Planner Guide

Industrial Boiler – Steam Systems 2

Hoval

Medium to big size steam boilers

Supplementation to Steam Systems 1

planning
planning
planning

1 System Description

The **Hoval steam system "1"** was developed to provide for the following applications a medium/high output of saturated steam where simple, safely and **cost-efficient solutions** are necessary.

- **Medium to big sized soft drink manufacturers**
  (steam for bottle washing and production)
- **Brick- and building material industry**
  (steam for production)
- **Food industries**
  (steam for production)
- **Big laundries**
  (steam for washing machines and ironing)
- **Hospitals**
  (steam for cooking, supply to heat exchangers – sterilization)
- **Textile industries**
  (steam for production)
- **Big sized Breweries**
  (steam for brewing procedures)
- **Big sized paper and cellulose industries**
  (steam for production)
- **Pharmacy industries**
  (steam for production)
- **Chemical industries**
  (steam for production)
- **Auxiliary steam boilers for power plants**
- **City district steam suppliers**

Principally anywhere, where steam is necessary as a heat carrier or as a power transmission force.

Steam plays an important role in many processes as energy carrier or driving force. More and more emphasis is laid on a highest possible efficiency and a lowest possible environmental harm.

Steam boilers do also represent a danger potential though. The equipment, as well as the installation and operation of steam boiler plants are therefore legally ruled in many countries, e.g. by
- 97/23/EG European pressure devices – Guiding rule
- EN 12953
- TRD

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Benefit of steam

Steam has some outstanding characteristics:
• High pressure for drive of machines
• High temperature for technical processes
• Flow to consumers without extern energy (pumps)
• Steam transfer through small pipe dimensions

The medium temperature does not change in evaporation and condensation process

In addition to the above also our best cost of ownership philosophy has been taken in consideration which means, the best price value for the end-user.

This takes in consideration the following aspects:

Planning costs	1. Planning
Procurement costs	2. Purchase
	3. Product
	4. Administration
Installation costs	5. Installation
	6. System integration
	7. Commissioning
Operating costs	8 .Operating
	9. Environmental
	10. Maintenance
Service costs	11. Service
Disposal costs	12. Disposal

1. Planner: Easy to plan (providing fast information in the required quality and quantity)
2. Installer: Easy to purchase (one order, one supplier)
3. Owner: Product costs are not necessarily to be low (high quality material and manufacturing, high efficiency, Swiss engineered products)
4. Installer: Administration cost (responsible one stop shop)
5. Installer: Installation cost (principle P&I including all information and supply of components for a perfect functional system)
6. Installer: System integration (Hoval System technology and controls matches all building requirements, eg. BMS, lead lag, etc.)
7. Installer: Commissioning costs (since all components match from the beginning,checked by Hoval engineers and Hoval on site engineers fast commissioning is possible)
8. Owner: Running cost (high efficiency, engineered products with focus to conservation of energy and environment lead to low running cost. Cheap products are not always cheap in the long run time.)
9. Owner: Environmental costs (all our products comply with the latest regulations and they are even better)
10. Owner: Maintenance costs (engineered products with focus to easy maintenance lead to lower costs)
11. Owner: Service cost's (engineered quality products usually need less Service in life)
12. Owner: Disposal cost's (Construction in combination with the selected materials allow a cost effective disposal)

Hoval is worldwide known as technological leading supplier of innovative easy- systems for heat and ventilation technology with a high measurably economical and ecological added value for the customer.

Innovative easy-systems with measurable added value

■ Disposal costs
■ Service costs
■ **Operating costs**
■ Installation costs
■ Procurement costs
■ Planning costs

Hoval   Competitor
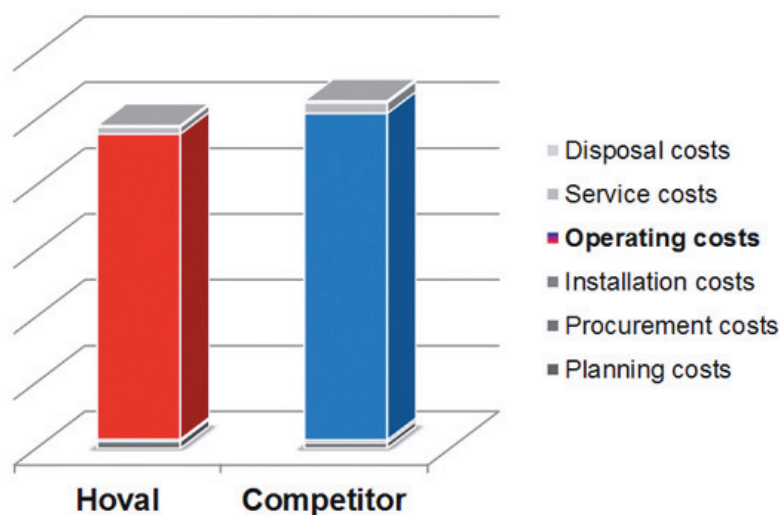
Last but not least, a Hoval steam system provides you the following advantages:
- Long life time of boiler, thanks the internal construction.
- Less fuel consumption since our steam systems operate on highest efficiency
- Reduced heat transmission loss of boilers due to completely watercooled boiler walls
- More safety by using 2 boilers smaller capacity instead of one large boiler
- Easy to be operated by boiler operator
- Lower investment cost for a split system (small steam system for steam demand and all the rest heated with hot water system). This gives best efficiency and load rates for both systems!
- Less pipe work, fittings (boiler could be supplied completely "preinstalled")
- More than 35 years experience on steam and superheated hot water systems

and finally, behind all you will find the Hoval family, friendly, professional, solution oriented, enthusiastic and responsible for energy and environment.

2 Product overview

Hoval steam boiler series THSD-I...E   (size 2000 – 22000 kg/h), steam pressure 10, 13, 16 bar(g)

Hoval feedwater tanks "SPW-E"   (size > 3000 - 30000 L/0,5 bar(g))

Hoval feedwater pumps

Hoval switchboards and SPS-controls

Hoval selected and matched control valves, safety valves, pressure gauges, sensors, etc.

3 Benefit of Hoval steam boilers

Compact 3-pass boiler construction according actual EN-norms (mainly EN 12953 and PED – 97/23/EG)

Natural circulation boiler with good purge possibilities

Flame tube dimensioned according actual burner technology

Relative thin turning chamber head results in a very good connection between distance of smoke tubes comparing to turning chamber head thickness and an optimized flexibility against heat tensions.

100% water cooled turning chamber back wall made from seamless fin-tubes, no anchors necessary and extension of heat transfer area at the „hot zone" of the boiler.

Good insulation – without metallic supports

Big water space – insensible against moving load peaks

High efficiency rate – up to higher then 90% – without eco

Easy to be equipped with economizer (on request)

Very good cleaning possibilities (easy to swivel boiler front door, no turbulators at the boiler smoke gas tubes)

Easy to maintain – except fire proof concrete at boiler front door there´s no other concrete at the boiler.

Reliable due to long year experience on boiler production and design.

Boiler could be supplied completely (mechanically and electrically) installed – so there´s a lot less work to do on site.

Efficiency coded according real boiler operation temperature

Boiler safety instrumentation with 1 safety pressure limiter, 2 safety valves and 2 independent water level insufficiency electrodes.

4 System P & I Diagram

steam to system

steam distributor

reserve

Hoval steam boiler

cooling water

sampling cooler

main steam pipe

to free air

to free air

NW

ECO

compressed air

flash tank

ventilation

cooling water

blow down expansion

sewer

Legend:

Symbol	Description		Symbol	Description		Symbol	Description		Symbol	Description		Symbol	Description
	shut off armature		TI	temperature indicator			overflow valve		PT	pressure sensor			electric actuated valve
	ball valve		PI	pressure indicator			pressure reducing valve		TS	thermostate			3 way electric actuated valve
	regulating valve		TT	temperatur transmitter			recirculation valve		PS	pressure switch			solenoid valve
	3 way valve		TC	temperatur control			safety valve		TZA	safety thermostate			pneumatic actuated valve
	Burner			on-site indication			control room indication			control SPS			flue gas compens.
	water level indicator			blind flange			border of delivery						

Hydr.	Verbindungshinweis / Notice / Nota / Remarque:
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1	

PZA	safety pressure switch	foot operated purge valve	**FS**	flow control switch	shut off flap	ignite-gas-burner
TA	safety temperature sensor	pressure regulated valve	**LI**	reflex level gauge	pneumatic flap	proval burner
QC	conductivity control	strainer	**LS**	level switch	**LZA−** water insuffiency control	orifice
FIQ	flow indicator with counter	non return flap	**LC**	continuous level control	**LZA+** overfill control	reduction
	pump	fan		gauge glas	condensate trap	filter

**P&I diagram steam boiler plant
with additional equipment**

Hoval

Achtung! Für die Installation muss das anlagenbezogene Schema verwendet werden!
Attention! This is just a schematic. For installation please use the detail-plan!
Attenzione! Per la messa in opera, utilizzare le schema dettagliato!
Attention! Pour la réalisation pratique de l'installation, il faut utiliser le schéma détaillé!

	Datum	Name
	17.01.2012	...
Version ...		...
Datei: ...		

5 Design Basics   *(See our tutorial Steam Systems 1, page 12)*

6 Steam boilers control systems   *(See our tutorial Steam Systems 1, page 13)*

7 Saturated steam tables – part 1   *For details (freeware – download) see: www.x-eng.com*

Absolute pressure p bar	Temperature t °C	Steam volume v" m³/kg	Steam density ϱ kg/m³	Water enthalpy h' kJ/kg	Steam enthalpy h" kJ/kg	Evaporation enthalpy r kJ/kg
0,010	6,98	129,200	0,008	29,34	2514,4	2485,0
0,015	13,04	87,980	0,011	54,71	2525,5	2470,7
0,020	17,51	67,010	0,015	73,46	2533,6	2460,2
0,025	21,10	54,260	0,018	88,45	2540,2	2451,7
0,030	24,10	45,670	0,022	101,00	2545,6	2444,6
0,035	26,69	39,480	0,025	111,85	2550,4	2438,5
0,040	28,98	34,800	0,029	121,41	2554,5	2433,1
0,045	31,04	31,140	0,032	129,99	2558,2	2428,2
0,050	32,90	28,190	0,035	137,77	2561,6	2423,8
0,055	34,61	25,770	0,039	144,91	2564,7	2419,8
0,060	36,18	23,740	0,042	151,50	2567,5	2416,0
0,065	37,65	22,020	0,045	157,64	2570,2	2412,5
0,070	39,03	20,530	0,049	163,38	2572,6	2409,2
0,075	40,32	19,240	0,052	168,77	2574,9	2406,2
0,080	41,53	18,100	0,052	173,86	2577,1	2403,2
0,085	42,69	17,100	0,055	178,69	2579,2	2400,5
0,090	43,79	16,200	0,058	183,28	2581,1	2397,9
0,095	44,83	15,400	0,062	187,65	2583,0	2395,3
0,10	45,83	14,670	0,065	191,83	2584,8	2392,9
0,15	54,00	10,020	0,100	225,97	2599,2	2373,2
0,20	60,09	7,650	0,131	251,45	2609,9	2358,4
0,25	64,99	6,204	0,161	271,99	2618,3	2346,4
0,30	69,12	5,229	0,191	289,30	2625,4	2336,1
0,40	75,89	3,993	0,250	317,65	2636,9	2319,2
0,45	78,74	3,576	0,280	329,64	2641,7	2312,0
0,50	81,35	3,240	0,309	340,56	2646,0	2305,4
0,55	83,74	2,964	0,337	350,61	2649,9	2299,3
0,60	85,95	2,732	0,366	359,93	2653,6	2293,6
0,65	88,02	2,535	0,395	368,62	2656,9	2288,3
0,70	89,96	2,365	0,423	376,77	2660,1	2283,3
0,75	91,79	2,217	0,451	384,45	2663,0	2278,6
0,80	93,51	2,087	0,479	391,72	2665,8	2274,0
0,85	95,15	1,972	0,507	398,63	2668,4	2269,8
0,90	96,71	1,869	0,535	405,21	2670,9	2265,6
0,95	98,20	1,777	0,563	411,49	2673,2	2261,7
1,00	99,63	1,694	0,590	417,51	2675,4	2257,9
1,5	111,37	1,159	0,863	467,13	2693,4	2226,2
2,0	120,23	0,885	1,129	504,70	2706,3	2201,6
2,5	127,43	0,718	1,392	535,34	2716,4	2181,0
3,0	133,54	0,606	1,651	561,43	2724,7	2163,2
3,5	138,87	0,524	1,908	584,27	2731,6	2147,4
4,0	143,62	0,462	2,163	604,67	2737,6	2133,0
4,5	147,92	0,414	2,417	623,16	2742,9	2119,7
5,0	151,84	0,375	2,669	640,12	2747,5	2107,4
5,5	155,46	0,343	2,920	655,78	2751,7	2095,9
6,0	158,84	0,316	3,170	670,42	2755,5	2085,0
6,5	161,99	0,293	3,419	684,12	2758,8	2074,0
7,0	164,96	0,273	3,667	697,06	2762,0	2064,9
7,5	167,75	0,255	3,915	709,29	2764,8	2055,5
8,0	170,41	0,240	4,162	720,94	2767,5	2046,5
8,5	172,94	0,227	4,409	732,02	2769,9	2037,9
9,0	175,36	0,215	4,655	742,64	2772,1	2029,5
9,5	177,66	0,204	4,901	752,81	2774,2	2021,4
10	179,88	0,194	5,147	762,61	2776,2	2013,6

8 Saturated steam tables – part 2

For details (freeware – download) see: www.x-eng.com
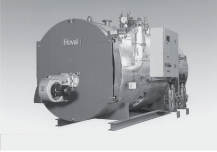
Absolute pressure	Temperature	Steam volume	Steam density	Water enthalpy	Steam enthalpy	Evaporation enthalpy
p	t	v"	ϱ	h'	h"	r
bar	°C	m³/kg	kg/m³	kJ/kg	kJ/kg	kJ/kg
10,5	181,98	0,185	5,39	771,87	2777,95	2006,05
11	184,07	0,175	5,64	781,13	2779,70	1998,50
11,5	186,02	0,169	5,88	789,78	2781,20	1991,40
12	187,96	0,163	6,13	798,43	2782,70	1984,30
12,5	189,79	0,157	6,37	806,57	2784,05	1977,50
13	191,61	0,151	6,617	814,70	2785,4	1970,7
13,5	193,33	0,146	6,86	822,39	2786,60	1964,20
14	195,04	0,141	7,106	830,08	2787,8	1957,7
14,5	196,67	0,136	7,35	837,38	2788,85	1951,45
15	198,29	0,132	7,596	844,67	2789,9	1945,2
15,5	199,83	0,128	7,84	851,62	2790,80	1939,20
16	201,37	0,124	8,085	858,56	2791,7	1933,2
16,5	202,84	0,120	8,33	865,20	2792,55	1927,35
17	204,31	0,117	8,575	871,84	2793,4	1921,5
17,5	205,71	0,113	8,82	878,21	2794,10	1915,90
18	207,11	0,110	9,065	884,58	2794,8	1910,3
18,5	208,46	0,108	9,31	890,70	2795,45	1904,80
19	209,80	0,105	9,555	896,81	2796,1	1899,3
19,5	211,09	0,102	9,80	902,70	2796,65	1893,95
20	212,37	0,100	10,05	908,59	2797,2	1888,6
20,5	213,61	0,097	10,30	914,28	2797,70	1883,40
21	214,85	0,095	10,54	919,96	2798,2	1878,2
22	217,24	0,091	11,03	930,95	2799,1	1868,1
23	219,55	0,087	11,52	941,60	2799,8	1858,2
24	221,78	0,083	12,02	951,93	2800,4	1848,5
25	223,94	0,080	12,51	961,96	2800,9	1839,0
26	226,04	0,077	13,01	971,72	2801,4	1829,6
27	228,07	0,074	13,51	981,22	2801,7	1820,5
28	230,05	0,071	14,01	990,48	2802,0	1811,5
29	231,97	0,069	14,51	999,53	2802,2	1802,6
30	233,84	0,067	15,01	1008,4	2802,3	1793,9
31	235,65	0,065	15,52	1016,90	2802,30	1785,40
32	237,45	0,062	16,02	1025,4	2802,3	1776,9
34	240,88	0,059	17,03	1041,8	2802,1	1760,3
36	244,16	0,055	18,05	1057,6	2801,7	1744,2
38	247,31	0,052	19,07	1072,7	2801,1	1728,4
40	250,33	0,050	20,10	1087,4	2800,3	1712,9
42	253,24	0,047	21,14	1101,6	2799,4	1697,8
44	256,05	0,045	22,18	1115,4	2798,3	1682,9
46	258,75	0,043	23,24	1128,8	2797,0	1668,3
48	261,37	0,041	24,29	1141,8	2795,7	1653,9
50	263,91	0,039	25,36	1154,5	2794,2	1639,7
55	269,33	0,036	28,07	1184,9	2789,9	1605,0
60	275,55	0,032	30,83	1213,7	2785,0	1571,3
65	280,82	0,030	33,65	1241,1	2779,5	1538,4
70	285,79	0,027	36,53	1267,4	2773,5	1506,0
75	290,50	0,025	39,48	1292,7	2766,9	1474,2
80	294,97	0,024	42,51	1317,1	2759,9	1442,8
85	299,23	0,022	45,61	1340,7	2752,5	1411,7
90	303,31	0,021	48,79	1363,7	2744,6	1380,9
95	307,21	0,019	52,06	1386,1	2736,4	1350,2
100	310,96	0,018	55,43	1408,0	2727,7	1319,7
110	318,05	0,016	62,48	1450,6	2709,3	1258,7
120	324,65	0,014	70,01	1491,8	2689,2	1197,4
130	330,83	0,013	78,14	1532,0	2667,0	1135,0
140	336,64	0,012	86,99	1571,6	2642,4	1070,7
150	342,13	0,010	96,71	1611,0	2615,0	1004,0
160	347,33	0,009	107,4	1650,5	2584,9	934,3
170	352,66	0,008	119,5	1691,7	2551,6	859,9
180	356,96	0,007	133,4	1734,8	2513,9	779,1
190	361,43	0,007	149,8	1778,7	2470,6	692,0
200	365,70	0,006	170,2	1836,5	2418,4	591,9
220	373,69	0,004	268,3	2011,1	2195,6	184,5
221,20	374,15	0,003	315,5	2107,4	2107,4	0

9 Technical details for industrial boilers

See external catalogue

Industrial Boiler

Hoval

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10 Selection of burners / technical data for boilers up to ~ 20 to/h steam capacity

Part 1:

To select the burner you need to know the following data:

Fuel type:	natural gas (example)
Supply pressure	300 mbar (example)
Mode of the burner	modulating burner (example)
Boiler load	4564 kW (example)

Flame tube length	3700 mm (example)
Flame tube diameter	900 mm (example)
Boiler flue gas side resistance	13,0 mbar (example)
Boiler efficiency at (full load)	94,0 % (example)
or **Burner capacity**	5088 kW (example)

> Note: Hoval industrial boilers are produced with direct burner connections to boiler front door (no adapter flange necessary) – so it´s absolutely necessary to know the exact burner type and dimensions before ordering the boiler!

