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Review Article

Three – Pass Fire Tube Boilers for production of Steam, Hot Water and Superheated Water

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Abstract

In this paper, the technical details and specifications of Three – Pass Fire Tube Boilers for production of Steam, Hot Water and Superheated Water, are introduced.

The most manufactured steam generator type for output flow rate capacities ranging from 1 t/h to 30 t/h is the three-pass fire tube boiler unit, fired by gas or oil and delivered in a pre-fabricated form.

Regarding the smaller or medium output ranges of saturated steam and hot water; saturated steam boiler, low pressure steam boiler, superheated steam boiler and hot water boiler variation models are manufactured. All models commonly must have the optimum production engineering and thermodynamical design specifications, the highest technically possible efficiency rate, easy to operate with low maintenance works, high quality and time-tested components for firing and control, modern manufacturing methods with corresponding high quality control, international supervision, classification, inspection and approval of an independent third party notified body as well as quality control and quality assurance activities to be realized by the independent quality department & organization of the boiler manufacturer company.

These three-pass fire tube boilers use fuel which is gas or oil and then produce heat energy, steam and power, respectively. As a general constructional structure, the pressurized boiler shell has end-shell plate, generous fire-tube dimensions for optimum combustion and lower emissions, optimum layout and dimensions of flue-gas passes, more steam space to obtain high quality steam, water cooled reversing chamber, large water volume.

The difference between the feed water and the exit flue gas temperature is the main source of energy. The three-pass fire tube boilers can achieve an average efficiency of 89%. This efficiency can be increased considerably by installing a feed water pre-heater (economizer) to take the advantage of temperature difference. In new boiler units economizers must always be included to the system.

Keywords: Three-Pass Fire Tube Boiler, Steam Generator, Steam, Hot Water, Superheated Water, Energy, Energy Efficiency, Energy Transfer, Heat Energy, Thermodynamics, Fluid Mechanics, Heat Transfer, Mathematics, Energy Production Systems.

INTRODUCTION

The most manufactured steam generator type for output flow rate capacities ranging from 1 t/h to 30 t/h is the three-pass fire tube boiler unit, fired by gas or oil and delivered in a pre-fabricated form. Hot water three-pass fire tube boilers are classified in two groups.

Low pressure hot water boilers have a maximum output temperature of 120 °C and are manufactured according to TRD 702 Standards. High pressure hot water boilers have output temperatures of above 120 °C and are also manufactured according to TRD 402 Standards.

Due to the large water volumes necessary in such units, these boilers have special pipe configuration and hot water supports which enable the return water to mix inside the boiler thoroughly.

Regarding the smaller or medium output ranges of saturated steam and hot water; saturated steam boiler, low pressure steam boiler, superheated steam boiler and hot water boiler variation models are manufactured. All models commonly must have the optimum production engineering and thermodynamical design specifications, the highest technically possible efficiency rate, easy to operate with low maintenance works, high quality and time-tested components for firing and control, modern manufacturing methods with corresponding high quality control, international supervision, classification, inspection and approval of an independent third party notified body as well as quality control and quality assurance activities to be realized by the independent quality department & organization of the boiler manufacturer company.

These three-pass fire tube boilers use fuel which is gas or oil and then produce heat energy, steam and power, respectively. As a general constructional structure, the pressurized boiler shell has end-shell plate, generous fire-tube dimensions for optimum combustion and lower emissions, optimum layout and dimensions of flue-gas passes, more steam space to obtain high quality steam, water cooled reversing chamber, large water volume. As the boiler material; the boiler body, dished ends, furnace and fire box according to DIN 17155, are made of 17 Mn 4 also known as P295 GH and/or HII quality special boiler steel, St 35.8-I quality seamless steel tubes are used for boiler tubes and these correspond to DIN 17175.

Boiler output, burner system and size determine the type of variant. Three pass system remains unchanged.

A superheater is installed to raise the steam temperature above that of the saturated steam. It is installed in the front reversing chamber if only low superheating is required. If higher temperatures are needed, it is installed in the inside or outside reversing chamber where a higher flue gas temperature is obtained. An economiser is added to the boiler exit for further utilization of the flue gas energy.

As the steam production; the boiler is fed with treated water. Guides installed in the water space ensure even distribution. The arrangement of the fire tube (furnace) and the flue gas smoke tubes guarantees undisrupted development of steam bubbles and stable water circulation under all operating conditions. This is one of the basic prerequisites for a long service life of the boiler.

