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Heat sector energy saving calculation and economic evaluation

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Korea Energy Agency (KEA)

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I. Gathering data for boiler heat balance

1. Gathering data for boiler heat balances

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◆ Performing heat balance about boiler's input/output heat flow

- Find out input/output component and scale
- Find out system operating performance
- Find out energy loss factor
- Find out energy saving and efficiency improvement ideas

❖ Data collection and calculation method about operating status for Boiler heat balance is regulated in Korean Industrial Standard (KSB6205: Heat balance method of the land forced boiler)

1. Gathering data for boiler heat balances

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- Operating status data is usually the result of the devices operated for long time (more than one hour) in constant load.

- Keep out blow down, soot blow, grab sample, leakage during measurement.

- Check the status of the devices, and correct exactly with test condition.

- Heat balance unit

  - Unit fuel amount (1kg or 1N㎥)

  - Total input heat amount by unit time (multi fuel fired boiler, waste heat boiler, etc.)

- Fuel caloric value: use higher heating value (Be specified when lower heating value is used)

1. Gathering data for boiler heat balances

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- Standard temperature
  - As a rule, it is based on the outdoor temperature, but interior temperature or 0℃ in cases.

- Steam quality : Apply steam quality above 98%

- Boiler efficiency calculating method
  - Input and output heat : method to calculate effective output heat among total input heat amount
  - Heat loss : method to calculate heat loss first, and use the rest as the effective heat among total input heat amount

- Heat calculation of waste heat boiler is done by total input heat amount in unit time.
- Electrical energy is calculated as 860kcal per kWh

1. Gathering data for boiler heat balances

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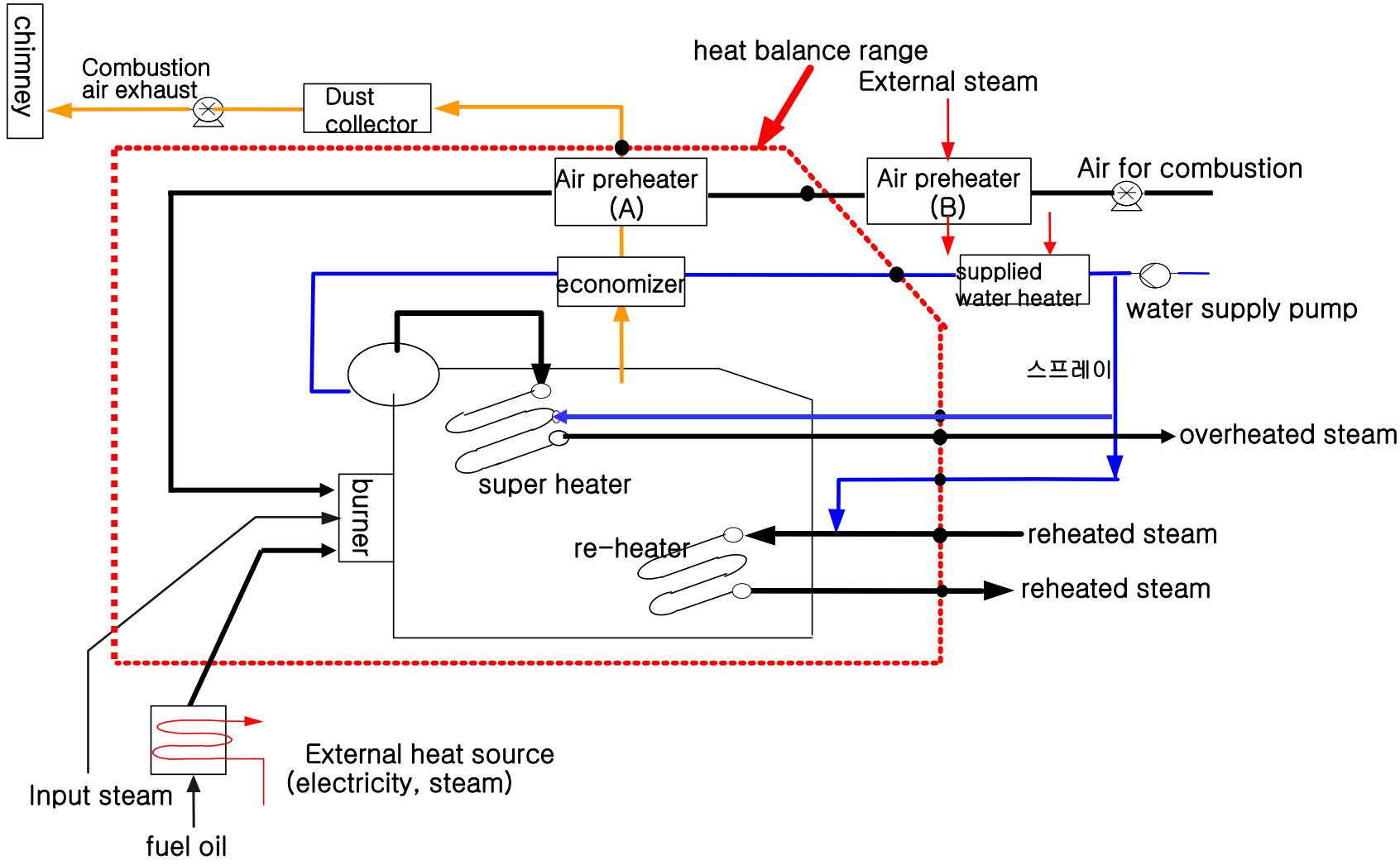
◆ Liquid fuel