If the burner is not an "mono bloc burner" (with integrated combustion air fan) but a "duo-bloc" burner (with separate combustion air fan) please observe necessary space for installation of fan and that it´s necessary to install a "air duct" between fan and burner (For duct design please observe max. static pressure of fan which could be up to > 600 mbar. Don't use "standard duct elements for building climate systems). For "duo bloc" installations please don´t forget that the boiler door must be opened for cleaning and "air duct" has to be removed – use compensators for vibration absorption, easy removal of duct and adaptation of placement differences.

For more details about burner selection see list below and Hoval technical catalogue:

Part 2:

Boiler type	Boiler capacity max. [kW]	Boiler capacity norm. [kW]	Boiler – Flame tube length [mm]	Boiler flame tube diameter inside/outside [mm]	Smoke gas resistance without ECO max/norm. [mbar]	Smoke gas resistance with ECO max/norm. [mbar]	Turning chamber length [mm]	Burner head length [mm]	Burner capacity without Eco max/norm. [kW]	Burner capacity with Eco max/norm. [kW]
THSD-I E 55/50-10 bar	3586	3260							4005/3629	3798/3453
13 bar	3596	3271	3500	850	12,5/10	15,5/13	380	300	4040/3661	3809/3465
16 bar	3606	3278							4068/3686	3820/3472
THSD-I E 70/60-10 bar	4564	3912							5088/4340	4834/4144
13 bar	4579	3925	3700	900	13/10,5	16/13,5	380	300	5132/4428	4850/4157
16 bar	4590	3934							5169/4408	4862/4167
THSD-I E 90/80-10 bar	5868	5216		1000 .					6607/5846	6216/5525
13 bar	5888	5234	4200	1000	40860	16/14	380	300	6665/5898	6237/5544
16 bar	5901	5246		1000/1050					6699/5929	6251/5557
THSD-I E 110/100-10 bar	7172	6520		1050					8076/7315	7597/6906
13 bar	7196	6542	4550	1050	15/13	18/16	380	300	8148/7380	7623/6930
16 bar	7213	6557		1050/1200					8192/7420	7640/6946
THSD-I E 130/120-10 bar	8476	7824		1100					9532/8771	8979/8288
13 bar	8505	7850	4950	1100/1250	15/13	18/16	380	300	9593/8827	9009/8315
16 bar	8524	7868		1100/1250					9658/8888	9029/8334
THSD-I E 150/140-10 bar	9780	9128		1150					10995/10234	10360/9669
13 bar	9813	9159	5250	1150/1300	15/13	18/16	380	300	11076/10311	10395/9702
16 bar	9835	9180		1150/1300					11152/10385	10418/9724
THSD-I E 170/160-10 bar	11084	10432		1200					12478/11716	11741/11050
13 bar	11121	10467	5550	1200/1350	15/13	18/16	380	300	12569/11802	11780/11087
16 bar	11147	10491		1200/1350					12656/11884	11808/11113
THSD-I E 190/180-10 bar	12388	11736		1250					13976/13210	13122/12432
13 bar	12430	11776	5750	1250/1400	15/13	18/16	380	300	14077/13306	13167/12474
16 bar	12458	11802		1250/1400					14173/13395	13197/12502
THSD-I E 220/200 10 bar	14344	13040							16142/14620	15195/13813
13 bar	14392	13084	6250	1300/1450	15/13	18/16	380	300	16286/14749	15245/13860
16 bar	14425	13114							16399/14852	15280/13892

11 Properties of some supply fuel oils (av. values - physical standard condition)

Parameters	Symbol	Unit	Extra-light fuel oil (diesel)	Heavy fuel oil
Calorific value	LCV	MJ/kg	42,7	40,7
	LCV	kWh/kg	11,86	11,3
	LCV	Mcal/kg	10,2	9,72
Density at 15 °C	$\rho 15$	kg/l	0,84	0,96
Flame point	ΔF	°C	70	120
Viscosity				
at 20 °C	v	mm²/s	Max. 6	-
at 50 °C	v	mm²/s	2	Max. 50
at 100 °C	v	mm²/s	-	30
Combustion value at $\lambda = 1$				
Air consumption	vL	m³/kg	11,0	10,7
Smoke gas volume dry	vA,tr	m³/kg	10,3	10,0
Smoke gas volume – wet	vA,f	m³/kg	11,8	11,4
Water quantity at smoke gas	vH_2O	m³/kg	1,5	1,4
Max. Carbon dioxide	CO_2,max	Vol.-%	15,5	15,9
Contents:				
Carbon	C	Weight-%	86	84
Hydrogen	H	Weight-%	13	12
Sulphur	S	Weight-%	< 0,2 (< 0,1)	< 2,8 (changes possible)
Oxygen	O_2	Weight-%	0,4	0,5
Nitrogen	N	Weight-%	0,02	0,3
Water	H_2O	Weight-%	0,4	0,4

12 Properties of some supply gases   (av. values - physical standard condition)

Parameters	Symbol	Unit	Natural gas "L"	Natural gas "H"	Propane C_3H_8	Butane C_4H_{10}
Calorific value	LCV	kWh/m³	8,83	10,0	25,9	34,4
	LCV	MJ/m³	31,8	36,0	93,2	123,8
	LCV	Mcal/m³	7,59	8,6		
Explosion limit (Vol % gas/air, at 20°C)						
Lowest limit	LFL	Vol.-%	5	4	2,1	1,4
Highest limit	HFL	Vol.-%	15	16	9,0	9,3
Density	ρ	Kg/m³	0,829	0,784	2,011	2,708
Relative Density	d	Kg/m³	0,641	0,606	1,555	2,094
Combustion value at λ =1						
Air consumption	vL	m³/m³	8,36	9,47	24,37	32,37
Smoke gas volume dry	vA,tr	m³/m³	7,64	8,53	22,81	29,74
Smoke gas volume – wet	vA,f	m³/m³	9,36	10,47	26,16	34,66
Max. Carbon dioxide	CO_2,max	Vol.-%	11,8	12,00	13,7	14,0
Water quantity at smoke gas (related to input gas quantity)	vH_2O	m³/m³	1,72	1,94	3,29	4,2
Dew point (dry combustion air)	∆T	°C	58	58	54	53
Contents:						
Nitrogen	N_2	Vol.	14	3,1	-	-
Oxygen	O_2	Vol.	-	-	-	-
Carbon dioxide	CO_2	Vol.	0,8	1,0	-	-
Hydrogen	H_2	Vol.	-	-	-	-
Carbon monoxide	CO	Vol.	-	-	-	-
Methan	CH_4	Vol.	81,8	92,3	-	-
Ethan	C_2H_6	Vol.	2,8	2,0	-	-
Propane	C_3H_8	Vol.	0,4	1,0	100	-
Butan	C_4H_{10}	Vol.	0,2	0,6	-	100

13 Excess of air – calculation

$$\lambda = \frac{V_L}{V_{L\,(st\ddot{o})}} \approx \frac{CO_{2,max}}{CO_{2,metered}} \approx \frac{21\%}{(21\% - O_{2,metered})}$$

$$\lambda = 1 + \left(\frac{CO_{2,max}}{CO_{2,metered} - 1}\right) * \frac{V_{tr,st\ddot{o}}}{V_{L,st\ddot{o}}}$$

$$\lambda = 1 + \left(\frac{O_{2,\,metered}}{21 - O_{2,\,metered}}\right) * \frac{V_{tr,st\ddot{o}}}{V_{L,st\ddot{o}}}$$

Guide value for $V_{tr,st\ddot{o}}/V_{L,st\ddot{o}}$

	Natural gas	Propane	Fuel oil extra light (diesel)	Heavy fuel oil
$V_{tr,st\ddot{o}}/V_{L,st\ddot{o}}$	0,91	0,93	0,93	0,94

Effective dry smoke gas quantity

$$V_{tr} = V_{tr,\,st\ddot{o}} + (\lambda - 1) * V_{L,\,st\ddot{o}}$$

Effective wet smoke gas quantity

$$V_f = V_{f,\,st\ddot{o}} + (\lambda - 1) * V_{L,\,st\ddot{o}}$$

λ = Excess air value

V_L = Effective air quantity m^3(i.N.)/kg (or m^3)

$V_{L,st\ddot{o}}$ = stoichiometrical air quantity m^3 (i.N.)/kg (or m^3/m^3 i.N.)

V_f = Effective smoke gas quantity (wet) m^3 (i.N.)/kg (or m^3/m^3 i.N)

$CO_{2,max}$ = max. CO_2-content at stoichiometrical combustion (Vol %)

$CO_{2,metered}$ = CO_2-content (Vol.-%)

$V_{tr,st\ddot{o}}$ = Effective smoke gas quantity (dry) m^3 (i.N.)/kg (or m^3/m^3 i.N) at stoichiometrical combustion

O_2 = O_2-content – dry (Vol.-%)

14 Comparison between smoke gas flow in Nm³/h and kg/h

Sometimes there´s a need to know the smoke gas flow in Nm³/h or in kg/h while having the other value only. So we´ve done a comparison list for some fuels.

General notes:
1.) The smoke gas flow in kg/h depends to fuel quality and smoke gas quality (especially CO2-content)
2.) Exact calculation must be done according EN 13384 - but it´s necessary to know the efficiency, the air humidity etc. for this calculation
3.) Exact figures for calculation of factors has to be done by knowing "dry smoke gas volume, wet smoke gas volume and water content of smoke gas" by using special software programs.

Following tables gives approximate figures for easy/quick calculations.
Calculation base: 10 kW capacity - efficiency 100%

Important note:
• These values are "approximate" values but exact enough to have a quick answer.
• It´s necessary to know the CO_2-figure/or "Lambda" and the used fuel to work with these flow charts.

How to work with the comparison figures:
Knowing the used fuel and the CO_2-value look to the comparison table and search the needed factor.

Example:
Natural gas, CO_2 value = 10,0 gives comparison factor 1,18

By multiplication of Nm³/h value with the correction factor you´ll receive the smoke gas flow in kg/h.

Result: 100 Nm³/h smoke gas are 118 kg/h

14.1. Smoke gas flow/comparison for natural gas firing)

A) For smoke gas "natural gas firing" (LCV = 36000 kJ/Nm^3, CO$_2$ max = 11,8%)

Smoke gas for natural gas firing
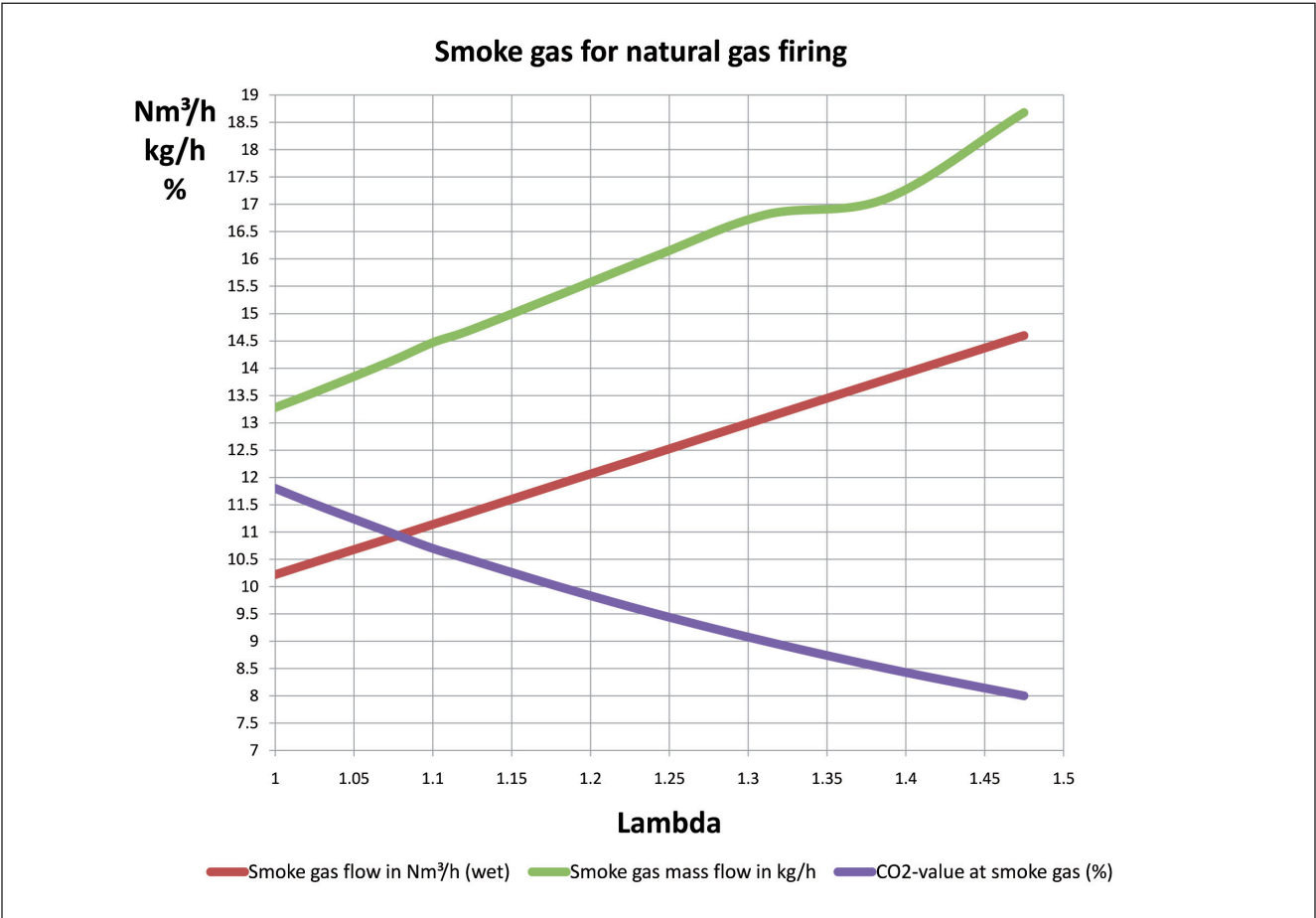
Approximate correction figures for natural gas firing:

Lambda	1	1,026	1,072	1,1	1,123	1,18	1,242	1,311	1,388	1,475
Correction value (multiplier) from Nm³/h to kg/h	1,299	1,297	1,296	1,298	1,294	1,291	1,289	1,284	1,283	1,279
Smoke gas flow in Nm³/h (wet)	10,22	10,46	10,88	11,14	11,35	11,88	12,45	13,09	13,8	14,6
Smoke gas mass flow in kg/h	13,28	13,57	14,11	14,47	14,69	15,34	16,06	16,81	17,11	18,68
CO$_2$-value at smoke gas	11,8	11,5	11	10,7	10,5	10	9,5	9	8,5	8

14.2   Smoke gas flow/comparison for light oil (diesel oil) firing

B) For smoke gas "light oil – diesel firing" (LCV = 42700 KJ/kg, CO_2 max = 15,4%)

Smoke gas for light oil diesel firing

Nm³/h
kg/h
%

Lambda

— Smoke gas flow in Nm³/h (wet)   — Smoke gas mass flow in kg/h   — CO2-value at smoke gas (%)
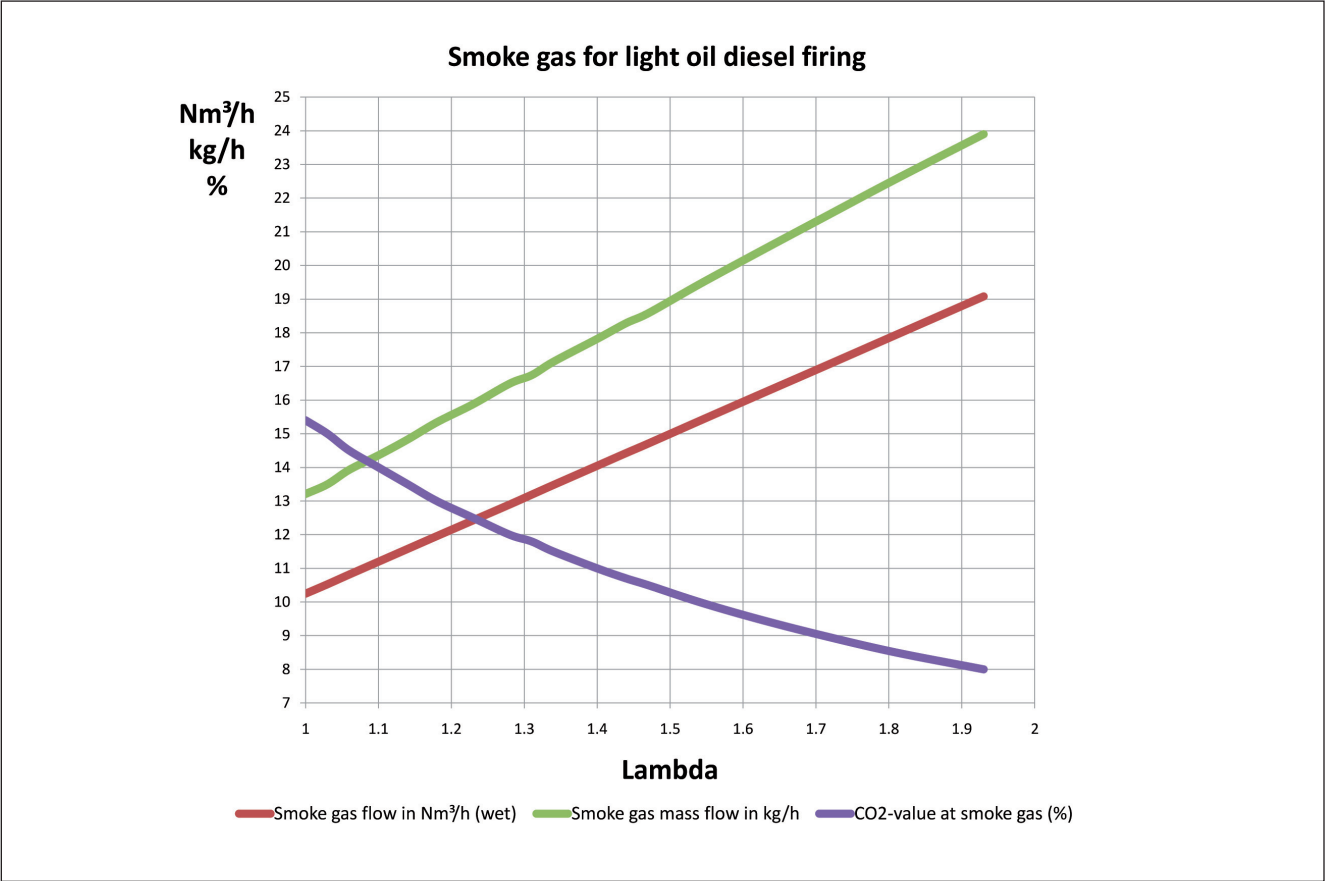
Approximate correction figures for light oil - diesel firing

Lambda	1	1,03	1,06	1,1	1,14	1,18	1,23	1,28	1,31
Correction value (multiplier) from Nm³/h to kg/h	1,288	1,282	1,287	1,282	1,28	1,282	1,277	1,278	1,269
Smoke gas flow in Nm³/h (wet)	10,25	10,53	10,82	11,2	11,58	11,96	12,43	12,9	13,19
Smoke gas mass flow in kg/h	13,21	13,5	13,93	14,36	14,83	15,34	15,88	16,49	16,74
CO_2-value at smoke gas	15,4	15	14,5	14	13,5	13	12,5	12	11,8