The steady and even admission of water to all tube banks and surrounding parts like the fire tube, flue gas tubes and reversing chambers guarantees highly efficient heat flux. Thus, the thermal stress is kept to a minimum.

The below diagram given by Figure 1 shows the temperature profile in the three-pass fire tube boiler for fuel-oil. [1]

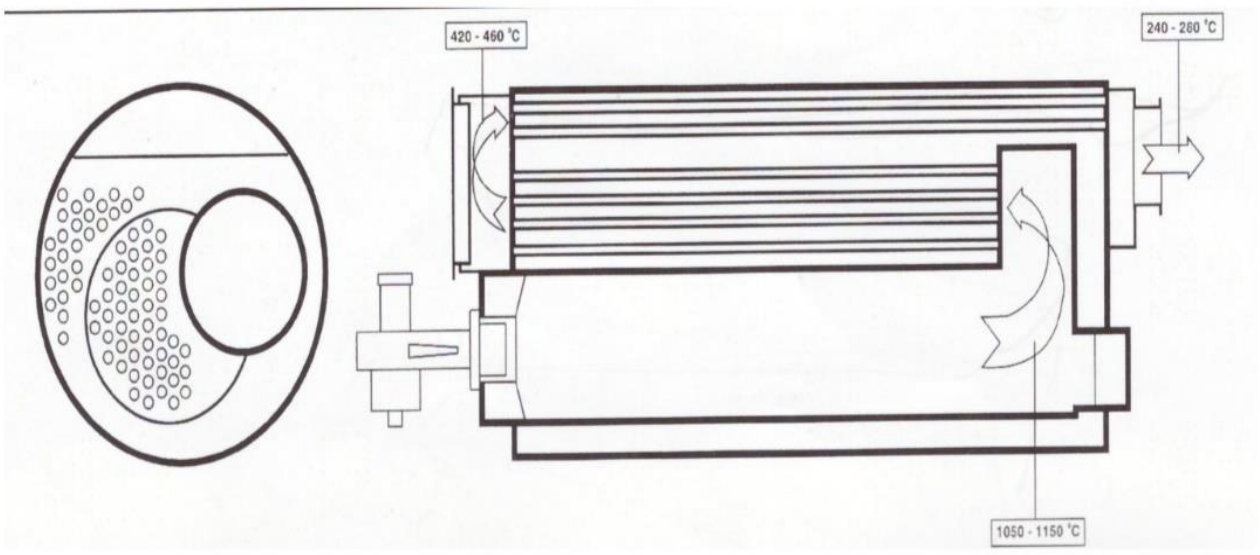

Figure_1: The diagram of temperature profile in the three-pass fire tube boiler for fuel-oil. [1]

Method, Findings and Discussion

The three-pass fire tube boiler is primarily designed for gas (natural gas) or liquid fuel. Other than the burner additional special equipment is not needed either for oil or gas firing or for a combination of both. For heavy oil firing, local directives regarding emissions are taken into account. The below diagram given by Figure 2 shows a time, tested boiler model for combined firing. Pressurized or rotary atomizing burner are installed. The gas lines are constructed and laid out to ensure safety and absolute gas tightness.