1. Gathering data for boiler heat balances

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- **Standard temperature**

- Be measured where there is no sunlight or device's radiant heat

- **Fuel consumption**

- Solid fuel : Be measured right before combustion to avoid water vapor evaporation after measurement
- Liquid fuel : Be measured by volumetric flow meter, then be converted to weight (mass) flow
- Gaseous fuel : Be measured by volumetric flow, then be converted to standard condition (0℃, 1ata)

- **Fuel supply temperature**

- Solid fuel : Be applied by measuring supply temperature
- Liquid fuel : Temperature of front/back of fuel heater be measured
- Gaseous fuel : Temperature supplied to the burner be measured
  (usually be applied with room temperature)

1. Gathering data for boiler heat balances

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- **Measuring water supply amount and temperature**

  - Be measured with volumetric flow meter, orifice flow meter.
  - Exclude water supply amount to be used for super heater and re-heater while supplying water
  - Convert measured volumetric flow to weighting flow
  - Supply water temperature is measured in the entrance of the economizer, or in the entrance of the boiler if economizer is not installed.

- **Measuring combustion air**

  - Calculate theoretical air amount by fuel composition
  - Analyzing exhaust gas, and calculate with excess air ratio to find out actual combustion air amount
    (Be measured with flow meter at the exit of the fan or air preheater with actual measurement)
  - Air temperature for combustion is measured at the entrance/exit of gas air preheater, (GAH) and steam air heater (SAH).

1. Gathering data for boiler heat balances

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- **Generated steam flow**

- Use the measured value of water supply flow meter (The measured value of steam flow meter can be used as a reference)
- If generated steam is partially used in heating fuel, atomizing, or air preheater, subtract them from water supply flow
- Water intermittently be supplied, then water supply measurement should be checked with water level at the beginning and the end of the test equal.
- Steam amount at the entrance of re-heater is subtracted from main steam amount by steam turbine grand steam amount and additional steam amount.
- Super heater and re-heater exit steam amount: : entrance steam amount+ spray amount

1. Gathering data for boiler heat balances

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- **Pressure of the generated steam**

- Saturated steam : measured and confirmed at boiler drum and main steam line
- Superheated steam : measured and confirmed at the exit of super heater and re-heater

- **Saturated steam quality**

- Measured at the exit of boiler drum
(If the data is difficult to obtain, use simple method and apply 98%)

1. Gathering data for boiler heat balances

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- **Exhaust gas amount**

- Analyzing exhaust gas composition and calculate exhaust gas amount by using excess air ratio (measure multiple points with cross section at the area of measurement)

- **Exhaust gas temperature**

- Measure before/after temperature of economizer, air preheater

- **Measuring the condensing water amount in the exhaust gas**

- Measure quantity and temperate when vapor in the exhaust gas is condensing.