Lambda	1,34	1,4	1,44	1,47	1,54	1,62	1,71	1,81	1,93
Correction value (multiplier) from Nm³/h to kg/h	1,271	1,268	1,267	1,263	1,264	1,262	1,26	1,258	1,252
Smoke gas flow in Nm³/h (wet)	13,48	14,05	14,43	14,71	15,38	16,14	16,99	17,94	19,08
Smoke gas mass flow in kg/h	17,14	17,82	18,29	18,58	19,44	20,38	21,42	22,57	23,9
CO_2-value at smoke gas	11,5	11	10,7	10,5	10	9,5	9	8,5	8

14.3. Smoke gas flow/comparison for heavy oil firing:

C) For smoke gas "heavy oil" (LCV = 40700 KJ/kg, CO_2 max = 16,1%)

Smoke gas for heavy oil firing

Nm^3/h kg/h %

Lambda

— Smoke gas flow in Nm^3/h (wet) — Smoke gas mass flow in kg/h — CO2-value at smoke gas (%)

Approximate correction figures for heavy oil firing

Lambda	1	1,04	1,07	1,11	1,15	1,19	1,24	1,29	1,34	1,36
Correction value (multiplier) from Nm^3/h to kg/h	1,539	1,527	1,53	1,525	1,521	1,521	1,512	1,51	1,511	1,511
Smoke gas flow in Nm^3/h (wet)	10,08	10,46	10,75	11,12	11,5	11,88	12,35	12,82	13,29	13,48
Smoke gas mass flow in kg/h	15,52	15,98	16,45	16,96	17,5	18,07	18,68	19,37	20,09	20,38
CO_2-value at smoke gas	16	15,5	15	14,5	14	13,5	13	12,5	12	11,8

Lambda	1,4	1,46	1,5	1,53	1,61	1,69	1,79	1,89	2,01
Correction value (multiplier) from Nm^3/h to kg/h	1,506	1,506	1,505	1,503	1,497	1,498	1,49	1,491	1,488
Smoke gas flow in Nm^3/h (wet)	13,86	14,43	14,8	15,08	15,84	16,6	17,54	18,49	19,62
Smoke gas mass flow in kg/h	20,88	21,74	22,28	22,68	23,72	24,88	26,14	27,58	29,2
CO_2-value at smoke gas	11,5	11	10,7	10,5	10	9,5	9	8,5	8

15 Boiler load/output – Steam quantity

15.1 Steam quantity calculation

1 t/h saturated steam ≈ 0,65 MW boiler load*
at 12 bar(g) and 102°C feed water temperature

1 kg oil or 1 m³ gas results in following saturated steam quantity (kg/h)**:**

$$\frac{\text{Lower calorific value in } \left(\frac{kJ}{kg}\right) \text{ or } \left(\frac{kJ}{m^3}\right) * \text{boiler efficiency in \%}}{234000}$$

1 kg oil produces round 16 kg steam

To produce 1t saturated steam the following oil- or gas quantity is needed (kg or m³):

$$\frac{2{,}34 * 10^8}{\text{Lower calorific value in } \left(\frac{kJ}{kg}\right) \text{ or } \left(\frac{kJ}{m^3}\right) * \text{boiler efficiency in \%}}$$

15.2 Boiler load, firing load and fuel consumption in connection with boiler efficiency

Boiler output – produced saturated steam quantity		Boiler efficiency	Firing load	Needed quantity of heavy fuel oil	Needed quantity of extra light fuel oil (diesel)
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

15.3 Exact calculation of fuel consumption at known steam capacity and steam parameters

$$m_B \text{ or } V_B = \left(\frac{M_D * (h''-h'_{sw}) * 100\%}{H_u * n_k} \right)$$

m_B bzw. V_B	= fuel consumption in kg/h or m³/h
M_D	= steam quantity in kg/h
h''	= Enthalpy of steam in kJ/kg
h'_{sw}	= Enthalpy of feed water in kJ/kg
H_u	= lower calorific value in kJ/kg or kJ/m3
η_K	= boiler efficiency in %

15.4 Determination of efficiency with smoke gas measurement*

$$\eta K \text{ (in \%)} = 100\% - X_A\%$$

$$\text{Smoke gas loss } X_A = f * \left(\frac{\vartheta_A - \vartheta_L}{CO_{2,tr}} \right) \text{ in \%}$$

X_A	= Smoke gas loss
ϑ_A	= Metered smoke gas temperature
ϑ_L	= Metered combustion air temperature
CO_2,tr	= metered CO2-value at dry smoke gas in vol.-%
f	= Constant figure

	Extra light fuel oil	Heavy fuel oil	Natural gas	Propane/Butane
f	0,59	0,61	0,46	0,50

calculation base: Siegert formula

16 Conversion from "Nm³" to "operating m³" (gas, air, smoke gas)

Example	3861		Nm³/h		
$V_{operation}$	=	V_{norm} * (1013/(1013 + p)) * ((273 + t)/273)			
$V_{operation}$	=	operation cubic meter (per hour) at actual gas temperature and gas pressure			
V_{norm}	=	Norm cubic meter (per hour) at 0°C and 1013 mbar			
p	=	gas pressure in mbar			
t	=	gas temperature in °C			
For this example =	1068,10606 operation m³/h				
actual gas temperature		15	°C	(see local indication + fill in)	
actual gas pressure		2850	mbar	(see local indication + fill in)	

17 Conversion from "operation m³" to "Nm³" (gas, air, smoke gas

Example	360		operation m³/h		
V_{norm}	=	$V_{operation}$/((1013/(1013 + p)) * ((27 3+ t)/273))			
$V_{operation}$	=	operation cubic meter (per hour) at actual gas temperature and gas pressure			
V_{norm}	=	Norm cubic meter (per hour) at 0°C and 1013 mbar			
p	=	gas pressure in mbar			
t	=	gas temperature in °C			
For this example =	1301,33144 Nm³/h				
actual gas temperature		15	°C	(see local indication + fill in)	
actual gas pressure		2850	mbar	(see local indication + fill in)	

18 Feed water tank and feed water conditioning

18.1   Operating temperature   *(See our tutorial Steam Systems 1, page 23)*

18.2   Cavitation of the boiler feed pump   *(See our tutorial Steam systems 1, page 24)*

18.3   Feed tank design   *(See our tutorial Steam systems 1, page 25)*

18.4   Feed tank materials   *(See our tutorial Steam systems 1, page 26)*

18.5   Feedtank capacity   *(See our tutorial Steam systems 1, page 26)*

18.6   Feed tank piping   *(See our tutorial Steam systems 1, page 26)*

19 Pressurised Deaerators

On larger boiler plants, pressurised deaerators are sometimes installed and live steam is used to bring the feed water up to approximately 105°C to drive off the oxygen. Pressurised deaerators are usually thermally efficient and will reduce dissolved oxygen to very low levels.

Pressurised deaerators:
• Must be fitted with controls and safety devices.
• Are classified as pressure vessels, and will require periodic, formal inspection.

This means that pressurised deaerators are expensive, and are only justified in very large boiler houses. If a pressure deaerator is to be considered, its part load performance (or effective turndown) must be investigated.

19.1 Why gases need to be removed from boiler feed water

Oxygen is the main cause of corrosion in hotwell tanks, feed lines, feed pumps and boilers. If carbon dioxide is also present then the pH will be low, the water will tend to be acidic, and the rate of corrosion will be increased. Typically the corrosion is of the pitting type where, although the metal loss may not be great, deep penetration and perforation can occur in a short period.

Elimination of the dissolved oxygen may be achieved by chemical or physical methods, but more usually by a combination of both.

The essential requirements to reduce corrosion are to maintain the feed water at a pH of not less than 8.5 to 9, the lowest level at which carbon dioxide is absent, and to remove all traces of oxygen. The return of condensate from the plant will have a significant impact on boiler feed water treatment - condensate is hot and already chemically treated, consequently as more condensate is returned, less feed water treatment is required.

Water exposed to air can become saturated with oxygen, and the concentration will vary with temperature: the higher the temperature, the lower the oxygen content. The first step in feed water treatment is to heat the water to drive off the oxygen. Typically a boiler feed tank should

be operated at 85°C to 90°C. This leaves an oxygen content of around 2 mg/litre (ppm). Operation at higher temperatures than this at atmospheric pressure can be difficult due to the close proximity of saturation temperature and the probability of cavitation in the feed pump, unless the feed tank is installed at a very high level above the boiler feed pump.

The addition of an oxygen scavenging chemical (sodium sulphite, hydrazine or tannin) will remove the remaining oxygen and prevent corrosion.

This is the normal treatment for industrial boiler plant. However, plants exist which, due to their size, special application or local standards, will need to either reduce or increase the amount of chemicals used. For plants that need to reduce the amount of chemical treatment, it is common practice to use a pressurised deaerator.

Table "solubility of O_2 and N_2 (from normal air) at 1 bar at clean water"
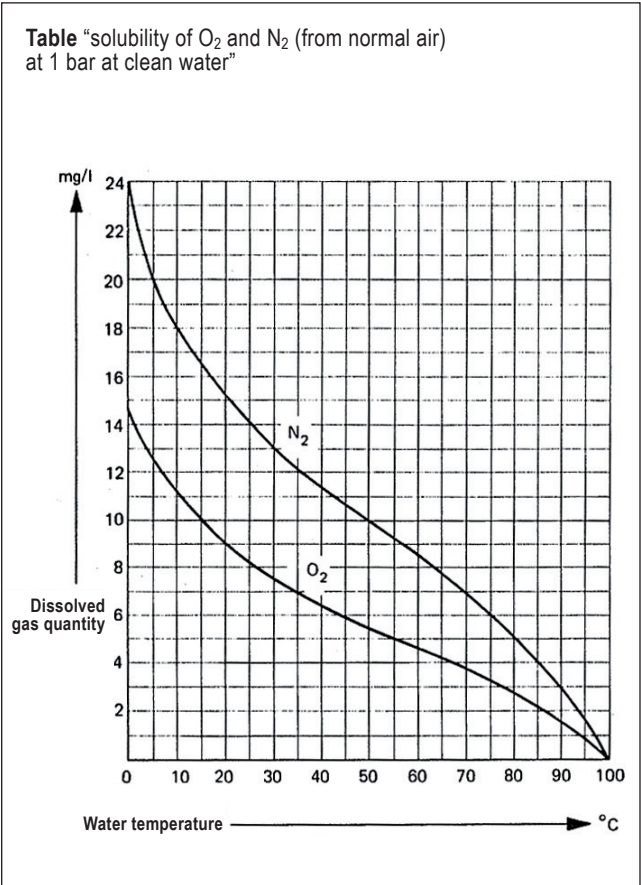
19.2 Operating principles of a pressurised deaerator

If a liquid is at its saturation temperature, the solubility of a gas in it is zero, although the liquid must be strongly agitated or boiled to ensure it is completely deaerated.

This is achieved in the head section of a deaerator by breaking the water into as many small drops as possible, and surrounding these drops with an atmosphere of steam. This gives a high surface area to mass ratio and allows rapid heat transfer from the steam to the water, which quickly attains steam saturation temperature. This releases the dissolved gases, which are then carried with the excess steam to be vented to atmosphere. (This mixture of gases and steam is at a lower than saturation temperature and the vent will operate thermostatically). The deaerated water then falls to the storage section of the vessel.

A blanket of steam is maintained above the stored water to ensure that gases are not re-absorbed.

Fig. 3.21.1 General arrangement of a pressure deaerator

Water level control system

Water inlet to distributor

Air vent

Make-up water and returned condensate

Steam pressure control system

Dome

Steam supply

Steam

Level gauge

Vessel

Note: Strainers and stop valves have been omitted for clarity

Feedwater to boiler feedpump
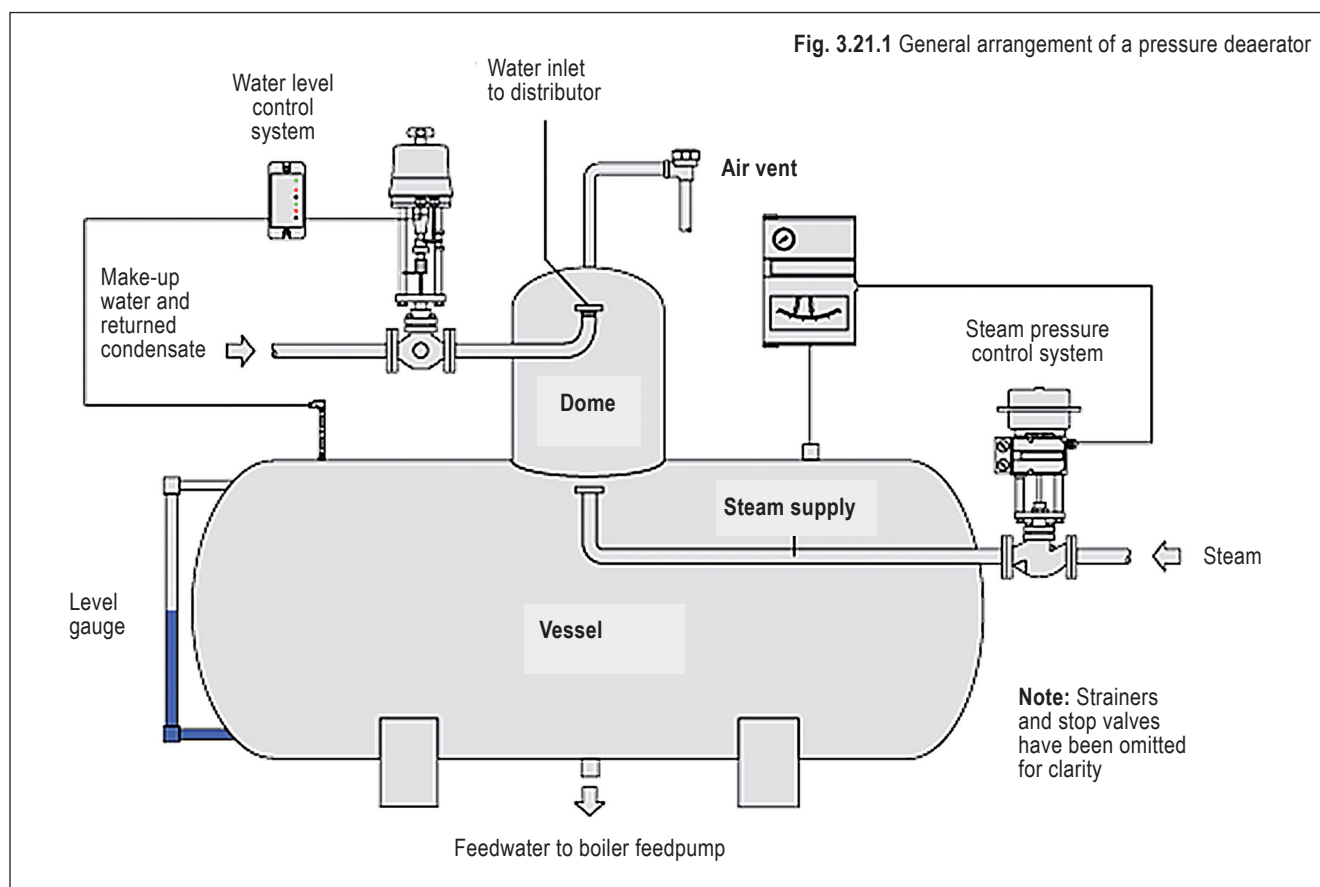
19.3   Water distribution

The incoming water must be broken down into small drops to maximise the water surface area to mass ratio. This is essential to raising the water temperature, and releasing the gases during the very short residence period in the deaerator dome (or head).

Breaking the water up into small drops can be achieved using one of the methods employed inside the dome's steam environment.

There are of course advantages and disadvantages associated with each type of water distribution, plus cost implications. Table 3.21.1 compares and summarises some of the most important factors:

	Tray type	Spray type
Life expectancy (years)	40	20
Turndown (maximum/minimum)	Very high	5
Cost factor	1	0,75
Typical application	Power plant	Process plant

Comparison of tray and spray type deaerators
Note: Hoval supplies "Tray type" deaerators only!

19.4   Control systems

Water control
A modulating control valve is (normally) used to maintain the water level in the storage section of the vessel. Modulating control is required to give stable operating conditions, as the sudden inrush of relatively cool water with an on/off control water control system could have a profound impact on the pressure control, also the ability of the deaerator to respond quickly to changes in demand. Since modulating control is required, a capacitance type level probe can provide the required analogue signal of water level.

Steam control
A modulating control valve regulates the steam supply. This valve is modulated via a pressure controller to maintain a pressure within the vessel. Accurate pressure control is very important since it is the basis for the temperature control in the deaerator, therefore a fast acting, pneumatically actuated control valve will be used. Note: A pilot operated pressure control valve may be used on smaller applications, and a self-acting diaphragm actuated control

Fig. 3.21.2 Deaerator water inlet options

Water flow

Perforated trays

Cascading the incoming water over a series of perforated trays

Water broken into drops

Water flow

A spring loaded spray nozzle

Spring loaded nozzle

Water spray   Water spray

Water flow

A jet impinging against a baffle plate

Water spray   Water spray

Baffle plate
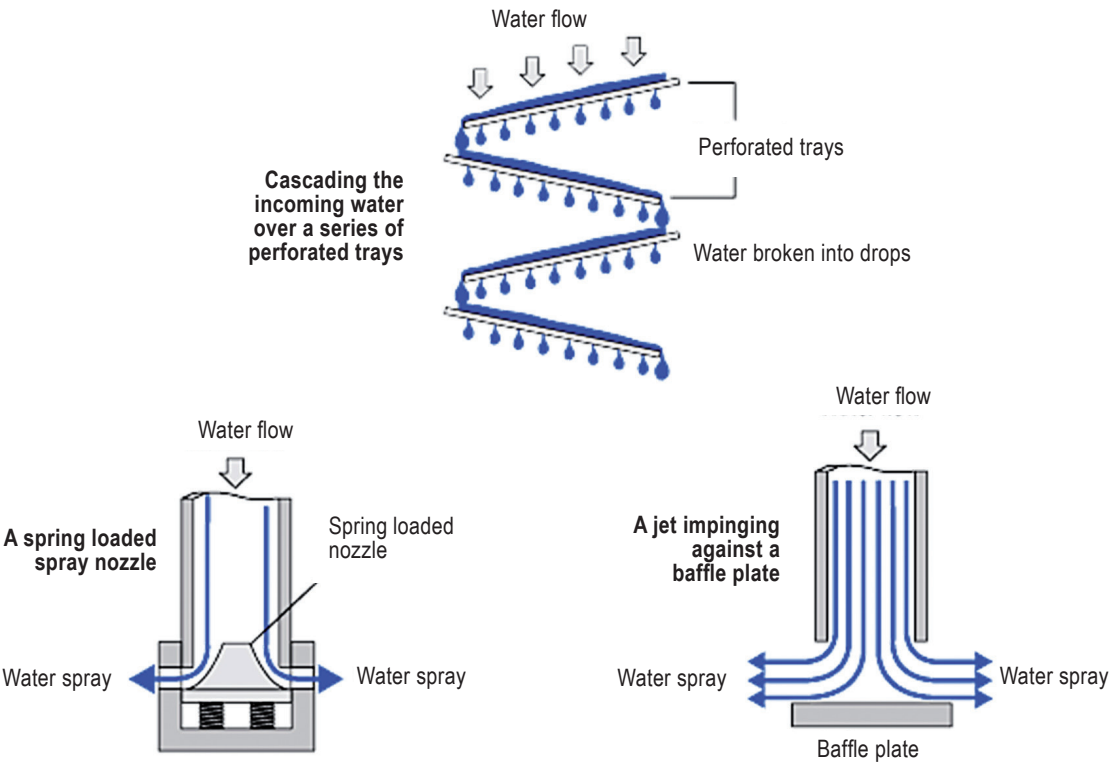
valve may be used when the load is guaranteed to be fairly constant.

