 Influence of Air Density and Air Temperature on Fan Power and Pressure Increase

$$\frac{T_1}{T_2} = \frac{\rho_1}{\rho_2} = \frac{\Delta p_2}{\Delta p_1} = \frac{p_{W1}}{p_{W2}}$$

**T_1 and T_2: Absolute temperatures in K*

5.2 Output Series for Electric Motors

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

5.3 Protection Classes with Enclosures (IP Codes) 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

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

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

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

$\dot{m}_F$ or V_F = fuel consumption in kg/h or m^3 /h
LHV = heating value in kJ/kg or kJ/m^3
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

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

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

$$\dot{V}_{(at\ OTP)} = \dot{V}_{(at\ STP)} \cdot \frac{1{,}013}{1{,}013 + p} \cdot \frac{273 + \vartheta}{273}$$

$$\rho_{(at\ OTP)} = \rho_{(at\ STP)} \cdot \frac{1013 + p}{1013} \cdot \frac{273}{273 + \vartheta}$$

$\dot{V}$ in m^3/h
ρ in kg/m^3
p in mbar (overpressure)
ϑ in °C

5.8 Pressure Loss via a Component through which a Liquid or Gas flows

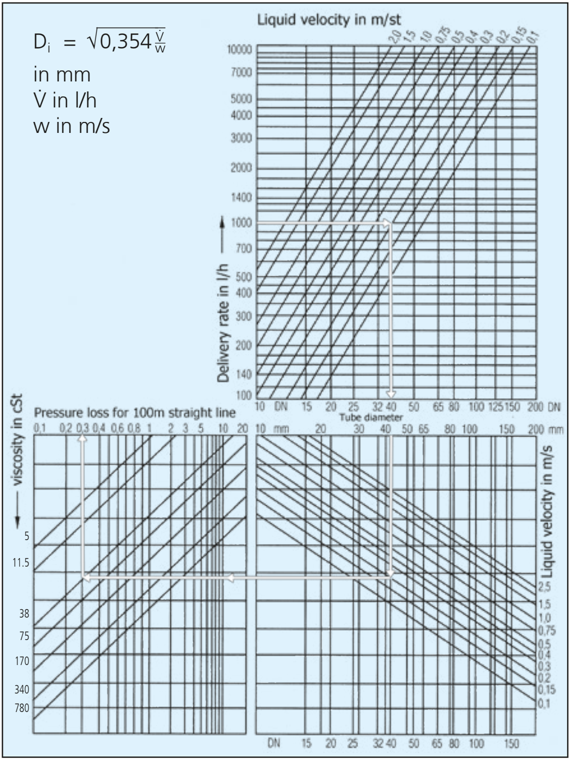
$$\Delta p = \zeta \cdot \frac{\rho}{2} \cdot w^2 \cdot \frac{1}{100} \qquad \text{in mbar}$$

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

5.9 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
	" " – 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
LFO	Suction lines	1
	Pressure lines	1.5 – 2
HFO	Suction lines	0.1 – 0.5
	Pressure lines	0.5 – 1

5.10 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

5.11 Seamless Steel Tubes to EN 10220, Series 1

Nominal bore DN in mm	Suitable for BSPT pipe thread R in inches	Outer diameter D_o in mm	Wall thickness d in mm	Inner diameter D_i in mm	Inner cross-section A in cm²	Tube weight G_1 in kg/m	Volume flow rate at 1 m/s $\dot{V}$ in m³ /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

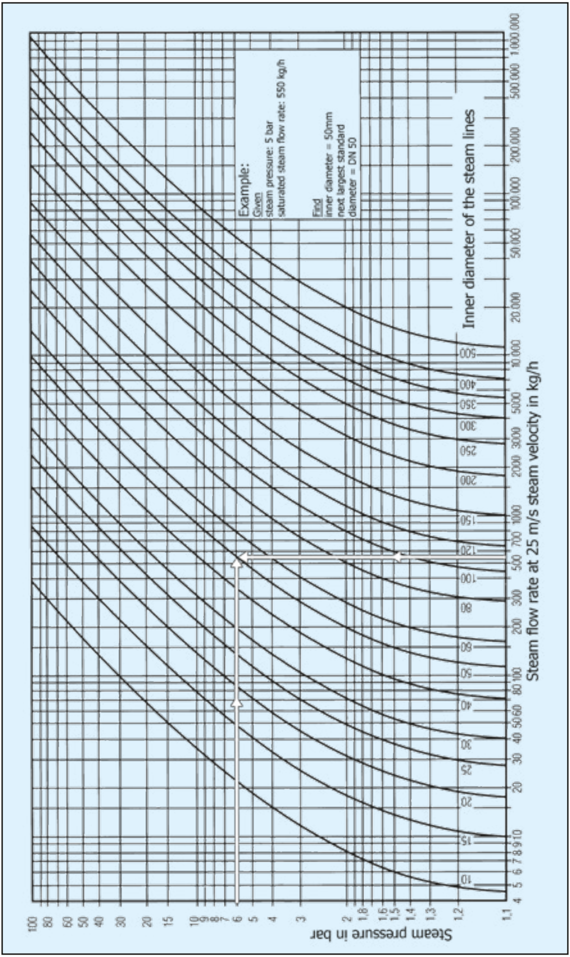
Example:

$\dot{V}$ = 5.25 m³ /h = 5,250 l/h

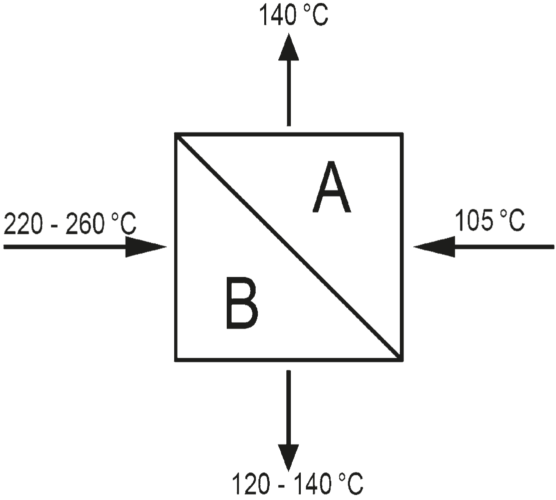
w = 1 m/s

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

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.

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 seperate 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.)

LFO / liquid standard fuels

		NO_x mg/m^3	CO mg/m^3	SO_2 mg/m^3	Dust mg/m^3	Soot no.	Remarks
1st BImSchV 2010-03-22	≤ 120 kW	110 1)	–	–	–	1	
	< 400 kW	120 1)	–	–	–	1	
	< 10 MW	185 1)	–	–	–	1	
	< 20 MW	180 1)6)	80	–	–	1	operating temp. < 110 °C
		200 1) 6)	80	–	–	1	operating temp. ≤ 210 °C
		250 1) 6)	80	–	–	1	operating temp. > 210 °C
4th BImSchV 2013-05-02 ("TA Luft")	< 50 MW	180 1)	80	–	–	1	operating temp. < 110 °C
		200 1)	80	–	–	1	operating temp. ≤ 210 °C
		250 1)	80	–	–	1	operating temp. > 210 °C
	≥ 1 (5) – < 50 MW	350 1)	80	850 2)	–	1	fuel oils except LFO
13th BImSchV 2013-05-02 5)	< 100 MW	180 1)	80	350	10	<1	operating temp. < 110 °C
		200 1)	80	350	10	<1	operating temp. ≤ 210 °C
		250 1)	80	350	10	<1	operating temp. > 210 °C
	< 300 MW	150 3)	80	200	10	<1	
	< 100 MW	300 4)	80	350	10	–	fuel oils except LFO
	< 300 MW	150 3)	80	200	10	–	
	> 300 MW	100 3)	80	150	10	<1	all fuel oils

Natural gas / other gaseous fuels

		NO_x mg/m^3	CO mg/m^3	SO_2 mg/m^3	Dust mg/m^3	Remarks
1st 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
4th BImSchV 2013-05-02 ("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
13th BImSchV 2013-05-02 5)	> 50 MW	100	50	35	5	
	< 300 MW	200	80 - 100	various	5 - 10	other standard fuels
	> 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% $O_{2,dry}$

1) The NO_x emissions for LFO are based on a fuel nitrogen content acc. to EN 267. They may be corrected according to Annex A.

2) The SO_2 emissions for a burner output of up to 5 MW must not be any higher than those from LFO.

3) Annual average must not exceed 100 mg/m^3.

4) Annual average must not exceed 250 mg/m^3.

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

6) Dual-fuel burners that are operated with liquid fuels for less than 300 h/a: 250 mg/m^3.