- **Fan pressure**

- Combustion air is measured at the outlet of the positive blower
- Exhaust gas is measure at the exit of the final heat exchanger

1. Gathering data for boiler heat balances

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- **Measuring combustion residue**

- Ignore liquid and gaseous fuel, Solid fuel is measured following the calibration method.

- **Measuring waste heat boiler**

- Measure input gas air flow, temperature, pressure, and composition

- Measure gas air flow and convert into standardized form

- Measure temperature at the entrance/exit of the boiler

  (Use average value of multiple values in the cross-sectional area)

- Gas composition analysis

1. Gathering data for boiler heat balances

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- **Measuring cycle**

- Generally measure every 10~30 minutes depending on the measurement object and condition
- Steam pressure and temperature, supply water temperature: every 10~30 minutes
- Water supply amount and fuel consumption: Every 5~10 minutes
- Temperature and pressure of the air and exhaust gas : Every 15~30 minutes
- Sampling of the exhaust gas : every 30 minutes

1. Gathering data for boiler heat balances

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◆ Device status

구분	항목	단위	기재란	비고
본체	보일러형식			
	최대연속증발량	kg/Hr		
	최고사용압력	kg/㎠.g		
	상용압력	kg/㎠.g		
	전열면적	㎡		
	제작일			
	제작처			
버너	형식			
	최대연소량	kg/Hr		
	유량범위	kg/Hr		
	제작처			
송풍기	형식			
	풍량	㎥/min		
	풍압	mmAq		
	동력	HP		
	제작처			
A/H	형식			
	전열면적	㎡		
	사용압력	kg/㎠.g		
	열용량			
	제작처			

◆ Measured data

측정항목		기호	단위	측정치	비고
외기온도(건)		To	℃		
실내온도(건)		Tr	℃		
연료	연료명				
	사용량	Vt	ℓ/h		
유	유량계전온도	Tf1	℃		
	버너전온도	Tf2	℃		
급수	급수량	W_1L	ℓ/h		
	보일러입구온도	Tw	℃		
증기	증발량	W_2kg	kg/h		
	드럼압력	Ps	ata		
연소용공기	SAH 입구온도	Ta1	℃		
	GAH 입구온도	Ta2	℃		
	보일러입구온도	Ta3	℃		
배기가스	보일러본체출구온도	Tg1	℃		
	공기예열기입구온도	Tg2	℃		
	공기예열기출구온도	Tg3	℃		
	CO_2 성분	(CO_2)	Vol %		
	O_2 성분	(O_2)	Vol %		
	CO 성분	(CO)	VoL %		
증기건도		X			
분입증기량			%		
BLOW DOWN 량			kg/h		
이론연소공기량			Nm³/kg		
이론배가스량		15	Nm³/kg		

Ⅱ. Boiler heat balance practice

2. Boiler heat balance practice

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- Question) water-tube 60t/h is measured on site, and its fuel consumption was 2,940ℓ/h, fuel supply temperature 85℃, supplied water 43,386ℓ/h, supplied water temperature was 90℃, and air for combustion temperature was 35℃ before APH and 159℃ after APH. Also, exhaust gas temperature was 200℃ after APH. O2 concentration was 8%, Steam generating pressure is 7kg/cm^2·g(Steam enthalpy: 651kcal/kg, steam quality: 0.98)

  (fuel caloric value: 9,870 kcal/kg-fuel,theoretical combustion air amount Ao:10.709 Nm3/kg, Theoretical exhaust gas amount Go:11.494Nm3/kg, specific heat of the exhaust gas: 0.33 kcal/Nm^3·℃, specific heat of the air: 0.31kcal/Nm^3·℃ , Atomizing steam inside the furnace: 265kg/h, Blow Down: 1,000 kg/h, Specific volume of supplied water: 1.03579ℓ/kg, fuel density:0.95kg/ℓ, fuel volume correction factor:0.954)