The steam injection may occur at the base of the head, and flow in the opposite direction to the water (counter flow), or from the sides, crossing the water flow (cross flow). Whichever direction the steam comes from, the objective is to provide maximum agitation and contact between the steam and water flows to raise the water to the required temperature.

The steam is injected via a diffuser to provide good distribution of steam within the deaerator dome.

The incoming steam also provides:
• A means of transporting the gases to the air vent
• A blanket of steam required above the stored deaerated water

Deaerator air venting capacity

In previous information, typical feed water temperatures have been quoted at around 85°C, which is a practical maximum value for a vented boiler feed tank operating at atmospheric pressure. It is also known that water at 85°C contains around 3.5 grams of oxygen per 1 000 kg of water, and that it is the oxygen that causes the major damage in steam systems for two main reasons. First, it attaches itself to the inside of pipes and apparatus, forming oxides, rust, and scale; second, it combines with carbon dioxide to produce carbonic acid, which has a natural affinity to generally corrode metal and dissolve iron. Because of this, it is useful to remove oxygen from boiler feed water before it enters the boiler. Low-pressure and medium-pressure plant supplied with saturated steam from a shell type boiler will operate quite happily with a carefully designed feed tank incorporating an atmospheric deaerator (referred to as a semi-deaerator). Any remaining traces of oxygen are removed by chemical means, and this is usually economic for this type of steam plant. However, for high-pressure water-tube boilers and steam plant handling superheated steam, it is vital that the oxygen level in the boiler water is kept much lower (typically less than seven parts per billion - 7 ppb), because the rate of attack due to dissolved gases increases rapidly with higher temperatures. To achieve such low oxygen levels, pressurised deaerators can be used.

If feed water were heated to the saturation temperature of 100°C in an atmospheric feed tank, the amount of oxygen held in the water would theoretically be zero; although in practice, it is likely that small amounts of oxygen will remain. It is also the case that the loss of steam from a vented feed tank would be quite high and economically unacceptable, and this is the main reason why pressurised deaerators are preferred for higher pressure plant operating typically above 20 bar(g) or if water quality and condensate return asks for using it.

A pressurised deaerator is often designed to operate at 0.2 bar g, equivalent to a saturation temperature of 105°C, and, although a certain amount of steam will still be lost to atmosphere via a throttled vent, the loss will be far less than that from a vented feed tank.

It is not just oxygen that needs to be vented; other non-condensable gases will be rejected at the same time. The deaerator will therefore vent other constituents of air, predominantly nitrogen, along with a certain amount of steam. It therefore follows that the rejection rate of air from the water has to be somewhat higher than 3.5 grams of oxygen per 1 000 kg of water. In fact, the amount of air in water at 80°C under atmospheric conditions is 5.9 grams per 1 000 kg of water. Therefore, a rejection of 5.9 grams of air per 1 000 kg of water is needed to ensure that the required amount of 3.5 grams of oxygen is being released. As this air mixes with the steam in the space above the water surface, the only way it can be rejected from the deaerator is by the simultaneous release of steam.

The amount of steam/air mixture that needs to be released can be estimated by considering the effects of Dalton's Law of partial pressures and Henry's Law.

Consider the feasibility of installing a deaerator. Prior to installation, the boiler plant is fed by feed water from a vented feed tank operating at 80°C. This essentially means that each 1 000 kg of feed water contains 5.9 gram of air. The proposed deaerator will operate at a pressure of 0.2 bar g, which corresponds to a saturation temperature of 105°C. Assume, therefore, that all the air will be driven from the water in the deaerator. It follows that the vent must reject 5.9 gram of air per 1 000 kg of feedwater capacity.

Consider that the air being released from the water mixes with the steam above the water surface. Although the deaerator operating pressure is 0.2 bar g (1.2 bar a), the temperature of the steam/air mixture might only be 100°C.

Total pressure in the deaerator	= 1.2 bar a
Temperature of the vapour in the deaerator	= 100°C
100°C corresponds to a saturation pressure of 1 atm	= 1.01325 bar a

Therefore, from Dalton's Law:

If the vapour space in the deaerator were filled with pure steam, the vapour pressure would be 1.2 bar a. As the vapour space has an actual temperature of 100°C, the partial pressure caused by the steam is only 1.013 25 bar a.

The partial pressure caused by the non-condensable gases (air) is therefore the difference between these two figures = 1.2 - 1.013 25 = 0.186 75 bar a.

$$\text{The proportion by volume of air to steam in the mixture} = \frac{0.18675}{1.01325} = 18.43\%$$

$$\text{Therefore every litre of released air is accompanied by} : \frac{100 - 18.43}{18.43} = 4.42 \text{ litres of steam}$$

The density of air at 100°C is approximately 0.946 grams/L
The density of steam at 100°C is approximately 0.6 grams/L

Therefore 0.946 g of air is released with 0.6 * 4.42 = 2.65 g of steam

$$\text{and 5.9 g of air is released with:} \quad \frac{2.65 * 5.9}{0.946} = 16.5 \text{ g of steam}$$

Therefore, the total mixture of air and steam released per 5.9 g of air can be calculated:

$$5.9 \text{ g} + 16.5 \text{ g} = 22.4 \text{ gram} \quad \text{of air/steam mixture per 1000 kg of deaerator capacity}$$

However:
- Because there is no easy way to accurately measure the discharge temperature;
- Because there is only a small pressure differential between the deaerator and atmospheric pressure;
- Because the vent rates are so small,

...an automatic venting mechanism is rarely encountered on deaerator vent pipes, the task usually being accomplished by a manually adjusted ball valve, needle valve, or orifice plate.

It is also important to remember that the prime objective of the deaerator is to remove gases. It is vital, therefore, that once separated out, these gases are purged as quickly as possible, and before there is any chance of re-entrainment. Although the theory suggests that 22.4 grams of steam/air mixture per tonne of deaerator capacity is required, in practice this is impossible to monitor or regulate successfully.

Therefore, based on practical experience, deaerator

Fig. 3.21.3 Inside a deaerator dome
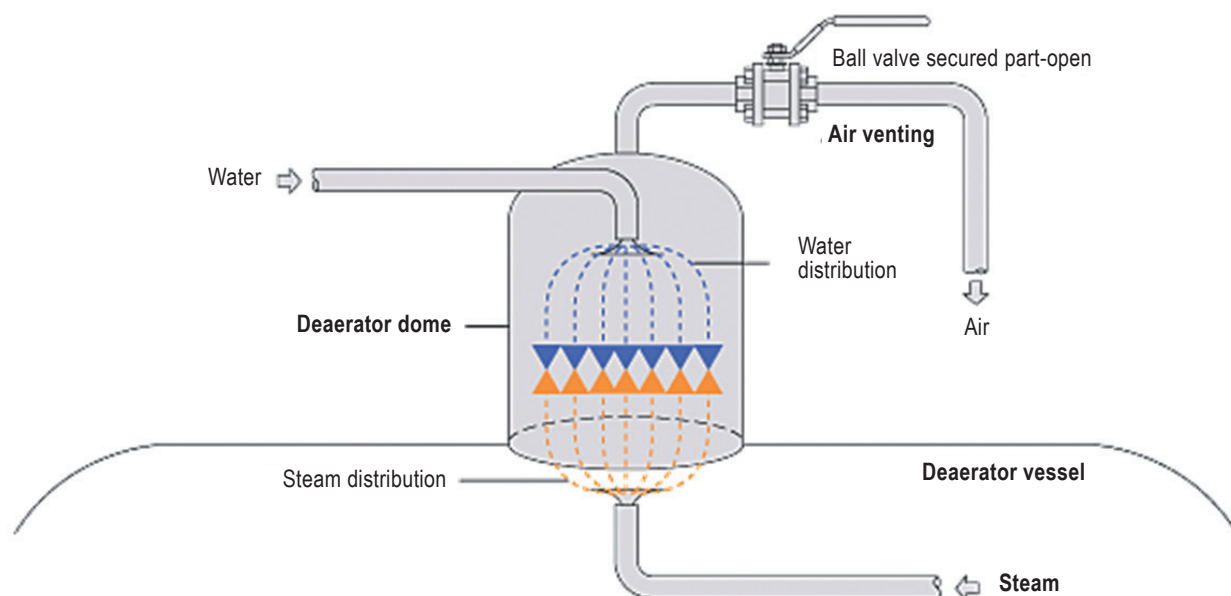
manufacturers will tend to recommend a venting rate of between 0.5 and 2 kg of steam/air mixture per 1 000 kg/h of deaerator capacity to be on the safe side. It is suggested that the deaerator manufacturer's advice be taken on this issue.

A typical way of controlling the vent rate is to use a DN20 steam duty ball valve of a suitable pressure rating, which can be secured in a part-open condition (Note: As ball valves are not the best "regulation armature" it´s recommended to use a "manual regulation valve" instead).

Typical operating parameters for a pressurised deaerator
The following information is typical and any actual installation may vary from the following in a number of ways to suit the individual requirements of that plant:
• The operating pressure will usually be approximately 0.2 bar (3 psi), which gives a saturation temperature of 105°C (221°F).
• The vessel will contain between 10 and 20 minutes water storage for the boiler on full-load.
• The water supply pressure to the deaerator should be at least 2 bar to ensure good distribution at the nozzle (Note: supply pressure is not so important if using "tray-type" deaerators but very important on "spray or nozzle type" deaerators).

This implies either a backpressure on the steam traps in the plant or the need for pumped condensate return.
• Steam supply pressure to the pressure control valve will be in the range 5 to 10 bar.
• Maximum turndown on the deaerator will be approximately 5:1.
• At flowrates below this from the process, there may be insufficient pressure to give good atomisation with nozzle or spray type water distributors (use "tray-type" deaerators for this pupose).
• This can be overcome by having more than one dome on the unit. The total capacity of the domes would be equal to the boiler rating, but one or more of the domes may be shut down at times of low demand (or by using "tray-type" deaerators
• Heating may be required in the storage area of the vessel for start-up conditions; this may be by coil or direct injection.
• However, the type of plant most likely to be fitted with a pressurised deaerator will be in continuous operation and the operator may consider the low performance during the occasional cold start to be acceptable.

The vessel design, materials, manufacture, construction, and certification will be in compliance with a recognised standard (EN-norms)

The heat balance on the deaerator will typically (but not always) have been calculated on a 20°C increase in the incoming water temperature.

It is normal for water at 85°C to be supplied to the deaerator. If the incoming water temperature is significantly higher than this, then the amount of steam required to achieve the set pressure will be less. This, in turn, means that the steam valve will throttle down and the steam flow rate may be too low to ensure proper dispersal at the steam nozzle.

This may suggest that, with a very high percentage of condensate being returned, some alternative action may be required for proper deaeration to occur.

In this instance, the deaerator heat balance may be calculated using different parameters, or the deaerator may operate at a higher pressure.

19.5   Cost and justification

Cost
There is no additional energy cost associated with operating a deaerator, and the maximum amount of steam exported to the plant is the same with, or without the deaerator, because the steam used to increase the feedwater temperature comes from the higher boiler output.

However:
• There will be some heat loss from the deaerator (This will be minimised by proper insulation).
• There is the additional cost of running the transfer pump between the feedtank and the deaerator.
• Some steam is lost with the vented non-condensable gases.

Justification
The principle reasons for selecting a pressurised deaerator are:
• To reduce oxygen levels to a minimum (< 20 parts per billion) without the use of chemicals. This will eliminate corrosion in the boiler feed system.
• A cost saving can be achieved with respect to chemicals - this argument becomes increasingly valid on large water-tube type boilers where flowrates are high, and low

TDS levels (< 1 000 ppm) need to be maintained in the boiler feedwater.

• Chemicals added to control the oxygen content of the boiler water will themselves require blowing down. Therefore by reducing/eliminating the addition of chemicals, the blowdown rate will be reduced with associated cost savings.

• To prevent contamination where the steam is in direct contact with the product, for example: foodstuffs or for sterilisation purposes.

19.6   Deaerator heat balance

To enable correct system design and to size the steam supply valve, it is important to know how much steam is needed to heat the deaerator. This steam is used to heat the feedwater from the usual temperature experienced prior to the installation of the deaerator to the temperature needed to reduce the dissolved oxygen to the required level.

The required steam flowrate is calculated by means of a mass/heat balance. The mass/heat balance works on the principle that the initial amount of heat in the feedwater, plus the heat added by the mass of injected steam must equal the final amount of heat in the feedwater plus the mass of steam that has condensed during the process. Equation 2.11.3 is the mass/heat balance equation used for this purpose.

$$\dot{m} * h_1 + \dot{m}_s * h_g = (\dot{m} + \dot{m}_s) * h_2$$

Equation 2.11.3

Where:

$\dot{m}$ = Maximum boiler output at the initial feedwater temperature (kg/h) - This is the boiler 'From and At' figure x the boiler evaporation factor.

$\dot{m}_s$ = Mass of steam to be injected (kg/h)

h_1 = Enthalpy of water at the initial temperature (kJ/kg)

h_2 = Enthalpy of water at the required temperature (kJ/kg)

h_g = Enthalpy of steam supplying the control valve (kJ/kg)

Note: if the supply steam is superheated, this value is the total heat in the superheated steam (h).

To calculate the required steam flowrate, Equation 2.11.4 is transposed to solve for s, and becomes Equation 3.21.1.

$$\dot{m}_s = \dot{m} * \frac{h_2 - h_1}{h_g - h_2}$$

Equation 3.21.1

Fig. 3.21.4 Typical pressurised deaerator installation

Make-up and condensate 85°C

Transfer pump

105°C

Steam supply to vessel

Feedwater 105°C

10 bar g

10 000 kg/h 'From and At' operating at 10 bar g
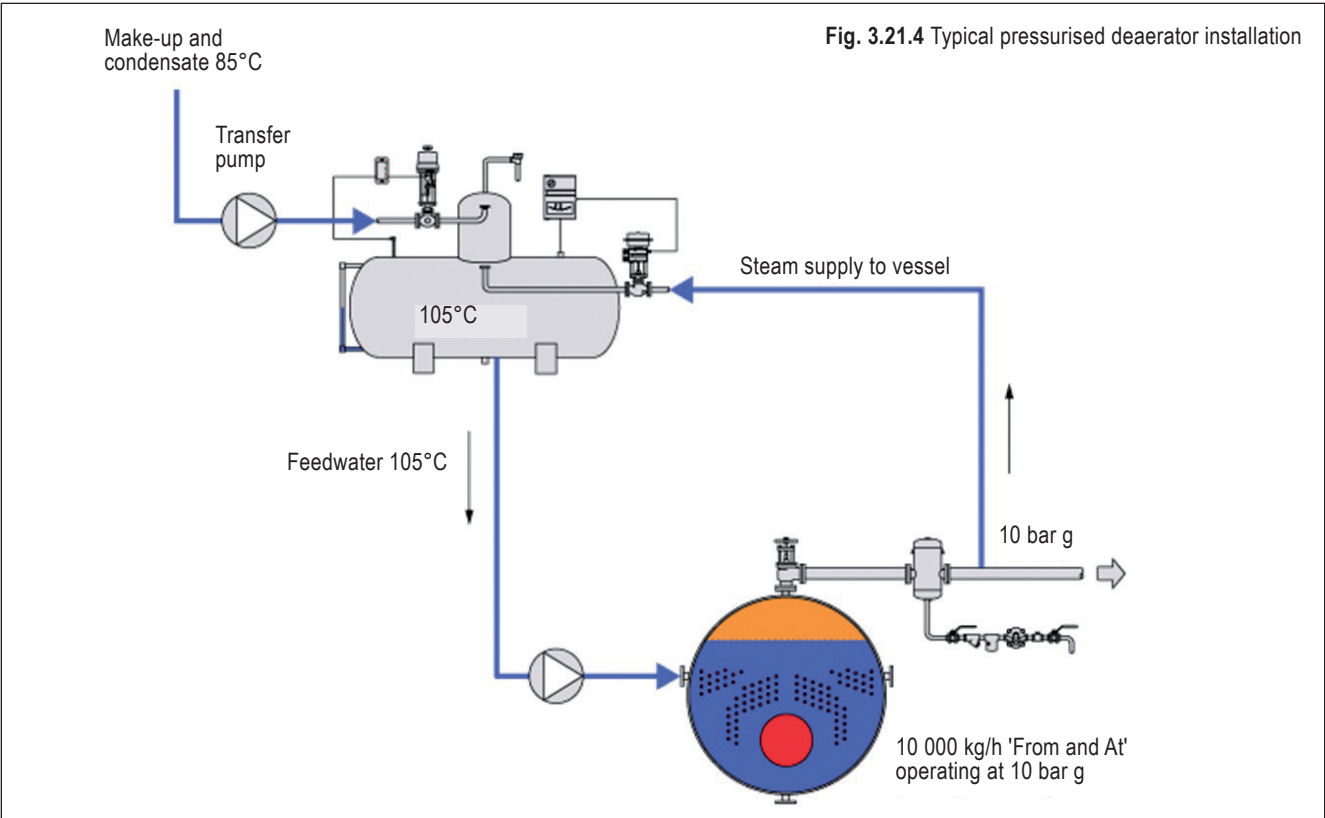
Example 3.21.1 Determine the amount of steam needed to heat a deaerator

An existing boiler plant is fed with feed water at a temperature of 85°C. Due to the rising cost of chemical treatment, it is proposed that a pressurised deaerator be installed, operating at 0.2 bar g to raise the feed water temperature to 105°C, reducing the solubility of oxygen to quantities typically measured in parts per billion. Steam, produced in the boiler at 10 bar g, is to be used as the heating agent. If the 'From and At' rating of the boiler plant is 10 tonne/h, determine the flow rate of steam required to heat the deaerator.

Where:
Boiler "From and At" rating =   **10 000 kg/h**
Initial feed water temperature =   **85°C**
Initial feedwater enthalpy = **356 kJ/kg (from steam tables)**
Boiler pressure =   **10 bar(g)**
Enthalpy of saturated steam at 10 bar g (hg) =   **2781 kJ/kg**

Before any calculations can be made to estimate the size of the deaerator, it is important to know the maximum likely feed water requirement. This is determined by calculating the boiler(s') maximum useful steaming rate, which in turn, depends on the initial feed water temperature. The maximum steaming rate is found by determining the Boiler Evaporation Factor.

From Equation 3.5.1

$$\text{Evaporation factor} \;=\; \frac{A}{B - C}$$

Equation 3.5.1

Where:
A = Specific enthalpy of evaporation at atmospheric pressure is 2 258 kJ/kg
B = Specific enthalpy of saturated steam at boiler pressure (hg) in (kJ/kg)
C = Specific enthalpy of the feed water (h_1) in (kJ/kg)

$$\text{Evaporation factor} \;=\; \frac{2258}{2781 - 356}$$

$$= 0.9311$$

The maximum possible boiler output = 'From and At' rating
$\qquad\qquad\qquad\qquad\qquad\qquad$ x evaporation factor
$\qquad\qquad\qquad\qquad\qquad = 10000 \times 0.9311$
$\qquad\qquad\qquad\qquad\qquad = 9311\ \text{kg/h}$

Equation 3.21.1 is used to find the required amount of steam to heat the deaerator.