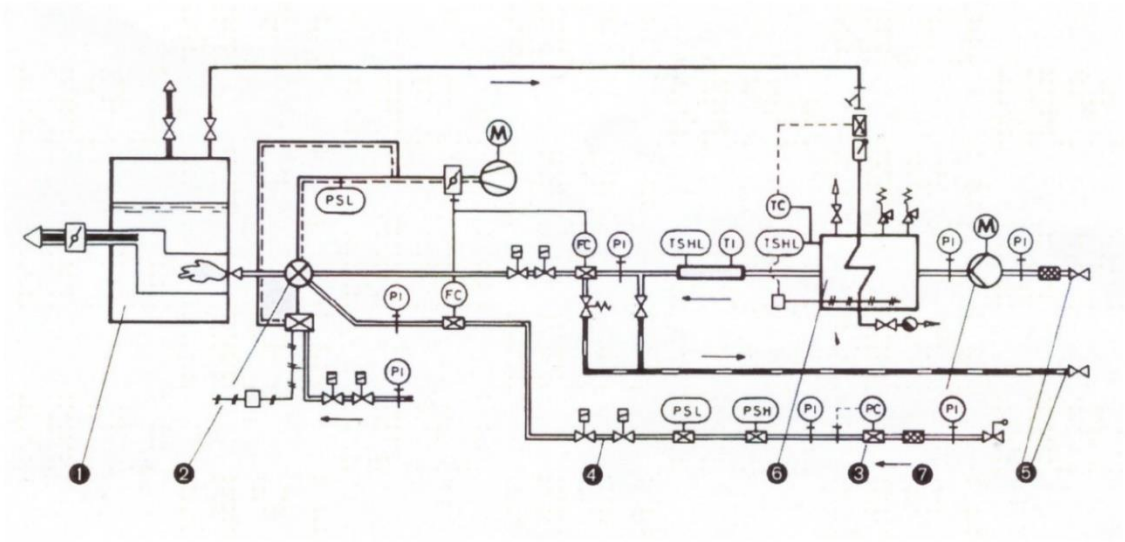

Figure_2: The boiler model for combined firing. [1]

The numbered parts and sections on Figure 2 are explained as follows: [1]

1. Boiler
2. Combined oil and gas burner
3. Gas pressure regulating
4. Safety valve
5. Oil supply and return
6. Fuel-oil pre-heater
7. Oil-pump

It is legally permitted to operate a boiler without continuous supervision when special supervisory equipment has been installed. 24 hours and 72 hours periodic controls are accepted by German TRD 604 Standard. This additional equipment is shown in the below diagram given by Figure 3. [1] According to German TRD 603 Standard, periodic high and low pressure operation is also possible.

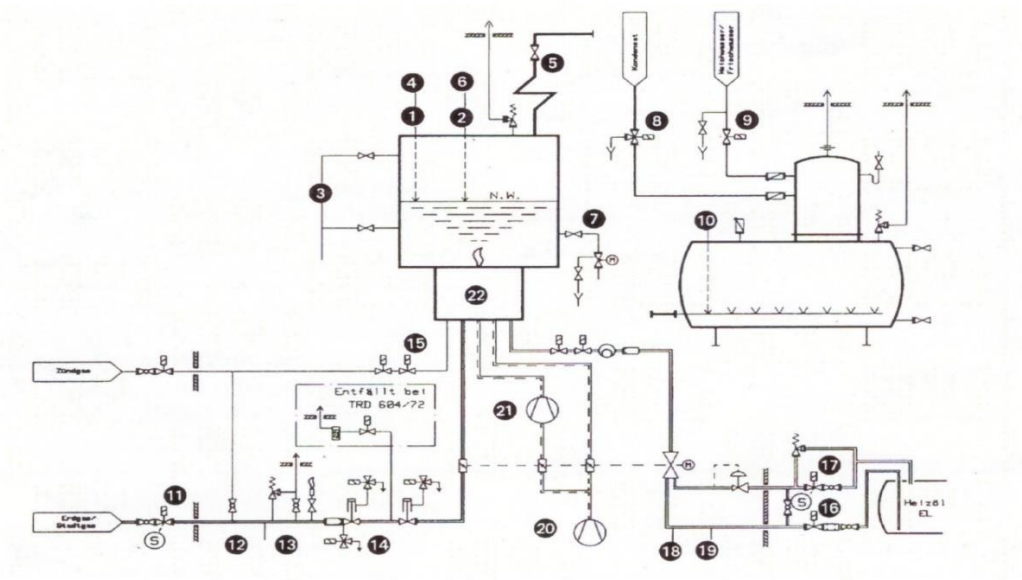

Figure_3: The diagram of special supervisory equipment required by German TRD 604 Standard. [1]

The numbered parts and items on Figure 3 are explained as follows: [1]
German TRD 604 / 24 hours:

1- Water level limiter “min”
2- 2nd water level limiter “min”
3- Limit switch to shut off boiler feed water pumps
4- Electrical conductivity limiter of boiler water
5- Limiter of superheated steam temperature

German TRD 604 / 72 hours:

6- Water level limiter “min”
7- Conductivity control + limitation (item 4 is cancelled)
8- Monitoring of conductivity and turbidity
9- Monitoring of fresh water hardness
10- Water level “min”
11- Safety valve in gas line
12- 2nd gas pressure monitor “min”
13- 2nd gas pressure monitor “max”
14- Gas tightness monitoring of main gas valve
15- 2nd gas ignition valve
16- Quick closing valve
17- Quick closing valve on oil return
18- Oil pressure monitor “min”
19- 2nd oil pressure monitor “min”
20- 2nd combustion air pressure switch
21- 2nd atomiser air pressure switch
22- Self-checking flame detector

The three-pass fire tube boiler for generation of saturated steam is shown in Figure 4, as below.