2. Boiler heat balance practice

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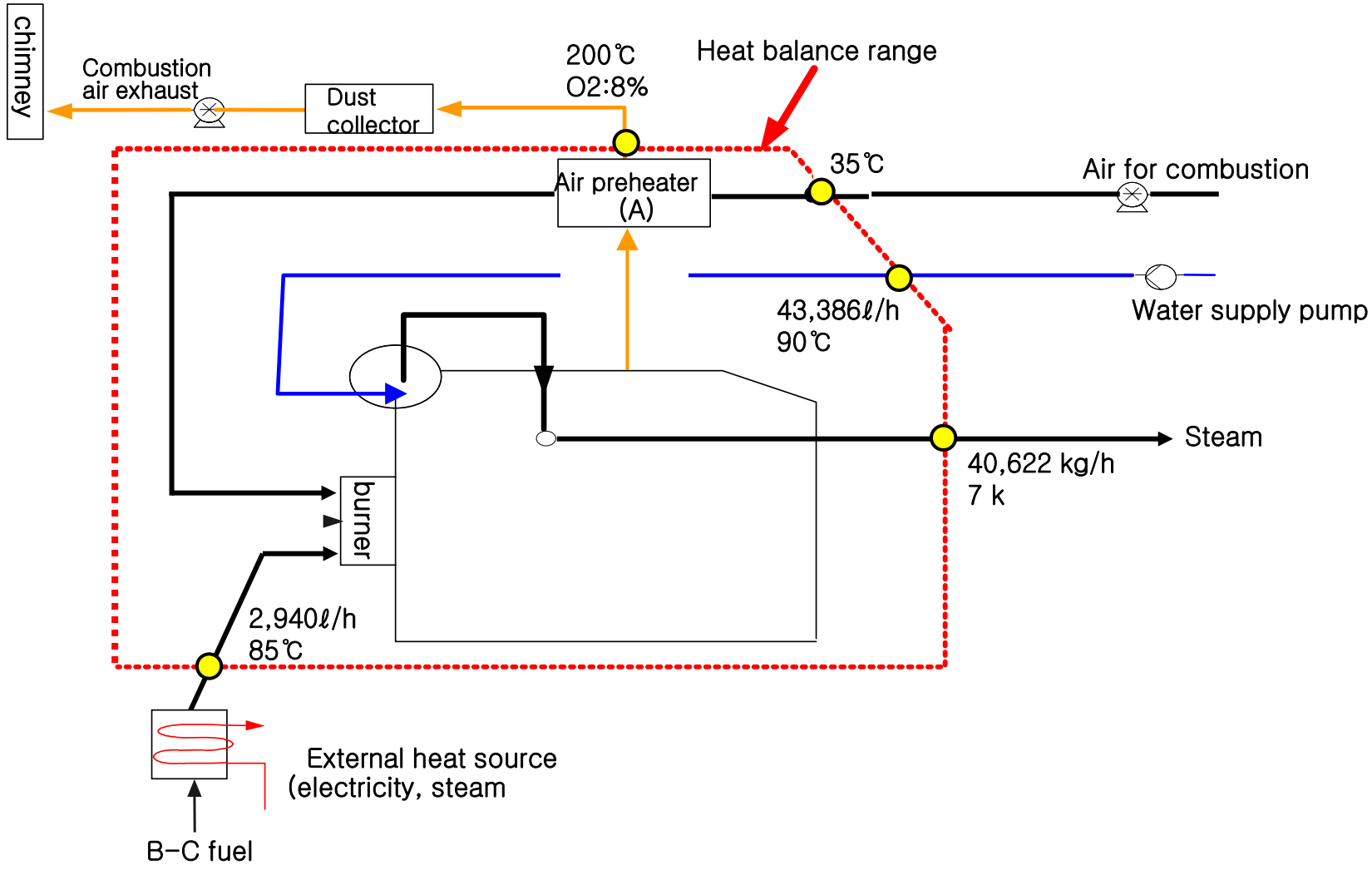
◆ Boiler heat balance range