From steam tables:
Enthalpy of feedwater at the
required temperature of 105°C (h_2)   = 440 kJ/kg

Enthalpy of steam supplying
the control valve at 10 bar g (h_g)   = 2781 kJ/kg

From above:
Enthalpy of the feed water at 85°C (h_1)   = 356 kJ/kg

Mass flowrate of water make-up
to deaerator ($\dot{m}$)   = 9 311 kg/h

$$\dot{m}_s \;=\; \dot{m} * \frac{h_2 - h_1}{h_g - h_2}$$

Equation 3.21.1

$$\dot{m}_s \;=\; \frac{9311 * (440 - 356)}{2781 - 440}$$

$$\dot{m}_s \;=\; 334\ \text{kg/h}$$

Therefore, the control valve has to be able to supply 334 kg/h of steam with a supply pressure of 10 bar g, and with a downstream pressure of 0.2 bar g.

Example 3.21.2 Sizing and selecting a control system for a pressurised deaerator
The selections in this example are not the only solutions, and the designer will need to consider the demands of an individual site with respect to the availability of electric and pneumatic services.

The objective of this Section is the selection of control valves and systems. Pipeline ancillaries such as strainers and stop valves have been omitted for clarity, they are, nevertheless, vitally important to the smooth running and operation of a pressurised deaerator.

Data
As shown in Figure 3.21.4 plus the actual output shown below:

Boiler:
• Operating pressure (P_1) = 10 bar g
• 'From and At' rating   = 10 000 kg/h
• Actual output   = 9 311 kg/h with a feedwater temperature of 85°C

Deaerator:
Operating pressure (P2) = 0.2 bar g
(Saturation temperature 105°C)

The steam control valve:
Sizing a control valve for saturated steam service can be determined using Equation 3.21.2:

$$\dot{m}_s = 12 * K_V * P_1 * \sqrt{1 - 5{,}67 * (0{,}42 - x)^2}$$

Equation 3.21.2

Where:
$\dot{m}_s$ = Steam mass flowrate (kg/h)
K_V = Valve coefficient required
P_1 = Pressure upstream of the control valve (bar a)
P_2 = Pressure downstream of the control valve (bar a)

$$x = \text{Pressure drop ratio} \quad \frac{P_1 - P_2}{P_1}$$

However, since P_2 (1.2 bar a) is less than 58% of P_1 (11 bar a) the steam flow is subjected to critical pressure drop, so Kv can be calculated from the simpler equation (Equation 6.4.3) used for critical flow conditions.

$$\dot{m}_s = 12 * K_V * P_1$$

Equation 6.4.3

From Equation 6.4.3:

$$K_V = \frac{334}{12 * 11} = 2{,}53$$

The selected control valve should have a K_{vs} larger than 2.53, and would normally be provided by a DN15 valve with a standard K_{vs} of 4, and an equal percentage trim.

19.7   Steam control equipment selection

This control will need to respond quickly to changes in pressure in the deaerator, and to accurately maintain pressure; a valve with a pneumatic actuator would operate in the required manner. The pressure sensing and control functions may be provided either by pneumatic or electronic equipment and the control signal output (0.2 to 1 bar or 4 - 20 mA) should go to an appropriate positioner.

Equipment required
(example – sizing depends to deaerator sizing):
• A DN15 two port valve with standard equal percentage trim (K_{vs} = 4).
• A pneumatic actuator able to close a DN15 valve against a pressure of 10 bar.
• A pneumatic-pneumatic positioner with mounting kit (alternatively an electropneumatic positioner with mounting kit).
• A pneumatic controller with a range of 0 - 7 bar (alternatively an electronic controller and sensor with an appropriate range).

As mentioned earlier, a pilot operated self-acting pressure control may be acceptable. A direct acting diaphragm actuated self-acting pressure control, however, should be avoided if the deaerator load changes considerably, as the wide P-band associated with such valves may not give accurate enough pressure control over the load range.

19.8   Control for the water system (level control)

Water supply:
• Transfer pump discharge pressure = 2 bar g
• Feedtank temperature = 85°C
• Steam flowrate to the deaerator ($\dot{m}_s$) has already been calculated at 334 kg/h.

In this example the maximum water flow rate (the actual capacity of the boiler) to the deaerator is 9 311 kg/h. Water valves are sized on volume flow rates, so it is necessary to convert the mass flow of 9311 kg/h to volumetric flow in m³/h.

The pump discharge pressure onto the control valve is 2 bar g. From steam tables, the specific volume of water at 2 bar g and 85°C is 0.001032 m³/kg.

It is important to determine the pressure required behind the water distribution nozzle to give proper distribution; the control valve selection must take this into consideration. For this example, it is assumed that a pressure of 1.8 bar is required at the inlet to the distributor nozzle.

The sizing parameters for the water control valve are:

$$\dot{v} = 9311 \left(\frac{kg}{h}\right) * 0{,}001032 \left(\frac{m^3}{kg}\right) = 9{,}6 \left(\frac{m^3}{h}\right)$$

P_1 = 2 bar g
P_2 = 1.8 bar g

Sizing a control valve for liquid service can be determined by calculating the Kv, see Equation 3.21.3:

$$\dot{v} = K_v * \sqrt{\frac{\Delta P}{G}}$$

Equation 3.21.3

Where:
$\dot{v}$ = Volumetric flowrate (m³/h)
K_v = Valve coefficient required
ΔP = Pressure drop across the valve (bar)
 G = Relative density of fluid (water = 1)

For water, as G = 1,

$$\dot{v} = K_v * \sqrt{\Delta P}$$

$$K_v = \frac{\dot{v}}{\sqrt{P}}$$

$$K_v = \frac{9,6}{\sqrt{2 - 1,8}}$$

$$K_v = \frac{9,6}{\sqrt{0,2}}$$

$$K_v = 21,5$$

The selected control valve should have a K_{vs} larger than 21.5

19.9   Water control equipment selection

Because of the relatively large mass of water held in the deaerator, the speed of control signal response is not normally an issue, and an electrically actuated control may provide an adequate solution.

However, a pneumatically actuated control will provide equally as good a solution.

Equipment required (example – sizing depends to deaerator sizing):
• A DN40 two port valve with standard trim (Kvs = 25).
• An electric actuator that will close a DN40 valve against the maximum transfer pump pressure.
• A feedback potentiometer will be needed with the actuator.
• A capacitance level probe of appropriate length with a preamplifier.

• A level controller to accept the signal from the capacitance probe, and then pass a modulating signal to the valve actuator.

Note that this only gives water level control plus either a high or low alarm. Should additional low or high alarms be required, the options are either:
• A capacitance level probe with level controller, which can provide two additional level alarms.
• A four-tip conductivity level probe, with a level controller, which can provide up to four level alarms.
  or
• A single tip high integrity, self-monitoring level probe and associated level controller which will provide either a high or low level alarm.

Table 3.21.2 identifies the major difficulties that may be encountered with a pressurised deaerator, and their possible causes.

Deaerator malfunction	Possible cause
High level of oxygen in feedwater	• Leakage of air into the deaerator
	• Insufficient residence time
	• Water/steam mixing equipment not designed/ installed/operating correctly
	• Flowrate outside design specification
Pressure fluctuations	• Control valves incorrectly sized
	• Wide temperature variation in the incomming water supply
Low outlet temperature	• Insufficient steam
	• Water/steam mixing equipment not designed/ installed/operating correctly
High level of carbon dioxide in feedwater	Feedwater pH is too high

Table 3.21.2 Diagnosing deaerator malfunctions

19.10   Conditioning treatment
*(please see our tutorial for **Steam systems 1,** Page 29)*

20 Water preparation for steam boiler plants

20.1 Good quality steam

20.2 External water treatment

20.3 Ion exchange

20.4 Base exchange softening

20.5 Dealkalisation

20.6 Dealkaliser

20.7 Demineralisation

20.8 Reverse osmosis

Reverse osmosis (RO) is a filtration method that removes many types of large molecules and ions from solutions by applying pressure to the solution when it is on one side of a selective membrane. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. To be "selective," this membrane should not allow large molecules or ions through the pores (holes), but should allow smaller components of the solution (such as the solvent) to pass freely.

In the normal osmosis process the solvent naturally moves from an area of low solute concentration, through a membrane, to an area of high solute concentration. The movement of a pure solvent to equalize solute concentrations on each side of a membrane generates a pressure and this is the "osmotic pressure." Applying an external pressure to reverse the natural flow of pure solvent, thus, is reverse osmosis. The process is similar to membrane filtration. However, there are key differences between reverse osmosis and filtration. The predominant removal

mechanism in membrane filtration is straining, or size exclusion, so the process can theoretically achieve perfect exclusion of particles regardless of operational parameters such as influent pressure and concentration. Reverse osmosis, however, involves a diffusive mechanism so that separation efficiency is dependent on solute concentration, pressure, and water flux rate.

20.8.1 RO-Process description

A semipermeable membrane coil used for Reverse osmosis

Osmosis is a natural process. When two liquids of different concentration are separated by a semi permeable membrane, the fluid has a tendency to move from low to high concentrations for chemical potential equilibrium.

Formally, reverse osmosis is the process of forcing a solvent from a region of high solute concentration through a semipermeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure.

The membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where most separation occurs. In most cases, the membrane is designed to allow only water to pass through this dense layer, while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–70 bar (600–1000 psi) for seawater, which has around 27 bar (390 psi) natural osmotic pressure that must be overcome. This process is best known for its use in desalination (removing the salt and other minerals from sea water to get fresh water), but since the early 1970s it has also been used to purify fresh water for medical, industrial, and domestic applications.

Osmosis describes how solvent moves between two solutions separated by a permeable membrane to reduce concentration differences between the solutions. When two solutions with different concentrations of a solute are mixed, the total amount of solutes in the two solutions will be equally distributed in the total amount of solvent from the two solutions. Instead of mixing the two solutions together, they can be put in two compartments where they are separated from each other by a semipermeable membrane. The semipermeable membrane does not allow the solutes to move from one compartment to the other, but allows the solvent to move. Since equilibrium cannot be achieved by the movement of solutes from the compartment with high solute concentration to the one with low solute concentration, it is instead achieved by the movement of the solvent from areas of low solute concentration to areas of high solute concentration.

When the solvent moves away from low concentration areas, it causes these areas to become more concentrated. On the other side, when the solvent moves into areas of high concentration, solute concentration will decrease. This process is termed osmosis. The tendency for solvent to flow through the membrane can be expressed as "osmotic pressure", since it is analogous to flow caused by a pressure differential. Osmosis is an example of diffusion.

In reverse osmosis, in a similar setup as that in osmosis, pressure is applied to the compartment with high concentration. In this case, there are two forces influencing the movement of water: the pressure caused by the difference in solute concentration between the two compartments (the osmotic pressure) and the externally applied pressure.

20.8.2   RO-Applications

20.8.2.1 Water and wastewater purification

In industry, reverse osmosis removes minerals from boiler water at power (boiler) plants. The water is boiled and condensed repeatedly. It must be as pure as possible so that it does not leave deposits on the machinery or cause corrosion. The deposits inside or outside the boiler tubes may result in under-performance of the boiler, bringing down its efficiency and resulting in poor steam production, hence poor power production at turbine.

The process of reverse osmosis can also be used for the production of deionized water (as first step).

RO process for water purification does not require thermal energy. Flow through RO system can be regulated by high pressure pump. The recovery of purified water depend upon various factor including - membrane sizes, membrane pore size, temperature, operating pressure and membrane surface area.

20.8.2.2 Pretreatment

Pretreatment is important when working with RO and nanofiltration (NF) membranes due to the nature of their spiral wound design. The material is engineered in such a fashion as to allow only one-way flow through the system. As such, the spiral wound design does not allow for backpulsing with water or air agitation to scour its surface and remove solids. Since accumulated material cannot be removed from the membrane surface systems, they are highly susceptible to fouling (loss of production capacity). Therefore, pretreatment is a necessity for any RO or NF system. Pretreatment in RO systems has four major components:

• Screening of solids: Solids within the water must be removed and the water treated to prevent fouling of the membranes by fine particle or biological growth, and reduce the risk of damage to high-pressure pump components.
• Cartridge filtration: Generally, string-wound polypropylene filters are used to remove particles between 1 – 5 micrometres.
• Dosing: Oxidizing biocides, such as chlorine, are added to kill bacteria, followed by bisulfite dosing to deactivate the chlorine, which can destroy a thin-film composite

membrane. There are also biofouling inhibitors, which do not kill bacteria, but simply prevent them from growing slime on the membrane surface and plant walls.

- Prefiltration pH adjustment: If the pH, hardness and the alkalinity in the feedwater result in a scaling tendency when they are concentrated in the reject stream, acid is dosed to maintain carbonates in their soluble carbonic acid form.

$$CO_3^{-2} + H_3O^+ = HCO_3^- + H_2O$$
$$HCO_3^- + H_3O^+ = H_2CO_3 + H_2O$$
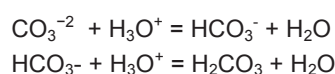
- Carbonic acid cannot combine with calcium to form calcium carbonate scale. Calcium carbonate scaling tendency is estimated using the Langelier saturation index. Adding too much sulfuric acid to control carbonate scales may result in calcium sulfate, barium sulfate or strontium sulfate scale formation on the RO membrane.
- Prefiltration antiscalants: Scale inhibitors (also known as antiscalants) prevent formation of all scales compared to acid, which can only prevent formation of calcium carbonate and calcium phosphate scales. In addition to inhibiting carbonate and phosphate scales, antiscalants inhibit sulfate and fluoride scales, disperse colloids and metal oxides. Despite claims that antiscalants can inhibit silica formation, there is no concrete evidence to prove that silica polymerization can be inhibited by antiscalants. Antiscalants can control acid soluble scales at a fraction of the dosage required to control the same scale using sulfuric acid.

20.8.3   RO-High pressure pump

The pump supplies the pressure needed to push water through the membrane, even as the membrane rejects the passage of salt through it. Typical pressures for brackish water range from 225 to 375 psi (15.5 to 26 bar, or 1.6 to 2.6 MPa). In the case of seawater, they range from 800 to 1,180 psi (55 to 81.5 bar or 6 to 8 MPa). This requires a large amount of energy.

20.8.4   RO-Membrane assembly

The membrane assembly consists of a pressure vessel with a membrane that allows feedwater to be pressed against it. The membrane must be strong enough to withstand whatever pressure is applied against it. RO

The layers of a membrane

membranes are made in a variety of configurations, with the two most common configurations being spiral-wound and hollow-fiber.

20.8.5   RO-Remineralisation and pH adjustment

The desalinated water is very corrosive and is "stabilized" to protect downstream pipelines and storages, usually by adding lime or caustic to prevent corrosion of concrete lined surfaces. Liming material is used to adjust pH between 6.8 and 8.1 to meet the potable water specifications, primarily for effective disinfection and for corrosion control.

20.8.6   Questions about reverse osmosis (RO)

Some questions about our reverse osmosis systems reoccur with such regularity that we have written this short question and answer brief to cover the most commonly asked questions.

Q: What is Reverse Osmosis (RO)?
A: Reverse Osmosis is a process where water is demineralized using a semipermeable membrane at high pressure. Reverse osmosis is osmosis in reverse. So, what is osmosis? Osmosis is most commonly observed in plants. If you don't water your plants they wilt. A plant cell is a semipermeable (water flows through the membrane but salts don't) membrane with the living stuff on the inside in a salt solution. Water is drawn into the cell from the outside because pure water will move across a semipermeable membrane to dilute the higher concentration of salt on the inside. This is how water is drawn in from the ground when you water your plants. If you salt your plants (over fertilize or spill some salt on the grass), the plant will wilt because the salt concentration on the outside of the cell is higher than the inside and water then moves across the membrane from the inside to the outside.

To reverse this process, you must overcome the osmotic pressure equilibrium across the membrane because the flow is naturally from dilute to concentrate. We want more pure water so we must increase the salt content in the cell (concentrate side of the membrane). To do this we increase the pressure on the salty side of the membrane and force the water across. The amount of pressure is determined by the salt concentration. As we force water out, the salt concentration increases requiring even greater pressure to get more pure water.

Q: How does industrial reverse osmosis work?

A: Industrial reverse osmosis use spiral wound membranes mounted in high pressure containers. The membrane stack is two, very long semipermeable membranes with a spacer mesh between them that is sealed along the two long sides. This is then wound up in a spiral tube with another spacer to separate the outside of the stack. The spiral winding provides a very high surface area for transfer. Between each membrane layer is a mesh separator that allows the permeate (pure) water to flow. Water is force in one end of the spiral cylinder and out the out other end. Backpressure forces the water through the membrane where it is collected in the space between the membranes. Permeate then flows around the spiral where it is collected in the centre of the tube.

Q: Is any pretreatment required?

A: There are various pretreatment configurations that will work on the front of an reverse osmosis water system. Part of the selection is based on the capabilities and experience of you maintenance staff. The better preventative maintenance you have, the easier it will be to maintain a chemical addition system. Chemical metering systems require more daily maintenance and calibration to insure consistent operation. Fixed bed systems such as softeners and carbon beds require little daily maintenance.

Water must have a very low silt (solids) content to keep the membranes from plugging up. This can be accomplished by removing the solids or keeping them in suspension while passing through the system. Chemicals can be added to the incoming water to keep the solids in suspension or efficient filtration can be used. We prefer to remove all solids before the system, which results in the lowest rate of membrane plugging.

As the water passes through the reverse osmosis system, the ionic content of the reject stream increases as water permeates the membranes. This increase in TDS can results in calcium and magnesium (the hardness ions) precipitating out in the system and plugging the membranes. Again, either the Calcium and Magnesium can be removed or a chemical can be added to keep them in solution. We prefer using a water softener to remove the hardness ions and replace them with sodium.

Chlorine must be removed for thin film membranes and should be minimal for CTA membranes. Either it can be removed by carbon treatment or reduced with a chemical addition of sodium metabisulfite. The carbon is preferred because the chemical addition can enhance bacterial growth in the system which can plug the membranes.

Q: What is required to install and use a reverse osmosis system?

A:. The reverse osmosis system itself is fairly simple, consisting of a series of tube containing the membranes with a high pressure pump to force the water through the system. Pretreatment is required for all systems which is designed to eliminate slit (suspended solids), water hardness and chlorine and other oxidizers. The schematic shows a simplified front end reverse osmosis system where the city water is filtered, softened to remove hardness, the carbon is used to remove the city chlorination (membranes

are sensitive to oxidizers). An alternative would be to dose the system with chemicals to remove the chlorine and hold the hardness ions in solution.

After the carbon filter, the water is passed through the membranes where the concentrate is recycled back to the front of the system for another pass and a bleed is taken off this line to drain. This recycling allows very high system efficiencies.

The permeate line will have a TDS (total dissolved solids) level of about 4% or less of the incoming water (membrane dependent). A sidestream off this line feeds a DI bottle service for DI water. The TDS is only 4% of the incoming water so the DI bottles will last 25 times longer!