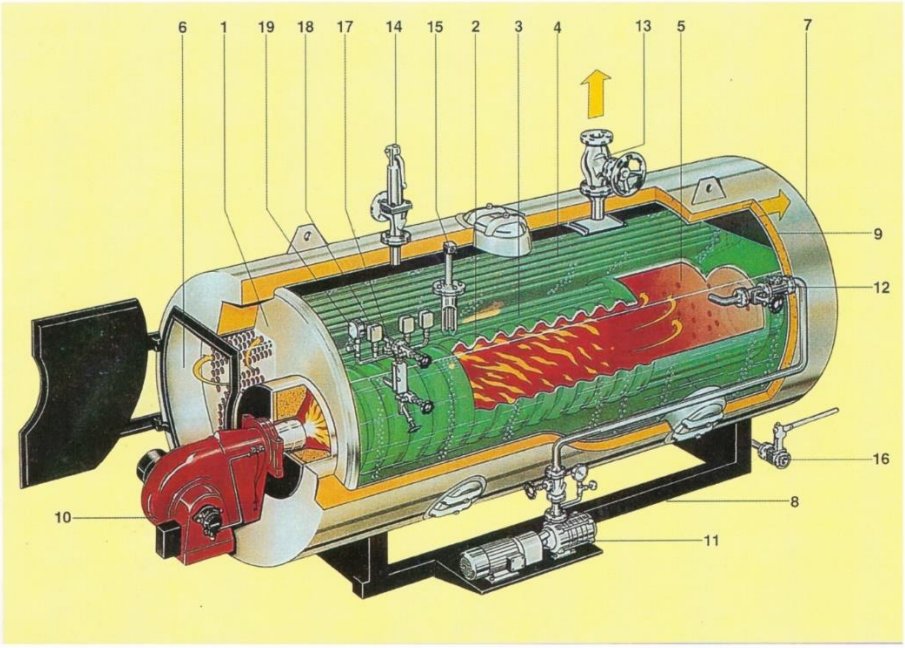

Figure_4: The three-pass fire tube boiler for generation of saturated steam. [1]

The numbered sections on Figure 4 are explained as follows: [1]

1- Boiler body
2- Furnace
3- Smoke tubes 2. Pass
4- Smoke tubes 3. Pass
5- Water cooled firebox
6- Front reversing chamber
7- Smoke outlet
8- Boiler frame
9- Insulation
10- Burning system gas or/and fuel-oil burner
11- Feed water pump(s)
12- Feed water valve
13- Steam valve
14- Safety valve
15- Water level limiter
16- Blow down valve
17- Water level indicator(s)
18- Pressure controller(s)
19- Pressure gauge(s)

The three-pass fire tube boiler for generation of high temperature hot water is shown in Figure 5, as below.