2. Boiler heat balance practice

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◆ Measurement result in table

		Unit	Measured value	Note
Exterior temperature		℃		
Interior temperature		℃		
Fuel	Name	-		Use sulfur 0.3%
	Used amount	ℓ/h		Fuel ratio :0.95
	Providing temperature	℃		
Water supply	Water supply amount	ℓ/h		
	Water supply temperature	℃		
Steam	Evaporation amount	Kg/h		
	Evaporation pressure	$Kg/cm^2 \cdot g$		Steam quality:0.98 applied
Air for combustion	Temperature before APH	℃		
	Temperature after APH	℃		
Exhaust gas	APH exit temperature	℃		
	O2 composition	%		
Blow Down		kg/h		
Atomizing steam		Kg/h		Used custom Steam
Theoretically combusted air		$Nm^3/kg\text{-}fuel$		
Theoretically exhaust gas		$Nm^3/kg\text{-}fuel$		

2. Boiler heat balance practice(Steam Table)

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온도	압력	비체적		m3/kg	엔탈피		kcal/kg	엔트로피		kcal/kg-K	온도
oC	kg/cm2 a	vl	dv	vv	hl	dh	hv	sl	ds	sv	oC
56	0.168 58	0.001 015 0	9.1444	9.1454	55.991	565.45	621.44	0.1865	1.7179	1.9044	56
57	0.176 77	0.001 015 5	8.7461	8.7471	56.990	564.87	621.86	0.1895	1.7110	1.9005	57
58	0.185 29	0.001 016 1	8.3678	8.3688	57.989	564.29	622.28	0.1925	1.7040	1.8965	58
59	0.194 16	0.001 016 6	8.0083	8.0093	58.988	563.71	622.70	0.1955	1.6971	1.8927	59
60	0.203 39	0.001 017 1	7.6666	7.6677	59.987	563.12	623.11	0.1985	1.6903	1.8888	60
61	0.212 99	0.001 017 6	7.3418	7.3428	60.987	562.54	623.53	0.2015	1.6835	1.8850	61
62	0.222 98	0.001 018 2	7.0328	7.0338	61.986	561.96	623.94	0.2045	1.6767	1.8812	62
63	0.233 35	0.001 018 7	6.7389	6.7399	62.986	561.37	624.36	0.2075	1.6700	1.8775	63
64	0.244 14	0.001 019 3	6.4591	6.4601	63.985	560.78	624.77	0.2105	1.6633	1.8738	64
65	0.255 35	0.001 019 9	6.1928	6.1938	64.985	560.20	625.18	0.2134	1.6566	1.8701	65
66	0.266 99	0.001 020 4	5.9392	5.9402	65.985	559.61	625.59	0.2164	1.6500	1.8664	66
67	0.279 08	0.001 021 0	5.6976	5.6986	66.985	559.02	626.00	0.2193	1.6434	1.8628	67
68	0.291 62	0.001 021 6	5.4674	5.4684	67.985	558.43	626.41	0.2222	1.6369	1.8591	68
69	0.304 65	0.001 022 2	5.2479	5.2490	68.986	557.84	626.82	0.2252	1.6304	1.8556	69
70	0.318 16	0.001 022 8	5.0387	5.0397	69.986	557.25	627.23	0.2281	1.6239	1.8520	70
71	0.332 17	0.001 023 4	4.8392	4.8402	70.987	556.65	627.64	0.2310	1.6175	1.8485	71
72	0.346 70	0.001 024 0	4.6488	4.6498	71.988	556.06	628.05	0.2339	1.6111	1.8450	72
73	0.361 77	0.001 024 6	4.4671	4.4681	72.989	555.47	628.45	0.2368	1.6047	1.8415	73
74	0.377 38	0.001 025 2	4.2937	4.2947	73.990	554.87	628.86	0.2397	1.5984	1.8380	74
75	0.393 56	0.001 025 8	4.1281	4.1291	74.991	554.27	629.26	0.2426	1.5920	1.8346	75
76	0.410 32	0.001 026 5	3.9699	3.9709	75.993	553.67	629.67	0.2454	1.5858	1.8312	76
77	0.427 68	0.001 027 1	3.8188	3.8198	76.995	553.08	630.07	0.2483	1.5795	1.8278	77
78	0.445 65	0.001 027 7	3.6743	3.6754	77.997	552.48	630.47	0.2512	1.5733	1.8245	78
79	0.464 25	0.001 028 4	3.5363	3.5373	78.999	551.87	630.87	0.2540	1.5672	1.8212	79