Q: How much pressure is required to purify water?
A: The pressure required is dependent on the concentration of the salt solution on the reject (concentrate) side of the membrane. Running as system at 1100 PPM on the concentrate side requires over 200 PSI (13,8 bar). Sea water systems at 33,000+ PPM run at 800+ PSI (55 bar).

Q: How pure will the water be?
A: Purity is determined by two things, first the "reject ratio of the membrane (92-99.5%) and secondly, the type of salts in solution. Membranes are very good at rejection high molecular weight compounds and multivalent ions. Monovalent ions such as Na+ and Cl- (Sodium and Chloride) are not rejected as well and are the leakage ions. The amount of leakage is determined by the reject ration. A 95% reject ration means that 5% of the salt concentration leaks through so a 200 PPM input stream would result in a 10 PPM output stream. A membrane rated at 99% would result in a 2 ppm output stream. The reject ratio changes over the life of the membrane and leakage increases. Each time you clean a membrane it slightly changes its properties so after many years the ratio may drop to 90% or less.

Q: What about membrane plugging?
A: As you concentrate salts on one side of the membrane, you can reach a point where salts of the hardness ions (or other ions) precipitate out. When they do, this will plug the very small pores of the membrane. Organic compounds can also plug the pores. Once plugged, the flow decreases and the membrane must be cleaned. Hardness can be eliminated by softening or continuously dosing a chemical chelating agent.

Q: How can I prevent plugging?
A: Initially the incoming water is filtered to remove particulates and colloidal substances. After this there are two

ways to reduce the chance of plugging. A chemical can be added to the feed stream that keeps the hardness from precipitating out. This is simply metered directly into the pipe feeding the reverse osmosis pump. The second way is to remove the hardness with a water softener. This will reduce the chance of plugging and also acts as another filter in front of the system.

Q: How do I clean a system?
A: Cleaning is fairly simple. A volume of water is recirculated on the high pressure side of the system with a cleaning agent (for hardness or organic plugging) for an hour or so then the membrane is flushed to drain and returned to service.

Q: How much maintenance is involved with a system?
A: If properly setup with effective pretreatment, a system usually has a 1 hour cleaning cycle once per month or even less often when softening is used as a pretreatment. A softener needs a daily check of salt level. Prefilters need a weekly check. Usually filters are alarmed through flow rate so absolute monitoring is not necessary.

Q: How much does it cost to run a reverse osmosis system?
A: The cost to operate is a total of three variables. These are, power, chemistry (pretreatment and pH adjust) and labour.

Power Costs
The power requirement is about 10 hp (7,5 kw) for 30 gpm (113 l/min) up to 15 hp (11 kW) for 60 gpm (227 l/min). This is constant while the system is running. A 10 hp (7,5 kW), 3-phase motor costs about 15 cents per hour to operate (or less).

Chemistry Costs
The chemistry costs for pretreatment involve either salt for a water softener or a polymer or sequestering agent to keep the hardness ions from precipitating out. A pH

adjustment is also usual with citric acid. Total costs for a 30 gpm (113 l/min) system runs about 10-15 dollars a day.

Labour costs

Labour costs for the system is usually very low due to the automated nature of the systems. If the proper pretreatment is used, little or no maintenance is required between cleanings except for chemical maintenance for the pH adjust system and softener or polymer systems. Calibration of pH probes is a weekly project. Cleaning is a simple chemical recirculation procedure taking about 1 hour.

Q: How much water is rejected?
A: This will vary with the configuration of the system. Up to 6 membranes can be connected in series and the theoretical capture rate is about 84% (rejecting 16%). We have used oversized systems and redirected the reject to the front of the system for a multiple pass system and have gotten recovery's of about 92% (half of the reject to drain, half to the system feed tank). This does require oversizing the pumps and system size to get the required flow rate.

Q: How do I dispose of reject water?
A: Reject water is discharged directly to drain. Usually the TDS is less than 1500 PPM and there are no contaminants. If a system is used to recycle some water after a plating application, monitoring of the reject may be necessary.

Q: What types of membranes are there?
A: There are two types of membrane materials in widespread use. These are thin film (TF) and Cellulose Triacetate (CTA) membranes. The thin film membrane is chlorine sensitive and requires carbon pretreatment to remove the chlorine. The CTA membranes don't. TF membranes have a little higher reject ratio and operate at a wider pH range than the CTA.

Q: Do I have to shut down for cleaning?
A: Small systems will have to shut down but in larger (>10 gpm/> 37,8 l/min) systems, the individual banks of membranes can be isolated and cleaned one at a time and only part of the flow will be lost.

Q: Do I have to pH adjust before the reverse osmosis system?
A: Complete systems have a pH adjust module to reduce the pH to between 5.5 and 6.5. This helps to prevent plugging of the membranes and aids in cleaning the system. If the system is to be used in water recycling, pH adjust is mandatory.

Q: What about bugs (bacteria) growing in the water?
A: For boiler feed-water treatment there's normally no need for sterilization - RO systems are sterilized periodically during cleaning. For drink water systems the water storage from a reverse osmosis system is optionally passed through an UV sterilization system, which kills any bacteria in the system. All tanks should be black or opaque to prevent algae growth.

Q: How automatic is automatic?
A: Standard systems have PLC controls with alarms and full sensors compliments. Full automatic controls are available including data monitoring, storage and analysis as are network interfaces. A typical system will have a holding tank with level controls feeding the reverse osmosis pump and a reverse osmosis water storage tank with level controls and duplex pumps for shop water pressurization. All this is monitored and controlled by the PLC. Gauges and instrumentation include high pressure gages on the reverse osmosis pump output and concentra-

te output, pressure switches on the reverse osmosis feed and output (monitored by the PLC), and flow monitors (sight gauges on smaller systems, electronic on larger ones) on the concentrate, permeate and recycle stream. Even the cleaning cycle can be automated on larger systems with automatic valves to isolate selected banks so down time is minimized.
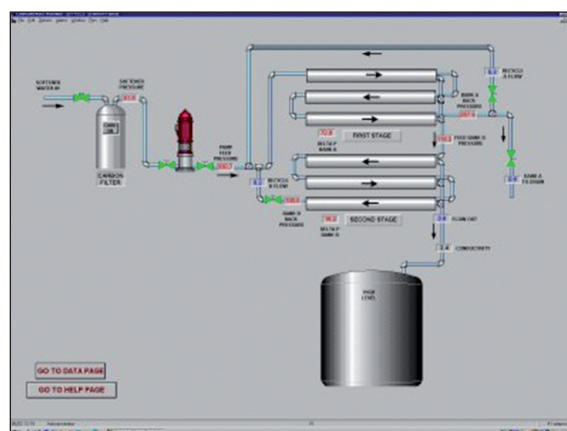
Q: How long will my reverse osmosis membranes last?
A: Reverse osmosis membranes usually last many years. They rarely fail all at once. Usually they slowly start leaking more ions until some unacceptable level is reached. There are membrane systems that have been in continuous use for 20 years. It is much more cost effective in the long run to buy over capacity initially so you can get several years more useful life out of the membranes.

20.8.7   Cost comparison between Ion-exchanger and RO System operation

Comparison of costs for steam boiler operated by "ion exchanger" or "reverse osmosis"

		notes:			notes:
Boiler producer	Hoval		Fill in all green fields !		
Capacity in to/h	1.6				
Condensate quantity in %	30				
Condensate quantity in t/h	0.48	1			
Steam quantity in t/h	1.6	2			
c	0.3	3	c = ration between condensate and steam quantity		
c	0.3	4	steam quantity in t/h	1.6	5
Conductivity of feed water	180		operating hours per day	12	
Conductivity boiler water	2200		operating days per year	265	
			steam quantity in t/year	5088	
factor for soda scission	0.35	6	desalination quantity %	6.24	7
desalination result %	**6.24**		**desalination quantity m3/year**	**317.37**	

desal. quant. with RO   **0.00**   % (not necessary to think about - can be ignored)

note: heating up 1 m³ cold water to steam with 180°C needs approximately 720 kW
(oil = LCV 11,8 kW/kg, gas = LCV 10 kW/Nm³) - results in round 61 kg oil / 72 Nm³ gas

used fuel quantity per ton   **72**   note: fill in 61 for oil fired or 72 for gas fired plants

Plant operation with Ion exchanger			**Plant operation with RO**		
desal. quant. m³ / year	317.37	8	necessary water quantity m³/h	1.12	9
oil/gas m³ or ton / year	22850.66	10	electric supply in kW	1.1	
€/kg or m³ oil / gas	0.6		electric energy costs €/kW	0.08	
result. energy costs / year	13710.40	11	energy costs / year	269.35	12
€/m³ water, waste water	2.76		operation hours / day	12	
water, waste water / year	875.94	13	operating days / year	265	
total desalination cost			lost RO concentrate	2457.50	14
per year	**14589.10**		**total costs for Reverse osmosis**	**3003.85**	

Comparison of costs	
desal. costs with ion exchanger	14589.10
costs for reverse osmosis	3003.85
Costs saved / year	**11585.25**

Investment costs for RO plant - approx. 14000
Payback period in years 1.2

Explanation to notes

1   calculation of relation between boiler capacity and condensate (result in percentage)
2   same value as boiler capacity
3   relation factor between condensate and steam quantity
4   see note 3
5   see note 2
6   fixed value (approximate value)
7   shows the result from left column
8   shows the result of needed desalination quantity (m³/year)

9   shows the result from calculation "steam quantity – condensate quantity" in m³/h
10   shows the result from calculation "desalination quantity m³/year * fuel quantity per ton"
11   shows the result from calculation "needed fuel quantity/year * fuel price"
12   shows the result from calculation "electric supply in kW * electric costs per kW * operation hours per day * operating days per year"
13   shows the result from calculation "desalination quantity m³/year * water costs"
14   shows the result from calculation "water quantity m³/h * fixed factor 0,25 * water costs per m³ * operating hours per day * operating days per year"

And not to forget – additional to above noted comparison:Saving costs for dosing chemicals which are otherwise lost with the desalination/blow down of boiler- Protection of environment and have greater saving due to: **Better water quality results in less fuel, less chemicals and blow down saving!**

20.9   Selection of external water treatment plant
*(See our tutorial for **Steam systems 1,** page 36)*

20.10   Shell boiler plant
*(See our tutorial for **Steam systems 1,** page 36)*

20.11   Summary

The quality of raw water is obviously an important factor when choosing a water treatment plant. Although TDS levels will affect the performance of the boiler operation, other issues, such as total alkalinity or silica content can some-times be more important and then dominate the selection process for water treatment equipment. Sometimes the investment for the "water treatment" station should be higher (i.e. reverse osmosis instead of "ion exchanger" but the costs are returned after a short time of operation due to much lower desalination rate and chemical costs.

20.12   Boiler – and Feed water specifications for Hoval steam boilers:

Hoval

Boiler - and feedwaterspecifications for steam boiler plants

according to Austrian steam boiler rules (353. rule, dated 23.May 1995 - Stationing and working of steam boiler plants - ABV)

Feed water specification (guiding lines) of natural circulating boilers

Working pressure	bar	<= 1	> 1 <= 22	> 22 <= 68
Property	---	colourless, clear, free from suspended matter and foam		
pH –Value at 25 °C	---	> 9	> 9	> 9
Sum of earthalkalies (Ca + Mg) *)	mmol/l	< 0,02	< 0,02	< 0,01
	°dH	< 0,112	< 0,112	< 0,056
Conductivity at 25 °C	μS/cm	see guiding lines for boiler water specifications only		
Oxygen (O_2)	mg/l	< 0,1	< 0,02	< 0,02
Carbon acid (CO_2) bound	mg/l	< 25	< 25	< 25
Iron, complete (Fe)	mg/l	---	< 0,05	< 0,03
Copper, complete (Cu)	mg/l	---	< 0,01	< 0,005
Silicic acid (SiO_2)	mg/l	see guiding lines for boiler water specifications only		
Consumption of $KMnO_4$	mg/l	< 10	< 10	< 10
Oil, fat	mg/l	< 3	< 1	< 1

*) Noted in the past as °dH, changing factor: 1 mmol/l = 5,6 °dH (German hardness)

It's not necessary to make continuous control of following parameters:

Conductivity, Oxygen (O_2), Carbon acid (CO_2) bound, Iron complete (Fe), Copper complete (Cu), Silicic acid (SiO_2), Consumption of $KMnO_4$, Oil, and Fat.

Boiler water specification of natural circulation boilers

Working pressure	bar	<= 1	> 1 <= 22	> 22 <= 44
Property	---	colourless, clear, free from suspended matter and foam		
pH – Value at 25 °C	---	10,5 – 12	10,5 - 12	10 -11,8
Conductivity at 25 °C	μS/cm	< 5000 *)	< 5000 *)	< 2000 *)
Sum of earthalkalies (Ca + Mg) **)	mmol/l	< 0,02	< 0,02	< 0,010
	° dH	< 0,112	< 0,112	< 0,056
Acid capacity KS 8,2 ***) (p – value)	mmol/l	1 –12	1 -12	0,5 - 6
Silicic acid (SiO_2)	mg/l	< 150	< 100	< 50
Phosphate (P_2O_4) ****)	mg/l	10 – 20	5 - 10	5 - 10
Natriumsulfit (Na_2SO_3) ****)	mg/l	5 – 10	5 - 10	3 - 5
(Polyamide) *****)	mg/l	(3 - 5)	(3 - 5)	---

*)   Take care to the allowed value of acid capacity - according to this point the allowed conductivity has to be lower on many plants
**)   Noted in the past as °dH, changing factor: 1 mmol/l = 5,6 °dH (German hardness)
***)   Noted in the past as p - Value, Changing factor: KS 8,2 = 1 according p-Value = 1
****)   Measuring only necessary if dosing chemicals are used which contains these values.
*****)   It's recommended to use Amine (film producing) only (instead of other dosing chemicals) for boilers which have a small load of heating areas and up to max. 16 bar working pressure. According to the danger of foam production a too high dosing is not permitted!

It's not necessary to make continuous control of following parameter: Silicic acid (SiO_2)

21 Purge pit *(See our tutorial for **Steam Systems 1**, Page 38)*

21.1 Desalination/purge rate calculation

To answer this question is not so easy, the answer is related to many operation figures which are seldom known (i.e.: percentage of fresh water/condensate, design of water treatment station and chemical dosing, real operation load of plant etc.)

We could give "guide values" only:

a) Purge (boiler bottom blow down):
1 – 2 x day for round 5 sec.
For this please see technical data sheets from „purge valve supplier" (mostly they have tables which are connected to boiler pressure)
The „open time" is also related if there´s a conductivity regulation system installed (TDS-control). If yes the above noted value is surely enough – if not it´s mostly necessary to "purge" more often because by "purging" the water quality inside the boiler is "regulated" (especially conductivity and "p-value/alkalinity") too.

b) Continuous blow down of boiler
(conductivity/TDS regulation – if installed)
The flow rate through regulation valve could be taken from technical data sheets from supplier (i.e. Gestra – valve type "BA 46" – for standard boilers the supplied dimension is "DN 15").

Calculation of necessary blow down rate works as follows:

$$A \ (kg/h) = (S/(K-S)) * Q$$

A = blow down rate in kg/h
S = existing content of dissolved solids (or conductivity) at the feed water (value mg/l or µS/cm)
K = allowed content of dissolved solids (or conductivity) at the boiler water (value mg/l or µS/cm)
Q = Boiler capacity in kg/h

Example:
S = conductivity at the feed water tank = 300 µS/cm
K = allowed conductivity at the boiler water = 3500 µS/cm (maximum allowed are 5000 µS/cm but we recommend not to operate the boiler higher then 3500 µS/cm – higher rates could lead to bad steam quality)
Q = boiler capacity 15000 kg/h

Result: 1406 kg/h necessary blow down quantity

Note: Please observe the allowed "p-value/alkalinity" value at the boiler water too – the "p-value/alkalinity" should always stay below "12"!

22 Economiser units – fuel saving

22.1 What is a economiser and what´s the use (benefit) of it

A boiler economizer is a heat exchanger device that captures the "lost or waste heat" from the boiler's hot stack gas which could not be used inside the boiler furnace (due to physical reasons; i.e. boiler water temperature). The economizer typically transfers this waste heat to the boiler's feed water or return water circuit, but it can also be used to heat domestic water or other process fluids. Capturing this normally lost heat reduces the overall fuel requirements for the boiler. Less fuel equates to money saved as well as fe-

wer emissions - since the boiler now operates at a higher efficiency. This is possible because the boiler feed-water or return water is pre-heated by the economizer therefore the boilers main heating circuit does not need to provide as much heat to produce a given output quantity of steam or hot water. Again fuel savings are the result. Boiler economizers improve a boiler's efficiency by extracting heat from the flue gases discharged.

For steam boilers, the economiser is a typically a heat exchanger through which the feed water is pumped. The flue gases, having passed through the main boiler area will still

be hot. The energy in these flue gases is used to improve the thermal efficiency of the boiler.
The feed water thus arrives in the boiler at a higher temperature than would be the case if no economiser was fitted. Less energy is then required to raise the steam. Alternatively, if the same quantity of energy is supplied, then more steam is raised. This results in a higher efficiency. In broad terms a 10°C increase in feed water temperature will give an efficiency improvement of round 2%.

On shell boilers the economiser is either installed directly at the boiler or – also possible – installed as a separate unit. The smoke gas coming from the last boiler smoke gas pass is guided into the economiser.
Note: The smoke gas temperature leaving a normal boiler is round 50 – 80°C higher (full load and clean heating surfaces) then the saturated steam temperature. The minimum allowed smoke gas temperature (behind economiser) depends – mainly - to chimney design (resistant against acids?).
For steam boilers operated at 10 bar(g) the temperature levels which could be used at the economiser are round 250°C down to 140°C (smoke gas out from boiler compared to smoke gas out from eco) – this gives a fuel saving of round 5% comparing to boilers without economiser. The feed water temperature will rise from 105°C to round 135°C in that case.

The heat output recovery from smoke gas is limited. At smoke gases from oil- or gas firing plants there´s a steam content of 100 – 120 g/kg; the condensing point of this water content is situated at 57°C. For heating up the feed water by an economiser it´s only possible to use the sensible heat (dry heat) because the feed water has to have a min. temperature of 90°C – so it´s not possible to condense the smoke gases and to use the condensing energy too.

The heat output recovery of sensible/dry heat in kcal/h is calculated „roughly" as follows:

$$Q_{sens} \approx RGM * \Delta t * \left(\frac{cp_{mte} - cp_{mta}}{2} + cp_{mta} \right)$$

Q_{sens} = heat output recovery (sensible) – kcal/h
RGM = smoke gas quantity – Nm³/h
Δt = temperature difference between smoke gas in and out - °C
cp_{mte} = specific heat at smoke gases kcal/Nm³ °C – entering the heat exchanger
cp_{mta} = specific heat at smoke gases kcal/Nm³ °C – outlet of heat exchanger

Take the cpM-value from tables; for smoke gas heat exchangers – after standard boilers and for cooling the smoke gases from 260°C to 140°C you could use – roughly – value 0,3224 for entering the exchanger and 0,3178 for outlet of exchanger.