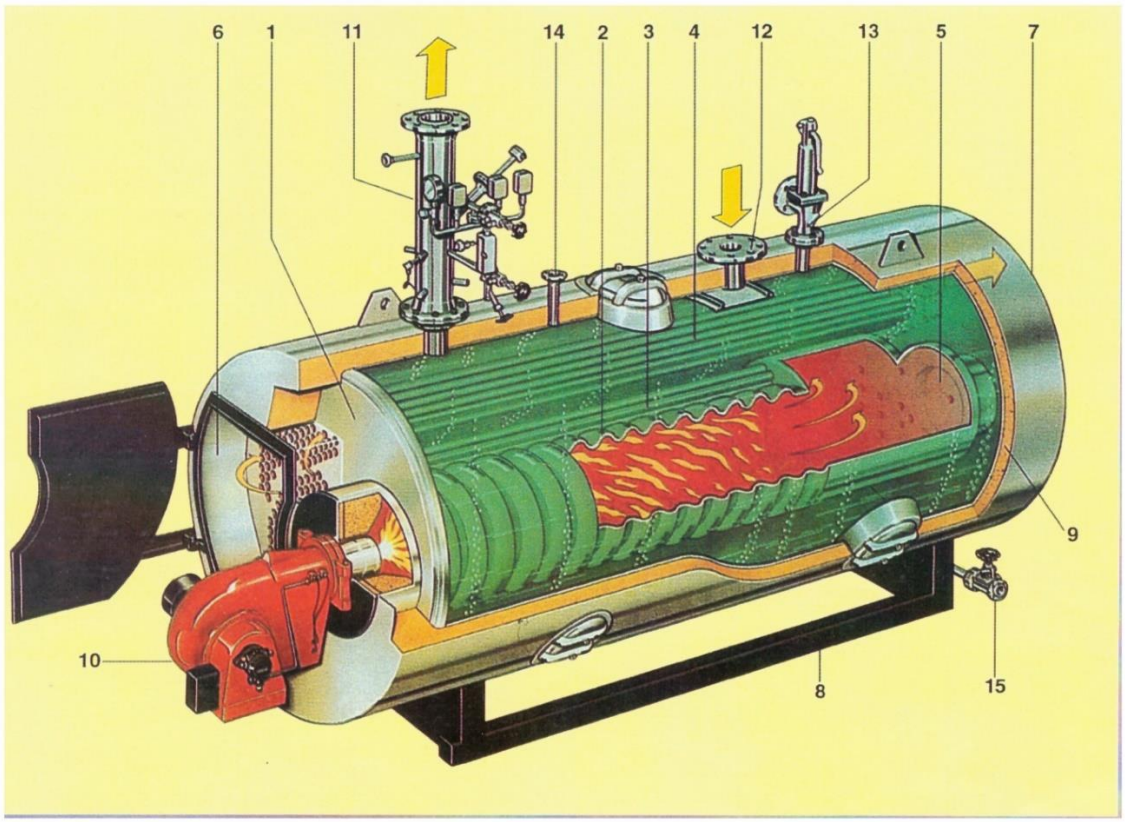

Figure_5: The three-pass fire tube boiler for generation of high temperature hot water. [1]

The numbered sections on Figure 5 are explained as follows: [1]

1- Boiler body
2- Furnace
3- Smoke tubes 2. Pass
4- Smoke tubes 3. Pass
5- Water cooled firebox
6- Front reversing chamber
7- Smoke outlet
8- Boiler frame
9- Insulation
10- Burning system gas or/and fuel-oil burner
11- Hot water outlet with armatures
12- Water return
13- Safety valve
14- Feed water inlet
15- Blow down valve

CONCLUSION

The numbered parts, items and also the general dimensions of the three-pass fire tube boiler for generation of saturated steam are shown in Figure 6, as below. [1]

The numbered parts, items and also the general dimensions of the three-pass fire tube boiler for generation of high temperature hot water are shown in Figure 7, as below. [1]

All the detailed technical specifications including boiler type, maximum permissible operating pressure, heating surface, water volume, transport weight, furnace type, fuel consumption, etc. and the boiler dimensions for generation of saturated steam is shown in Table 1, as below. [1]

All the detailed technical specifications including boiler type, maximum permissible operating pressure, heating surface, water volume, transport weight, furnace type, fuel consumption, etc. and the boiler dimensions for generation of high temperature hot water is shown in Table 2, as below. [1]

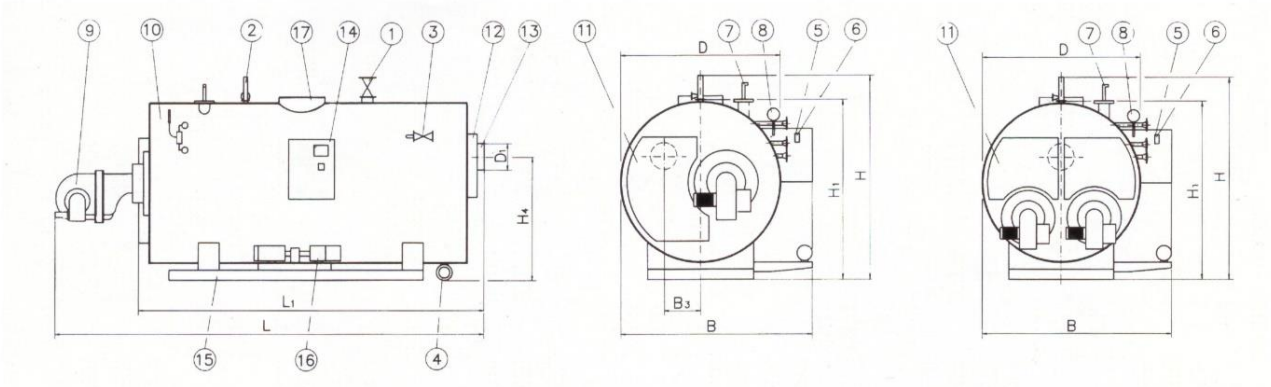

Figure_6_ The numbered parts, items and also the general dimensions of the three-pass fire tube boiler for generation of saturated steam. [1]