80	0.483 50	0.001 029 0	3.4042	3.4053	80.001	551.27	631.27	0.2569	1.5610	1.8179	80
81	0.503 41	0.001 029 7	3.2780	3.2790	81.004	550.67	631.67	0.2597	1.5549	1.8146	81
82	0.524 01	0.001 030 4	3.1572	3.1582	82.007	550.06	632.07	0.2625	1.5488	1.8113	82
83	0.545 31	0.001 031 0	3.0415	3.0426	83.010	549.46	632.47	0.2653	1.5428	1.8081	83
84	0.567 32	0.001 031 7	2.9309	2.9319	84.013	548.85	632.86	0.2681	1.5367	1.8049	84
85	0.590 08	0.001 032 4	2.8249	2.8259	85.016	548.24	633.26	0.2709	1.5308	1.8017	85
86	0.613 60	0.001 033 1	2.7234	2.7244	86.020	547.63	633.65	0.2737	1.5248	1.7985	86
87	0.637 90	0.001 033 8	2.6262	2.6272	87.024	547.02	634.05	0.2765	1.5189	1.7954	87
88	0.662 99	0.001 034 5	2.5330	2.5341	88.028	546.41	634.44	0.2793	1.5130	1.7923	88
89	0.688 91	0.001 035 2	2.4437	2.4448	89.033	545.80	634.83	0.2821	1.5071	1.7892	89
90	0.715 66	0.001 035 9	2.3581	2.3591	90.037	545.18	635.22	0.2849	1.5012	1.7861	90
91	0.743 28	0.001 036 7	2.2760	2.2771	91.042	544.56	635.61	0.2876	1.4954	1.7831	91
92	0.771 77	0.001 037 4	2.1973	2.1983	92.048	543.95	635.99	0.2904	1.4896	1.7800	92
93	0.801 17	0.001 038 1	2.1217	2.1228	93.053	543.33	636.38	0.2931	1.4839	1.7770	93
94	0.831 50	0.001 038 9	2.0492	2.0502	94.059	542.71	636.76	0.2959	1.4782	1.7740	94
95	0.862 77	0.001 039 6	1.9796	1.9806	95.065	542.08	637.15	0.2986	1.4724	1.7710	95
96	0.895 02	0.001 040 4	1.9128	1.9138	96.071	541.46	637.53	0.3013	1.4668	1.7681	96
97	0.928 26	0.001 041 1	1.8486	1.8497	97.078	540.83	637.91	0.3041	1.4611	1.7652	97
98	0.962 51	0.001 041 9	1.7870	1.7880	98.085	540.21	638.29	0.3068	1.4555	1.7623	98
99	0.997 81	0.001 042 7	1.7277	1.7288	99.092	539.58	638.67	0.3095	1.4499	1.7594	99
100	1.034 2	0.001 043 5	1.6708	1.6719	100.10	538.95	639.05	0.3122	1.4443	1.7565	100
101	1.071 6	0.001 044 2	1.6161	1.6171	101.11	538.32	639.43	0.3149	1.4388	1.7536	101
102	1.110 2	0.001 045 0	1.5635	1.5645	102.12	537.68	639.80	0.3176	1.4332	1.7508	102
103	1.149 9	0.001 045 8	1.5129	1.5140	103.12	537.05	640.17	0.3202	1.4277	1.7480	103
104	1.190 8	0.001 046 6	1.4642	1.4653	104.13	536.41	640.55	0.3229	1.4223	1.7452	104
105	1.232 9	0.001 047 4	1.4174	1.4185	105.14	535.77	640.92	0.3256	1.4168	1.7424	105
106	1.276 1	0.001 048 3	1.3724	1.3734	106.15	535.13	641.29	0.3283	1.4114	1.7396	106
107	1.320 7	0.001 049 1	1.3290	1.3301	107.16	534.49	641.66	0.3309	1.4060	1.7369	107
108	1.366 5	0.001 049 9	1.2873	1.2883	108.17	533.85	642.02	0.3336	1.4006	1.7342	108
109	1.413 6	0.001 050 7	1.2471	1.2481	109.18	533.20	642.39	0.3362	1.3953	1.7315	109
110	1.462 0	0.001 051 6	1.2083	1.2094	110.19	532.56	642.75	0.3388	1.3899	1.7288	110
111	1.511 8	0.001 052 4	1.1710	1.1721	111.21	531.91	643.11	0.3415	1.3846	1.7261	111
112	1.563 0	0.001 053 3	1.1351	1.1362	112.22	531.26	643.47	0.3441	1.3793	1.7234	112
113	1.615 6	0.001 054 1	1.1005	1.1015	113.23	530.60	643.83	0.3467	1.3741	1.7208	113
114	1.669 6	0.001 055 0	1.0671	1.0681	114.24	529.95	644.19	0.3493	1.3688	1.7182	114
115	1.725 1	0.001 055 9	1.0349	1.0359	115.26	529.29	644.55	0.3520	1.3636	1.7156	115