Example:
Smoke gas flow: 4045 Nm³/h (for ~ 5 to/h steam boiler)
Temperature smoke gas – eco in: 260°C
Temperature smoke gas – eco out: 140°C

Calculation of sensible/dry heat output recovery:

$$4045 * (260 - 140) * \left(\frac{0,3224 - 0,3178}{2} + 0,3178 \right)$$

$$= 155376 \left(\frac{kcal}{h} \right)$$

$$= 180.7 \left(\frac{kWh}{h} \right)$$

$$= 180.7 \ kW$$

$$\text{with: } 1 \left(\frac{kcal}{h} \right) = \left(\frac{1}{860} \right) * \left(\frac{kWh}{h} \right) = \left(\frac{1}{860} \right) * kW$$

By cooling down the smoke gases below the condensing point it´s possible to collect – additional to "sensible/dry heat" the "latent" heat too. The condensing point of smoke gases – as noted above – is round 57°C. The condensation runs – with better results – if the "wall temperature" of exchanger tubes is below 50°C and lower (note: smoke gases leaving the exchanger are still with higher temperature level as the smoke gas condensing temperature).

Calculation of „latent heat" runs – roughly – as follows:

$$Q_{lat} \left(\frac{kcal}{h} \right) \approx \text{condensate quantity [kg] * 600}$$

The real received condense quantity results from detailed heat exchanger design.

For every Nm³ of smoke gas (if fully condensed and r especting the air humidity) there´s received approx. 0,165 g/kWh of smoke gas condensate (natural gas firing). For practical use this value is not reached – the realistic condensate quantity is between 0,06 and 0,09 g/kWh (natural gas firing).

Why is there condensate at smoke gas?
On cold surfaces the – at the smoke gases contained - water is condensed – this water is a result from:

By burning H_2 (which is a chemical part of natural gas) with oxygen O_2 coming from the combustion air results water vapour which leaves – on higher temperatures – the chimney as invisible content (without condensing to liquid water). During winter seasons this water vapour results in white clouds at the chimney outlet because the smoke gas temperature align with the surrounding air temperature, cools down and the water vapour condense in form of white cloud.

For full combustion of 1 Nm³ natural gas results 2 Nm³ H2O (water vapour) which – if fully condensed results in 1,6 kg of water.

The complete heat output recovery is calculated by summary of sensible and latent heat

$$Q_{ges} = Q_{sens} + Q_{lat}$$

Note: The smoke gas condensate (natural gas firing) is with pH-value between 3 and 5 – so it´s acid and very corrosive. This results directly in special material selection for the exchanger, the exchanger casing, the chimney and the piping/treatment into the sewer system.

The used materials for these elements have to be resistant against the low pH-value (normally stainless steel with quality 1.4571) and the condensate has to be „neutralised" before entering the sewer system.

Also it´s to be noted that – during condensing operation – the white cloud on chimney outlet is increased due to water saturated smoke gases. This "flag" is often seen as "smoke" and gives negative comments from passing peoples (especially at hospitals and human treatment centres).

Attention: If there´s Sulphur contained at used fuel and the smoke gas is condensed there´s resulting sulphur and/or sulphurous acid. This acid is very corrosive to standard stainless steel so it´s not possible to use this material. For such operations it´s necessary to use special heat exchangers – which are very expensive - made from ceramic, Teflon or glass.

Take care that the economiser is only used for the designed fuel (standard = gas) because the heat transfer area is mainly done from finned tubes which could be blocked by using oil or coal firing in a very short time.

So Hoval recommends installing – standard – economisers

only for "gas" fired boilers. In "dual fuel" plants the smoke gas collector box should be equipped with an automatic smoke gas bypass unit which will change the smoke gas flow "bypassing" the economiser during oil firing. The bypass is not only for "dirt and soot" problems but also for "smoke gas condensing" and acid production at economisers by using other fuels then gas.

The flow of water through the economiser is general counter flow to the smoke gas flow – this gives best results in "temperature difference" between smoke gas and feed water and the highest energy transfer rate.

Vent and drains are fitted to header where isolating valves are fitted a safety valve must also be added.

Efficient burner operation is absolutely essential to ensure that economiser surfaces are kept clear of combustion products which can not only lead to heavy corrosion and a drop in efficiency, but also to the possibility of an economiser "soot blocking" with potentially disastrous consequences.

If due to failure it is required to run the economiser dry then the maximum gas inlet temperature should be limited to about 400°C, vents and drains should be left open to ensure that there is no build up of pressure from any water that may be still located in the tubes.
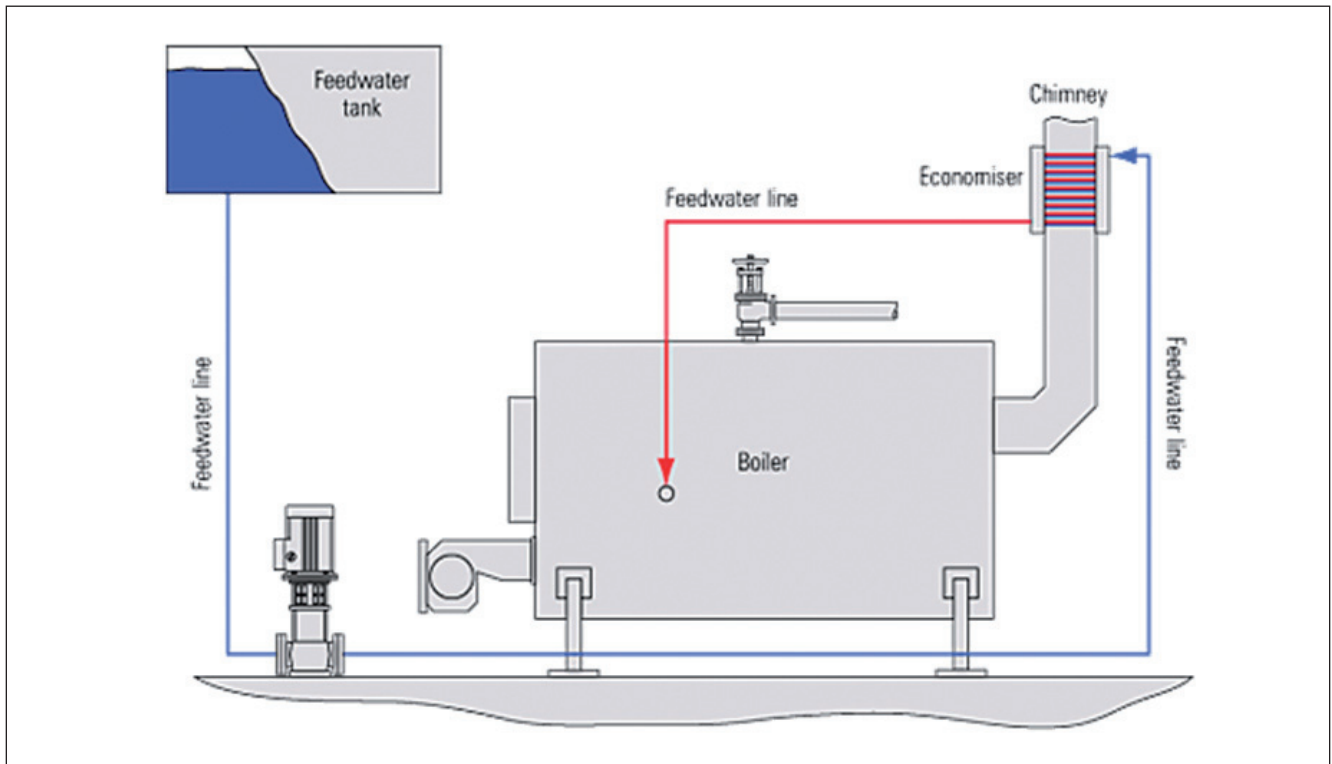
Notes: • Because the economiser is on the high-pressure side of the feed pump, feed water temperatures in excess of 100°C are possible. The boiler water level controls must be of the 'modulating' type, (i.e. not 'on-off') to ensure a continuous flow of feed water through the heat exchanger.
• The heat exchanger should not be so large that:
• The flue gases are cooled below their dew point, as the resulting liquor may be acidic and corrosive.
• The feed water boils in the heat exchanger.

22.3   Economiser – exchanger – tubes (examples)

Elliptic fin tubes are low in smoke gas flow resistance, round tubes are producing more turbulence at the smoke
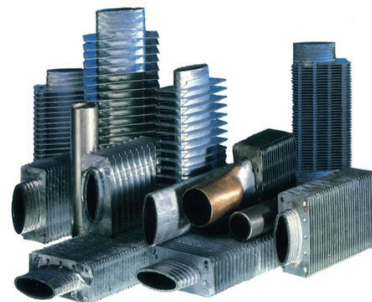
gas flow and results a better heat transfer - comparing to elliptic tubes. But please observe the increasing smoke gas backpressure from the economiser by using this design. Note: detailed design of tubes depends to detailed case studies – so the pictures are only examples
„Not condensing" heat exchangers are normally built with "finned tubes" to receive a bigger heat transfer surface. "Condensing" heat exchangers are built with "round tubes and without fins" to receive a big – cold – contact surface between smoke gas and secondary medium.
Note: As "black oil" firing tend to more soot production and contains also more dirt then diesel oil or natural gas it´s not possible to use "fined" tube heat exchangers for "black oils" For such a fuel it´s necessary to use "round tubes without fins" or "smoke tube heat exchangers" even if there´s no "condensing" operation.

45

22.4   Picture – examples – of economiser heat exchanger unit
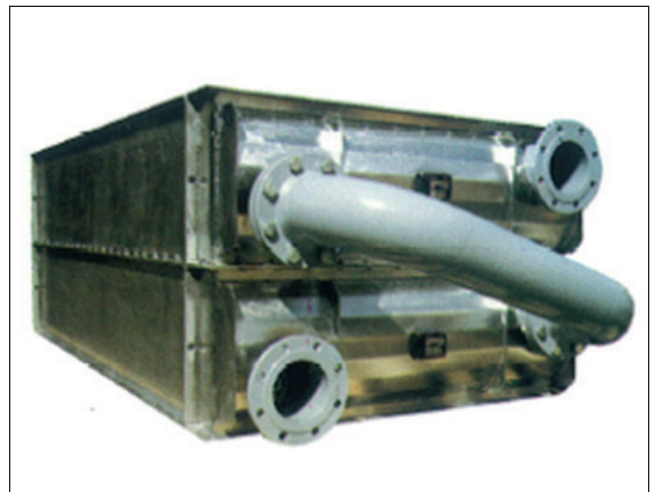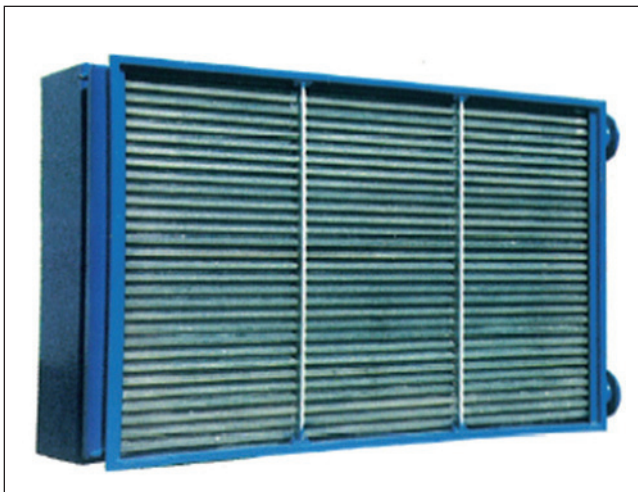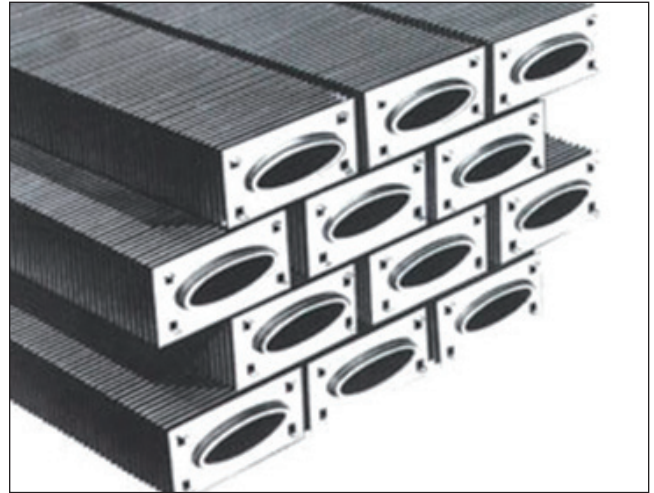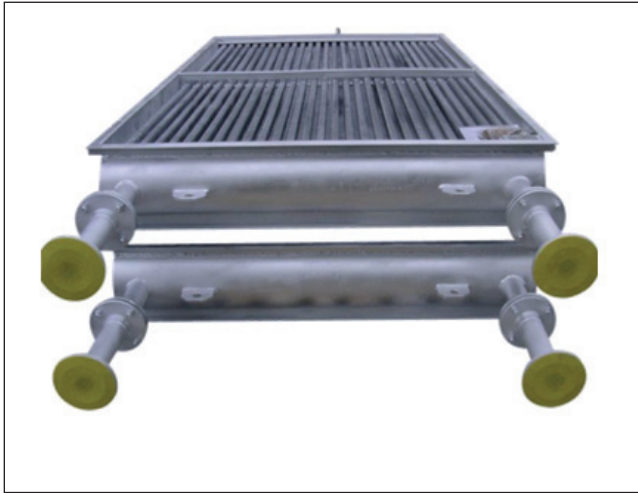
22.5   Cleaning of heat exchanger

Smoke gas side:

Finned tubes are difficult to be cleaned. It´s not possible to make any mechanical cleaning. If it´s necessary to clean the exchangers it´s only possible by using a "wet cleaning method" – for example with high pressure cleaner and special cleaning liquids (but be careful not to damage the fins on the tubes). The – during cleaning – received washing water has to be collected and treated before draining into city sewer system. After cleaning it´s necessary to rinse the heat transfer surface till the waste water is back to neutral pH-value.

The heat transfer area from the boiler has to be protected against washing/rinsing water during this process.

Water side

(normally only necessary if there was something wrong with boiler feeding water quality):

Also here it´s a lot to do and it´s very difficult. As there´re more tubes parallel connected at the exchangers there´s the danger that the cleaning liquid will not flow into all tubes – so the cleaning will be not successful.

If the "register" is blocked by lime or any other substances it´s often necessary to cut off the exchanger water chambers, to clean the tubes one by one with mechanical and chemical methods, and then to weld the chambers to the exchanger again. The resulting time and costs are very high – sometimes it will make more sense to change the register completely.

22.6 Efficiency diagram for boiler with/without economiser

The graph below shows the advantages of using the economizer for preheating of feed water. Clearly seen without using a boiler economizer the work efficiency of a steam boiler will decrease, in the sense that without heating which is assis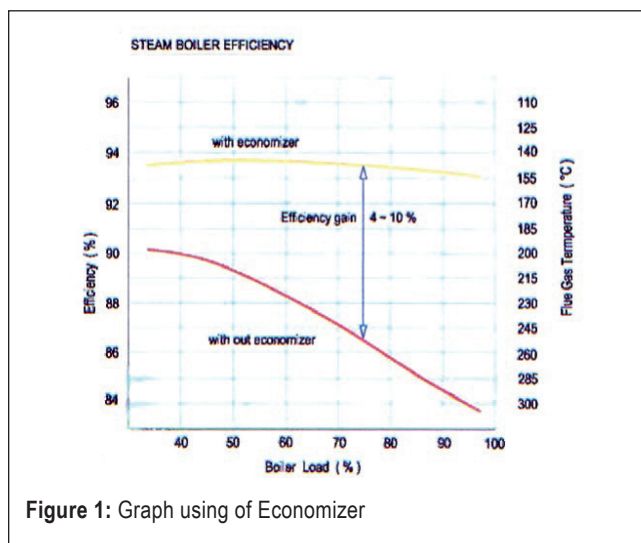ted by the economizer, the boiler must work longer in the production of steam and in addition boiler will require more fuel to reach the hot temperature that has been determined. Without economizer a plant will experience huge losses in the boiler operation for using more fuel.

The operating costs of a boiler with economiser will be more efficient and will benefit to plant performance.

It is apparent that using a boiler economizer will increase the efficiency, so it will doing more fuel savings - far enough difference if compared to the boilers which running without economizer!

Figure 1: Graph using of Economizer

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23 **Calculation of temperatures and quantities**
(Mixture of 2 water streams)
*(See our tutorial for **Steam Systems 1,** page 40)*

24 **Pressure loss at steam pipes**
(see also point 25, 26, 28 and 32)
*(See our tutorial for **Steam Systems 1,** page 40)*

25 **Pressure loss at straight water pipes**
*(See our tutorial for **Steam Systems 1,** page 42)*

26 **Determination of pipe size**
*(See our tutorial for **Steam Systems 1,** page 43)*

27 **Flow speed at pipes (liquid, gaseous)**
*(See our tutorial for **Steam Systems 1,** page 43)*

28 **Steam pipes - dimensions**
*(See our tutorial for **Steam Systems 1,** page 44)*

29 **Condensate pipes – dimensions**
*(See our tutorial for **Steam Systems 1,** page 45)*

30 **Pipe expansion and support**
*(See our tutorial for **Steam Systems 1,** page 46 ff.)*

31 **Pipe dimensions and weights**
*(See our tutorial for **Steam Systems 1,** page 53)*

32 **Dimensions for gaskets and connections**
*(See our tutorial for **Steam Systems 1,** page 54 ff.)*

33 **Steam lines and drains**
*(See our tutorial for **Steam Systems 1,** page 56)*

34 **Steam consumption of plants**
*(See our tutorial for **Steam Systems 1,** page 63 ff.)*

35 **Steam consumption of plant items**
*(See our tutorial for **Steam Systems 1,** page 69 ff.)*

36 **Safety valves – Installation**
*(See our tutorial for **Steam Systems 1,** page 73 ff.)*

37 Required formulas and conversion tables

37.1 Conversion of pressure units *(quick use – rounded):*

Einheit Unité Unit	bar	mbar	Pa N/m²	kPa kN/m²	MPa MN/m²	at kp/cm²	atm	mmWS mmCE 1000 kp/m²	mWS mCE 1000 kp/m²	Torr mmHg mmQS	psi lbf/in²	kgf/cm²
1 bar	1	1000	$1 * 10^5$	100	0,1	1,02	0,987	$1.02 * 10^4$	10,2	750	14,5	1,02
1 mbar	0,001	1	100	0,1	$1 * 10^{-4}$	$1.02 * 10^{-3}$	$0.987 * 10^{-5}$	10,2	0,010	0,75	0,015	$1.02 * 10{-3}$
1 Pa 1 N/m²	$1 * 10^{-5}$	0,01	1	0,001	$1 * 10^{-6}$	$1.02 * 10^{-5}$	$0.987 * 10^{-5}$	0,102	$1.02 * 10^{-4}$	0,0075	$1.45 * 10^{-4}$	$1.02 * 10^{-5}$
1 kPa 1 kN/m²	0,01	10	1000	1	0,001	0,010	$9.87 * 10^{-3}$	102	0,102	7,5	0,145	0,010
1 MPa 1 MN/m²	10	$1 * 10^4$	$1 * 10^5$	1000	1	10,2	9,87	$1.02 * 10^5$	10^2	7500	145	10,2
1 at 1 kp/cm²	0,981	981	$0.981 * 10^5$	98,1	0,098	1	0,968	$1 * 10^4$	10	736	14,22	1
1 atm	1,013	1013	$1.013 * 10^5$	101,3	0,101	1,033	1	$1.033 * 10^4$	10,332	760	14,696	1,033
1 mmWS 1 mmCE	$0.981 * 10^{-4}$	0,098	9,807	$9.81 * 10^3$	$9.81 * 10^{-6}$	$1 * 10^{-4}$	$9.68 * 10^{-5}$	1	0,001	0,074	$1.422 * 10^{-3}$	$1 * 10^{-4}$
1 mWS 1 mCE	0,098	98,07	9807	9,81	$9.81 * 10^{-3}$	0,1	0,097	1000	1	73,6	1,422	0,1
1 Torr 1 mmHg	$1.333 * 10^{-3}$	1,333	133,322	0,133	$0.133 * 10^{-3}$	$1.36 * 10^{-3}$	$1.316 * 10^{-3}$	13,595	$1.359 * 10^{-2}$	1	$1.934 * 10^{-2}$	$1.36 * 10^{-3}$
1 psi 1 lbf/in²	$6.895 * 10^{-2}$	68,95	6895	6,895	$6.895 * 10^{-3}$	$7.031 * 10^{-2}$	0,068	703,1	0,703	51,7	1	$7.031 * 10^{-2}$
1 kgf/cm²	0,981	981	$0.981 * 10^5$	98,1	0,098	1	0,968	$1 * 10^4$	10	736	14,22	1