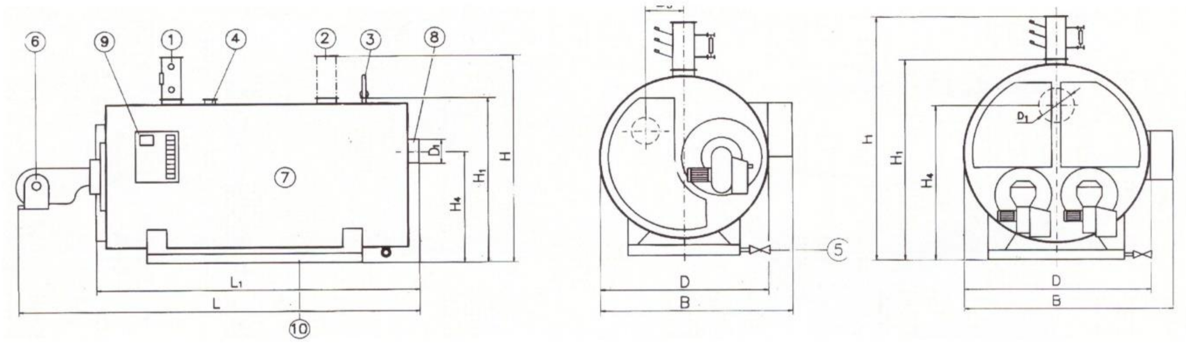

Figure_7: The numbered parts, items and also the general dimensions of the three-pass fire tube boiler for generation of high temperature hot water. [1]

Tip / Type			HD	8	12	16	18	22	30	40	52	65	80	100	125	140	165	200	240	280	300	305	335	370	410	460	500	540
																						Çift külhan ; Double furnace						
Maksimum çalışma basıncı / Max. Permissible operation press			bar	18	18	18	18	18	18	14	19	27	25	23	25	20	24	22	20	18	18	24	24	23	22	20	18	18
Kapasite / Rating [1]	Buhar / Steam	Nominal / Nominal	kg/h	260	400	650	800	1000	1250	1600	2100	2600	3200	4000	5000	6000	7000	8000	10000	11500	12500	13000	14000	16000	18000	20000	23000	25000
		Sürekli maksimum / Maximum continuous [2]	kg/h	325	500	800	1000	1250	1600	2000	2600	3200	4000	5000	6000	7000	8000	10000	12000	14000	15000	16000	18000	20000	22000	25000	28000	30000
	Isı / Heat	Nominal / Nominal	MW	0,17	0,26	0,42	0,52	0,65	0,81	1,00	1,37	1,69	2,80	2,60	3,25	3,90	4,55	5,20	6,50	7,48	8,13	8,45	9,10	10,40	11,70	13,00	14,95	16,25
			Gcal/h	0,15	0,22	0,36	0,45	0,56	0,70	0,86	1,17	1,45	1,79	2,24	2,80	3,35	3,91	4,47	5,59	6,43	6,99	7,27	7,83	8,94	10,06	11,18	12,86	13,98
		Sürekli maksimum / Maximum continuous [2]	MW	0,21	0,33	0,52	0,65	0,81	1,00	1,30	1,69	2,08	2,60	3,25	3,90	4,55	5,20	6,50	7,80	9,10	9,75	10,40	11,70	13,00	14,30	16,25	18,20	19,60
			Gcal/h	0,18	0,28	0,45	0,56	0,70	0,86	1,12	1,45	1,79	2,24	2,80	3,35	3,91	4,47	5,59	6,71	7,83	8,39	8,94	10,06	11,18	12,30	13,98	15,65	16,77
Isıtma yüzeyi / Heating surface			m^2	8	12	15,5	18	22	29	39	52	65	80	100	127	140	165	200	240	280	300	305	335	370	410	460	500	540
Su hacmi (dolu) / Water volume (full)			m^3	0,76	0,98	1,13	1,40	1,72	2,18	3,42	4,80	6,00	7,60	9,80	12,60	13,40	15,10	19,40	22,80	24,10	25,70	31,30	33,60	36,60	41,80	45,40	45,80	49,00
Taşıma ağırlığı / Trasport weight			t	1,90	2,40	2,80	3,30	4,00	4,80	5,90	7,30	8,60	10,30	12,20	15,20	16,80	18,30	21,20	25,00	26,90	28,20	31,40	33,40	35,80	39,40	43,50	48,10	50,40