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_xH_y	Remarks
17th 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 LFO	
Dust	> 25 MW except for LFO	
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 LFO 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

solid content = ash content· 830 + X in mg/m^3

solid content in mg/m^3 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

SO_x content in mg/m^3 =
fuel sulphur content in wt. % · 1,700

fuel sulphur content:

HFO approx.	1.0 wt. % ≙ 10000 mg/kg
LFO approx.	0.015 wt. % ≙ 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 ($O_{2,\ dry}$ 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

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

E ≙ 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

1 ppm CO = 1.25 mg CO/m^3
1 ppm NO ⇨ 2.05 mg NO_2/m^3*
1 ppm NO = 1.34 mg NO/m^3
1 ppm SO_2 = 2.93 mg SO_2/m^3

**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 mg NO_2/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 to15 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 10 g/kg and a temperature of 20 °C (reference conditions)

For this calculation the temperature ϑ_{meas} must be within a tight range:
- for LFO between 15 and 30 °C
- for 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 in mg/kg**
N_{ref} = reference value for the nitrogen content

Use N_{ref} = 140 mg/kg for burner capacities ≥ 10MW
Use N_{ref} = 0 mg/kg for burner capacities < 10 MW

** According to EN267; symbols harmonised*
*** Should not exceed 200 mg/kg*

6.6 Acid Dew Points and Minimum Flue Gas Temperatures

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

**1% sulphur content*

6.7 Emissions Conversion

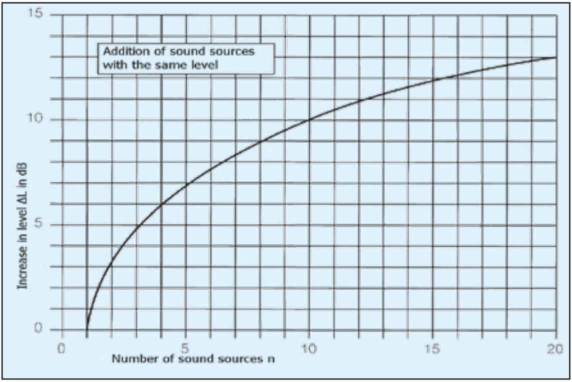
	ppmv 0% O_2, dry	ppmv 3% O_2, dry	mg NO_x/kg fuel	mg NO_x/m³ (at STP) fuel	mg NO_x/m³ (at STP) dry flue gas , 3% O_2	mg NO_x/MJ (LHV)	mg NO_x/kWh or g NO_x/MWh
ppmv 0% O_2, dry	1	0.87	23.39	19.84	1.78	0.49	1.76
ppmv 3% O_2, dry	1.15	1	27.29	23.15	2.05	0.57	2.05
mg NO_x/kg fu-el	0.043	0.037	1	0.85	13.29	0.021	0.075
mg NO_x/m³ (at STP) fuel	0.050	0.043	1.18	1	0.089	0.025	0.089
mg NO_x/m³ (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

Example

Given: 83.5 mg/m³ NO_x at 3% O_2
Wanted: NO_x in mg/MJ (rel. to LHV)

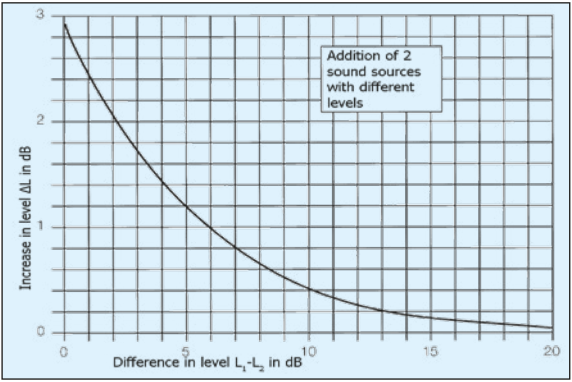
Solution: 83.5·0.28 mg/MJ NO_x = **23.4 mg/MJ NO_x**

6.8 Addition of the Sound Levels of Several Sound Sources



Example:
2 sound sources with 80 dB each

difference in level : 3 dB
total level : 83 dB



Example:
sound source 1: 80 dB
sound source 2: 75 dB

difference in level : 5 dB
increase in the level : 1.2 dB
total level : 81.2 dB

7

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]