37.2 Conversion of anglo - american units to SI units

Length

Name of unit	Symbol	Definition	Relation to SI units
foot (International)	ft	= 1/3 yd = 0.3048 m = 12 inches	= 0.3048 m
inch (International)	in	= 1/36 yd = 1/12 ft	= 0.0254 m
metre (SI base unit)	m	= Distance light travels in 1 / 299792458 of a second in vacuum.[8] ≈ 1 / 10000000 of the distance from equator to pole.	= 1 m
mile (international)	mi	= 80 chains = 5280 ft = 1760 yd	= 1609.344 m
nanometer	nm	$= 1 \times 10^{-9}$ m	$= 1 \times 10^{-9}$ m
nautical mile (international)	NM; nmi	= 1852 m	= 1852 m
yard (International)	yd	= 0.9144 m = 3 ft = 36 in	= 0.9144 m

Aerea

Name of unit	Symbol	Definition	Relation to SI units
acre (international)	ac	= 1 ch × 10 ch = 4840 sq yd	= 4 046.856 4224 m^2
hectare	ha	= 10 000 m^2	=10 000 m^2
shed		= 10^{-52} m^2	= 10^{-52} m^2
square foot	sq ft	= 1 ft × 1 ft	= 9.290 304 × 10^{-2} m^2
square inch	sq in	= 1 in × 1 in	= 6.4516 × 10^{-4} m^2
square kilometre	km^2	= 1 km × 1 km	= 106 m^2
square metre (SI unit)	m^2	= 1 m × 1 m	= 1 m^2
square mile	sq mi	= 1 mi × 1 mi	= 2.589 988 110 336 × 106 m^2

Volume

Name of unit	Symbol	Definition	Relation to SI units
barrel (petroleum)	bl; bbl	= 42 gal (US)	= 0.158 987 294 928 m^3
bucket (Imperial)	bkt	= 4 gal (Imp)	= 0.018 184 36 m^3
cubic foot	cu ft	= 1 ft × 1 ft × 1 ft	= 0.028 316 846 592 m^3
cubic inch	cu in	= 1 in × 1 in × 1 in	= 16.387 064 × 10^{-6} m^3
cubic metre (SI unit)	m^3	= 1 m × 1 m × 1 m	= 1 m^3
cubic mile	cu mi	= 1 mi × 1 mi × 1 mi	= 4 168 181 825.440 579 584 m^3
cubic yard	cu yd	= 27 cu ft	= 0.764 554 857 984 m^3
gallon (Imperial)	gal (Imp)	= 4.546 09 L	= 4.546 09 × 10^{-3} m^3
litre	L	= 1 dm^3	= 0.001 m^3
ounce (fluid Imperial)	fl oz (Imp)	= 1/160 gal (Imp)	= 28.413 0625 × 10^{-6} m^3
pint (Imperial)	pt (Imp)	= ⅛ gal (Imp)	= 568.261 25 × 10^{-6} m^3
quart (Imperial)	qt (Imp)	= ¼ gal (Imp)	= 1.136 5225 × 10^{-3} m^3
ton (freight)		= 40 cu ft	= 1.132 673 863 68 m^3
ton (water)		= 28 bu (Imp)	= 1.018 324 16 m^3

Flow (volume)

Name of unit	Symbol	Definition	Relation to SI units
cubic foot per minute	CFM	= 1 ft^3/min	= 4.719474432 × 10^{-4} m^3/s
cubic foot per second	ft^3/s	= 1 ft^3/s	= 0.028316846592 m^3/s
cubic inch per minute	in^3/min	= 1 in^3/min	= 2.7311773 × 10^{-7} m^3/s
cubic inch per second	in^3/s	= 1 in^3/s	= 1.6387064 × 10^{-5} m^3/s
cubic metre per second (SI unit)	m^3/s	= 1 m^3/s	= 1 m^3/s
gallon (U.S. fluid) per day	GPD	= 1 gal/d	= 4.381263638 × 10^{-8} m^3/s
gallon (U.S. fluid) per hour	GPH	= 1 gal/h	= 1.051503273 × 10^{-6} m^3/s
gallon (U.S. fluid) per minute	GPM	= 1 gal/min	= 6.30901964 × 10^{-5} m^3/s
litre per minute	LPM	= 1 L/min	= 1.6 × 10^{-5} m^3/s

Force

Name of unit	Symbol	Definition	Relation to SI units
kilogram-force; kilopond; grave-force	kgf; kp; Gf	= g × 1 kg	= 9.806 65 N
newton (SI unit)	N	A force capable of giving a mass of one kg an acceleration of one metre per second	= 1 N = 1 kg·m/s^2
pound	lb	= slug·ft/s^2	= 4.448 230 531 N
pound-force	lbf	= g × 1 lb	= 4.448 221 615 2605 N
ton-force	tnf	= g × 1 sh tn	= 8.896 443 230 521 × 10^3 N

Energy, work or amount of heat

Name of unit	Symbol	Definition	Relation to SI units
British thermal unit (ISO)	BTU_{ISO}	$= 1.0545 \times 10^3$ J	$= 1.0545 \times 10^3$ J
British thermal unit (International Table)	BTU_{IT}		$= 1.055\,055\,852\,62 \times 10^3$ J
British thermal unit (39 °F)	$BTU_{39\,°F}$		$\approx 1.059\,67 \times 10^3$ J
British thermal unit (59 °F)	$BTU_{59\,°F}$	$= 1.054\,804 \times 10^3$ J	$= 1.054\,804 \times 10^3$ J
British thermal unit (60 °F)	$BTU_{60\,°F}$		$\approx 1.054\,68 \times 10^3$ J
British thermal unit (63 °F)	$BTU_{63\,°F}$		$\approx 1.0546 \times 10^3$ J
calorie (International Table)	cal_{IT}	$= 4.1868$ J	$= 4.1868$ J
calorie (mean)	cal_{mean}	1/100 of the energy required to warm one gram of air-free water from 0 °C to 100 °C @ 1 atm	$\approx 4.190\,02$ J
foot-pound force	ft lbf	$= g \times 1$ lb $\times 1$ ft	$= 1.355\,817\,948\,331\,4004$ J
foot-poundal	ft pdl	$= 1$ lb$\cdot$ft^2/s^2	$= 4.214\,011\,009\,380\,48 \times 10^{-2}$ J
horsepower-hour	hp·h	$= 1$ hp $\times$ 1 h	$= 2.684\,519\,537\,696\,172\,792 \times 10^6$ J
inch-pound force	in lbf	$= g \times 1$ lb $\times 1$ in	$= 0.112\,984\,829\,027\,6167$ J
joule (SI unit)	J	The work done when a force of one newton moves the point of its application a distance of one metre in the direction of the force.[24]	$= 1$ J $= 1$ m$\cdot$N $= 1$ kg$\cdot$m^2/s^2 $= 1$ C$\cdot$V $= 1$ W$\cdot$s
therm (E.C.)		$= 100\,000\ BTU_{IT}$	$= 105.505\,585\,262 \times 106$ J

Power or heat flow rate

Name of unit	Symbol	Definition	Relation to SI units
BTU (International Table) per hour	$BTU_{IT/h}$	$= 1\ BTU_{IT/h}$	$\approx 0.293\,071$ W
BTU (International Table) per minute	$BTU_{IT/min}$	$= 1\ BTU_{IT/min}$	$\approx 17.584\,264$ W
BTU (International Table) per second	$BTU_{IT/s}$	$= 1\ BTU_{IT/s}$	$= 1.055\,055\,852\,62 \times 10^3$ W
horsepower (boiler)	bhp	≈ 34.5 lb/h $\times$ 970.3 $BTU_{IT/lb}$	$\approx 9.810\,657 \times 103$ W $(= 9,81$ kW$)$
horsepower (European electrical)	hp	$= 75$ kp·m/s	$= 736$ W
watt (SI unit)	W	The power which in one second of time gives rise to one joule of energy	$= 1$ W $= 1$ J/s $= 1$ N$\cdot$m/s $= 1$ kg$\cdot$m^2/s^3

Conversion of water hardnes units

Total hardness ($CaCO_3$ – Calciumcarbonate)

	Symbol	°dH	°e	°fH	ppm	mval / l	mmol / l
German hardness	°dH	1	1,253	1,78	17,8	0,357	0,1783
English hardness	°E	0,798	1	1,43	14,3	0,285	0,142
French hardness	°fH	0,560	0,702	1	10	0,2	0,1
ppm $CaCO_3$ (USA)	ppm	0,056	0,07	0,1	1	0,02	0,01
mval/l earthalcali-Ions	mval/l	2,8	3,51	5	50	1	0,50
mmol/l earthalcali-Ions	mmol/l	5,6	7,02	10,00	100,0	2,00	1

General hardness level

(°dH/mmol/l calciumcabonate)

	°dH	mmol/l
Soft	< 8,4	< 1,5
Medium	8,4 - 14	1,5 – 2,5
Hard	> 14	> 2,5

37.3 Software Conversions see (examples - freeware)

http://joshmadison.com/convert-for-windows/
(easy download possible)

http://www.convertworld.com
(Internet based calculations only)
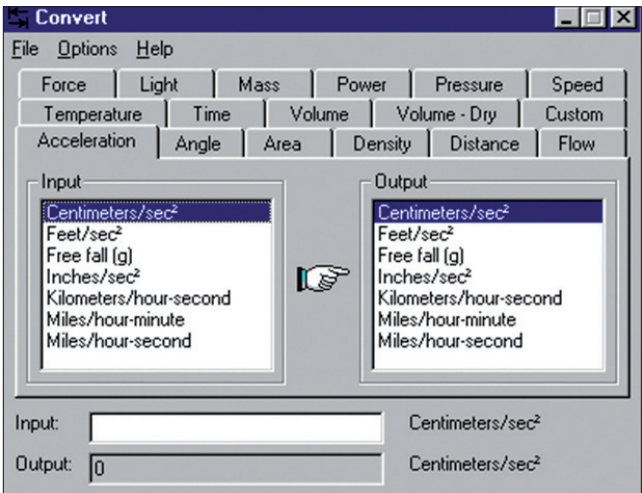
**http://online.unitconverterpro.com/conversion-tables/
convert-group/factors.php**
(Internet based calculations only)

38 Literature references

Literature references
Hoval data sheets and guidelines, Hoval handbooks
Spirax-Sarco steam tutorials (www.spiraxsarco.com)
Gestra handbook (www.gestra.de)
Saacke - rules of thumb (www.saacke.de)
Wikipedia encyclopedia (www.wikipedia.org)

39 System P&I Diagram

Diagram labels:
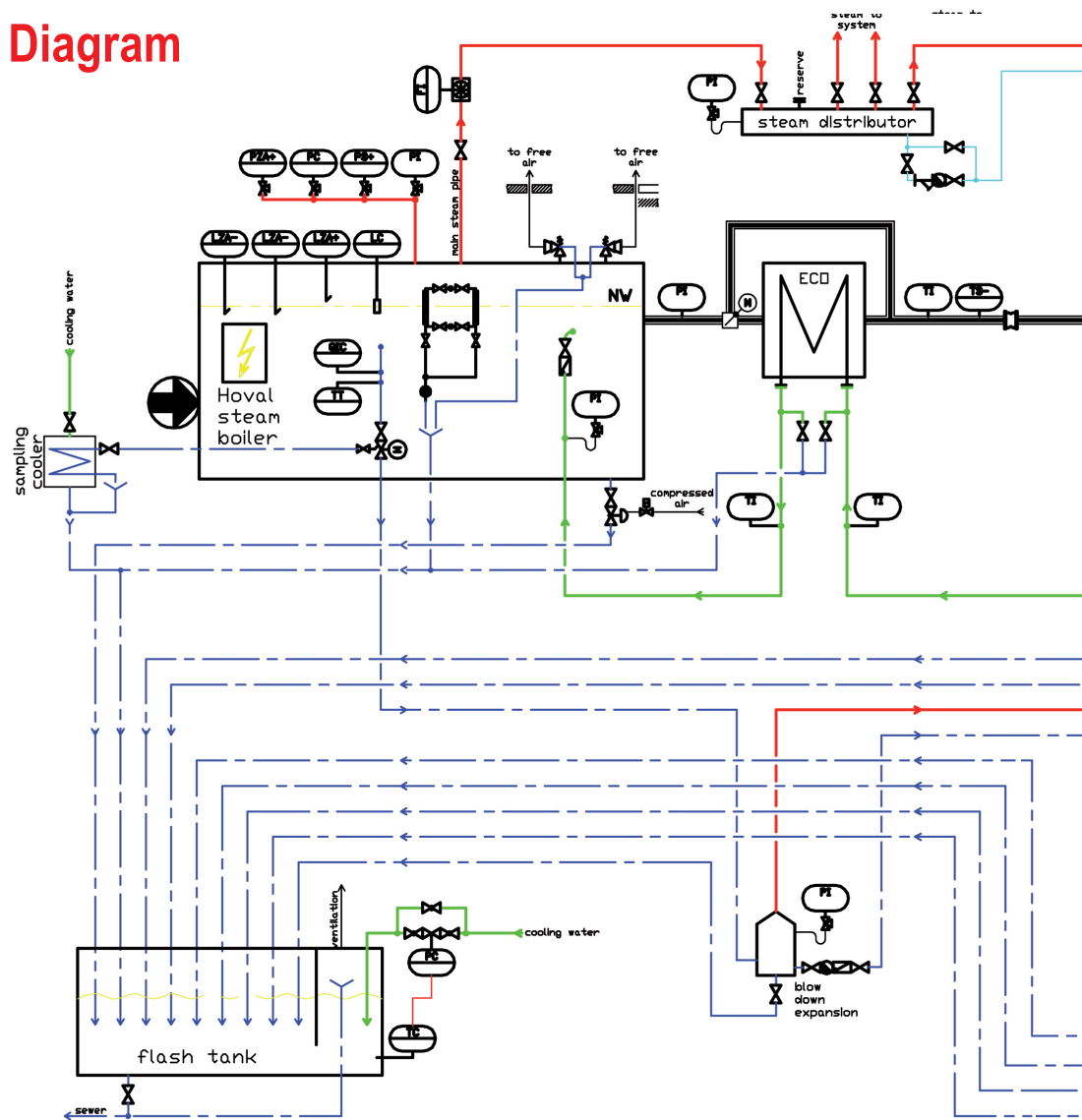- steam to system
- steam distributor
- reserve
- to free air
- to free air
- main steam pipe
- cooling water
- sampling cooler
- Hoval steam boiler
- NW
- ECO
- compressed air
- ventilation
- cooling water
- flash tank
- sewer
- blow down expansion
- PZA, PC, PS, PI
- LZA, LZA, LZA, LC

Legend:

Symbol	Description	Symbol	Description	Symbol	Description	Symbol	Description
	shut off armature	TI	temperature indicator		overflow valve	PT	pressure sensor		electric actuated valve
	ball valve	PI	pressure indicator		pressure reducing valve	TS	thermostate		3 way electric actuated valve
	regulating valve	TT	temperatur transmitter		recirculation valve	PS	pressure switch		solenoid valve
	3 way valve	TC	temperatur control		safety valve	TZA	safety thermostate		pneumatic actuated valve
	Burner		on-site indication		control room indication		control SPS		flue gas compens.
	water level indicator		blind flange		border of delivery				

Hydr.	Verbindungshinweis / Notice / Nota / Remarque:
	>>
1	

chimney

exhaust vapor

condensate

deaerator

feedwater tank

dosing

condensate
condensate
fresh water

raw water

water treatment station

condensate from steam system

condensate tank (pressureless)

Na | NaCl | Na

Symbol	Description		Symbol	Description		Symbol	Description		Symbol	Description		Symbol	Description
PZA	safety pressure switch			foot operated purge valve		**FS**	flow control switch			shut off flap			ignite-gas-burner
TA	safety temperature sensor			pressure regulated valve		**LI**	reflex level gauge			pneumatic flap			proval burner
QC	conductivity control			strainer		**LS**	level switch		**LZA–**	water insufficiency control			orifice
FIQ	flow indicator with counter			non return flap		**LC**	continuous level control		**LZA+**	overfill control			reduction
	pump			fan			gauge glas			condensate trap			filter

**P&I diagram steam boiler plant
with additional equipment**

Achtung! Für die Installation muss das anlagenbezogene Schema verwendet werden!
Attention! This is just a schematic. For installation please use the detail-plan!
Attenzione! Per la messa in opera, utilizzare le schema dettagliato!
Attention! Pour la réalisation pratique de l'installation, il faut utiliser le schéma détaillé!

Hoval

	Datum	Name
	17.01.2012	...
Version ...		...
Datei: ...		

Notes:

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Although Hoval does everything possible to ensure the accuracy of all data within this document, we cannot be held responsible for the contained information
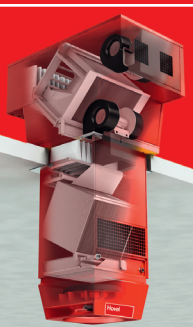
Hoval

Hoval heating technology

As an energy neutral supplier with a full range of products, Hoval helps its customers to select innovative system solutions for a wide range of energy sources, such as heat pumps, biomass, solar energy, gas, oil and district heating. Services range from private residential units to large-scale industrial projects.

Hoval residential ventilation

Increased comfort and more efficient use of energy from private housing to industrial halls: our controlled residential ventilation products provide fresh, clean air for living and working space. Our innovative system for a healthy room climate uses heat and moisture recovery, while at the same time protecting energy resources and providing a healthier environment.

Hoval indoor climate systems

Supplying fresh air, removing extract air, heating, cooling, filtering and distributing air, utilising heat gains or recovering cold energy – no matter what the task, Hoval indoor climate systems provide tailor-made solutions with low planning and installation costs.

Responsibility for energy and environment.

The Hoval brand is internationally known as one of the leading suppliers of indoor climate control solutions. More than 66 years of experience have given us the necessary capabilities and motivation to continuously develop exceptional solutions and technically superior equipment. Maximising energy efficiency and thus protecting the environment are both our commitment and our incentive. Hoval has established itself as an expert provider of intelligent heating and ventilation systems that are exported to over 50 countries worldwide.

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