Yakıt sarfiyatı / Fuel consumption	Fuel-oil / Heavy oil / Hu=41000 kJ/kg	Nominal / Nominal	kg/h	19	28	45	55	69	86	103	144	178	220	274	343	411	480	548	685	789	857	891	960	1096	1233	1370	1576	1714
		Sürekli maksimum / Maximum continuous	kg/h	22	35	55	69	86	103	137	178	220	274	343	411	480	548	685	822	959	1028	1096	1233	1370	1508	1714	1918	2055
	Doğalgaz / Natural gas / Hu=35000 kJ/Nm³	Nominal / Nominal	Nm³/h	22	32	52	65	80	100	127	167	207	256	320	400	478	558	638	798	917	994	1037	1117	1275	1435	1595	1834	1994
		Sürekli maksimum / Maximum continuous	Nm³/h	27	40	65	80	100	127	160	207	256	320	400	478	558	638	798	957	1117	1197	1275	1435	1595	1754	1994	2232	2392
Ölçüler (yaklaşık) / Dimensions (app)		L	mm	2540	2645	2795	2885	3125	3615	3915	4560	4970	5740	5840	6150	6785	7080	7670	7870	8550	8950	7435	7720	7920	8370	8420	8800	9250
		B	mm	1550	1700	1750	1850	1900	1950	2150	2250	2350	2450	2650	2850	2850	2950	3150	3350	3450	3450	3900	4000	4100	4200	4400	4500	4500
		H	mm	1880	2030	2080	2230	2230	2280	2540	2640	2810	2910	3165	3365	3500	3600	3800	4100	4200	4200	4515	4695	4795	4895	4995	5225	5380
		L_1	mm	2050	2050	2200	2250	2500	2900	3200	3850	4200	4850	5050	5350	5750	6050	6550	6750	7100	7500	6500	6600	6800	7250	7300	7350	7800
Dumangazı çıkış ölçüleri / Smoke outlet dimensions		D	mm	1200	1350	1400	1500	1550	1600	1800	1900	2000	2100	2300	2500	2500	2600	2800	3000	3100	3100	3600	3700	3800	3900	4100	4200	4200
		H_1	mm	1500	1650	1700	1800	1850	1900	2100	2200	2300	2400	2600	2800	2800	2900	3100	3300	3400	3400	3760	3860	3960	4060	4260	4360	4360
		D_1	mm	200	200	250	300	300	300	400	400	400	500	500	600	600	700	700	800	900	900	1000	1000	1100	1100	1200	1300	1300
		H_4	mm	850	950	955	950	1035	1090	1280	1370	1390	1480	1600	1710	1710	1770	1920	2110	2075	2075	2380	2450	2650	2700	2750	2850	2650
		B_1	mm	300	320	365	390	390	430	430	520	530	570	620	675	675	670	750	810	850	850							