$$CR = S + W$$

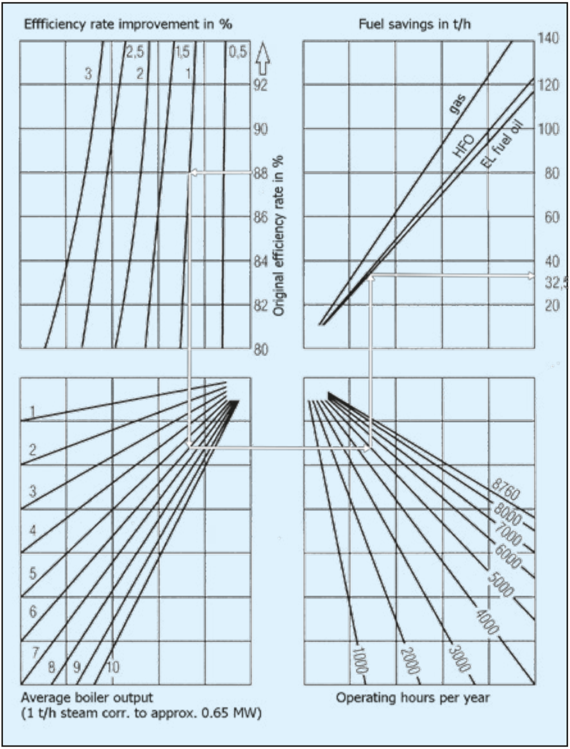
6. Calculation of the amortisation / pay-off period / pay-back period [PB]

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

7. Calculation of the return on investment [ROI] / yield*
**You can also use $\frac{C}{2}$ 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 LFO per year.

7.3 Calculation of the Gross and Net Price of Heat

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

$$\text{net heat price} [€/GJ] = \frac{\text{gross heat price } [€/GJ] \cdot 100\%}{\text{annual operating efficiency rate } \%}$$

Average annual operating efficiency rates*

with LFO	82%
with HFO	81%
with natural gas and liquid gas	83%

**assuming an optimum combustion efficiency rate*

Example calculation:

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

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

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

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 298	Automatic burner control systems for burners and appliances burning gaseous or liquid fuels
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
Directive 2014/34/EC	of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres
Directive 2006/42/EC	of the European Parliament on Machinery **("Machinery Directive")**
Directive 2014/68/EC	of the European Parliament and of the Council of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment **("Pressure Equipment Directive")**

Directive 2009/142/EC	of the European Parliament and of the Council of 30 November 2009 relating to appliances burning gaseous fuels **("Gas Appliance Directive")**
Regulation (EU) 2016/24	of the European Parliament and of the Council of 9 March 2016 on appliances burning gaseous fuels and repealing Directive 2009/142/EC **("Gas Appliance Regulation")**
Directive 2014/35/EC	of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits **("Low Voltage Directive")**
Directive 2009/104/EC	of the European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work
EN ISO 23553	Safety and control devices for oil burners and oil-burning appliances
EN 12067-2	Safety and control devices for burners and appliances burning gaseous or liquid fuels – Control functions in electronic systems – Part 2: Fuel/air ratio control/supervision of the electronic type
EN ISO 13849	Safety of Machinery – Safety-related parts of control systems

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_3H_8
T2	surface temperature < 300°C	Cyclohexanone
T3	surface temperature < 200°C	H_xS_y
T4	surface temperature < 135°C	Acetaldehyd
T5	surface temperature < 100°C	-
T6	surface temperature < 85°C	C_xS_y

8.2.7 Complete Designation (Example)

	II 2G EEx d IIC T4

Nomenclature

Conventions

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

Abbreviations and Symbols

A	area
c	concentration
cos φ	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
$\dot{q}$	heat release rate
$\dot{Q}$	burner output
r	latent heat of vaporisation
R	pipe thread
R	electric resistance
RR	flue gas recirculation rate
STP	standard temperature and pressure
T	Temperature
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
FGR	flue gas recirculation
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
RV	flue gas recirculation proportion
s	steam
sat	saturation
sh	shaft
st	stoichiometric
sta	static
std	standard
wet	wet

Notes

Notes

SAACKE Group Worldwide.

With service stations in more than 20 countries around the world, more than 70 international agents and a range of service centers in all of the key ports, we can be found wherever our customers need us.

↘ Germany

- Head Office in Bremen
- Development & burner production in Bremen
- Sales and service locations for industrial combustion systems and marine systems

↘ Europe

- SAACKE Austria
- SAACKE Benelux
- SAACKE Finland
- SAACKE France
- SAACKE Poland
- SAACKE Romania
- SAACKE Russia
- SAACKE Switzerland
- SAACKE Serbia
- SAACKE Spain
- SAACKE Turkey
- SAACKE UK
- Marine boiler production in Zagreb, Croatia

↘ Asia

- SAACKE China
- SAACKE Korea
- SAACKE Malaysia
- SAACKE Singapore
- SAACKE Vietnam
- Marine boiler production in Qingdao, China

↘ America

- SAACKE Argentina
- SAACKE Brazil
- SAACKE North America/USA

↘ Africa, Middle East

- SAACKE South Africa

↘ Australia

- SAACKE Australia

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