Table_1: Technical specifications including boiler type, maximum permissible operating pressure, heating surface, water volume, transport weight, furnace type, fuel consumption, etc. and the boiler dimensions for generation of saturated

steam. [1] (Note: 10 Bar(g) saturated steam, feed water temperature of 102 °C and maximum 12% excess air firing conditions)

																					Çift külhan ; Double furnace					
Tip / Type	HW	8	12	16	18	22	30	40	52	65	80	100	125	140	165	175	200	230	260	285	320	370	405	440	500
Maksimum çalışma basıncı / Max. Permissible operation press	bar	18	18	18	18	18	18	14	19	27	25	23	25	20	24	23	22	20	18	19	23	22	21	20	18
Kapasite / Rating – Isı / Heat – Nominal / Nominal	MW	0,17	0,26	0,38	0,45	0,55	0,73	0,98	1,36	1,68	2,08	2,64	3,2	3,68	4,16	4,8	5,6	6,56	7,44	8,4	9,6	11,2	12,00	12,8	14,88
	Gcal/h	0,15	0,22	0,33	0,39	0,47	0,63	0,84	1,17	1,44	1,79	2,27	2,75	3,16	3,58	4,13	4,82	5,64	6,40	7,22	8,26	9,63	10,32	11,01	12,80
Kapasite / Rating – Isı / Heat – Sürekli maksimum / Maximum continuous	MW	0,21	0,32	0,48	0,56	0,69	0,91	1,22	1,7	2,1	2,6	3,3	4,0	4,6	5,2	6,0	7,0	8,2	9,3	10,5	12,0	14,0	15,0	16,0	18,6
	Gcal/h	0,18	0,27	0,41	0,48	0,59	0,78	1,05	1,46	1,64	2,23	2,84	3,44	3,96	4,47	5,16	6,02	7,05	8,00	9,03	10,32	12,04	12,9	13,76	16,00
Isıtma yüzeyi / Heating surface	m²	8	12	15,5	18	22	29	39	52	65	80	100	127	140	165	174	199	228	260	285	320	370	405	440	500
Su hacmi (dolu) / Water volume (full)	m³	0,76	0,98	1,13	1,4	1,72	2,18	3,42	4,80	6,00	7,60	9,80	12,60	13,40	15,10	15,2	17,1	18,2	21,4	25,6	28,0	30,5	35,3	37,5	41,00
Taşıma ağırlığı / Trasport weight	t	1,7	2,2	2,4	2,8	3,2	4,2	5,4	7,3	8,6	10,3	12,2	15,2	16,8	18,3	19,6	20,8	22,4	24,5	27,6	30,05	33,8	38,7	40,7	46,2
Yakıt sarfiyatı / Fuel consumption – Fuel-oil Heavy oil Hu=41000 kJ/kg – Nominal / Nominal	kg/h	18	27	40	47	57	88	101	140	173	215	272	330	379	429	495	577	676	767	865	989	1153	1236	1319	1533
Fuel-oil – Sürekli maksimum / Maximum continuous	kg/h	22	33	49	58	71	94	126	175	197	267	340	412	475	536	618	721	844	958	1082	1236	1442	1545	1648	1916
Doğalgaz Natural gas Hu=35000 kJ/Nm³ – Nominal / Nominal	Nm³/h	21	31	46	55	66	102	117	163	201	250	317	383	440	499	576	672	786	802	1006	1151	1342	1438	1534	1784
Doğalgaz – Sürekli maksimum / Maximum continuous	Nm³/h	25	38	58	67	83	109	148	204	229	311	396	480	552	623	719	839	983	1115	1258	1438	1678	1798	1918	2230
Ölçüler (yaklaşık) / Dimensions (app) – L	mm	2540	2645	2795	2885	3125	3615	3915	4560	5150	5740	5840	6150	6785	7080	7520	7870	8020	8550	8940	7300	7650	7750	7800	8000
B	mm	1550	1700	1750	1850	1900	1950	2150	2250	2350	2450	2650	2850	2850	2960	2950	3050	3150	3350	3400	3500	3600	3800	3900	4100
H	mm	2200	2350	2400	2550	2600	2650	2850	3000	3100	3225	3425	3660	3660	3760	3780	3880	3980	4180	4260	4360	4460	4660	4760	5110
L_1	mm	2050	2050	2200	2250	2500	2900	3200	3850	4250	4850	5050	5350	5750	6050	6400	6750	6900	7100	6400	6650	7000	7100	7150	7350
D	mm	1200	1350	1400	1500	1550	1600	1800	1900	2000	2100	2300	2500	2500	2600	2600	2700	2800	3000	3400	3500	3600	3800	3900	4100
H_1	mm	1500	1650	1700	1800	1850	1900	2100	2250	2350	2450	2650	2850	2850	2950	2950	3050	3150	3350	3560	3660	3760	3960	4060	4260
Dumangazı çıkış ölçüleri / Smoke outlet dimensions – D_1	mm	200	200	250	250	300	300	400	400	400	500	500	600	600	700	700	700	800	900	1000	1100	1200	1200	1200	1300
H_1	mm	850	950	955	950	1035	1090	1280	1370	1390	1480	1600	1710	1710	1770	2060	2110	2190	2360	2470	2665	2715	2850	2880	3120
B_1	mm	300	320	365	390	390	430	430	520	530	570	620	675	675	670	530	500	500	525						

Table_2: Technical specifications including boiler type, maximum permissible operating pressure, heating surface, water volume, transport weight, furnace type, fuel consumption, etc. and the boiler dimensions for generation of high temperature hot water. [1] (Note: 10 Bar (g) operating pressure, 160 / 120 °C water outlet and return temperature and maximum 12% excess air firing conditions)

The difference between the feed water and the exit flue gas temperature is the main source of energy. The three-pass fire tube boilers can achieve an average efficiency of 89%. This efficiency can be increased considerably by installing a feed water pre-heater (economizer) to take the advantage of temperature difference. In new boiler units economizers must always be included to the system. In case of existing ones, adding an economizer can greatly improve the unit's efficiency. The economizer can be installed in various positions between the flue-gas outlet of the boiler and the stack. The most favorable route for the flue-gas must be applied. [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19]

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