온도	압력	비체적		m3/kg	엔탈피		kcal/kg	엔트로피		kcal/kg-K	온도
oC	kg/cm2 a	vl	dv	vv	hl	dh	hv	sl	ds	sv	oC
116	1.782 1	0.001 056 8	1.0038	1.0049	116.27	528.63	644.90	0.3546	1.3584	1.7130	116
117	1.840 7	0.001 057 6	0.973 90	0.974 95	117.28	527.97	645.25	0.3572	1.3532	1.7104	117
118	1.900 8	0.001 058 5	0.945 01	0.946 07	118.30	527.31	645.60	0.3597	1.3481	1.7078	118
119	1.962 5	0.001 059 4	0.917 14	0.918 20	119.31	526.64	645.95	0.3623	1.3430	1.7053	119
120	2.025 8	0.001 060 3	0.890 24	0.891 30	120.33	525.97	646.30	0.3649	1.3378	1.7028	120
121	2.090 8	0.001 061 2	0.864 28	0.865 34	121.34	525.30	646.65	0.3675	1.3327	1.7002	121
122	2.157 5	0.001 062 2	0.839 21	0.840 28	122.36	524.63	646.99	0.3701	1.3277	1.6977	122
123	2.225 9	0.001 063 1	0.815 01	0.816 07	123.37	523.96	647.33	0.3726	1.3226	1.6952	123
124	2.296 1	0.001 064 0	0.791 63	0.792 69	124.39	523.28	647.68	0.3752	1.3176	1.6928	124
125	2.368 0	0.001 064 9	0.769 05	0.770 11	125.41	522.61	648.01	0.3777	1.3126	1.6903	125
126	2.441 8	0.001 065 9	0.747 23	0.748 29	126.43	521.92	648.35	0.3803	1.3076	1.6879	126
127	2.517 5	0.001 066 8	0.726 14	0.727 21	127.44	521.24	648.69	0.3828	1.3026	1.6854	127
128	2.595 0	0.001 067 8	0.705 76	0.706 83	128.46	520.56	649.02	0.3854	1.2977	1.6830	128
129	2.674 5	0.001 068 7	0.686 06	0.687 13	129.48	519.87	649.35	0.3879	1.2927	1.6806	129
130	2.755 9	0.001 069 7	0.667 01	0.668 08	130.50	519.18	649.68	0.3904	1.2878	1.6782	130
131	2.839 3	0.001 070 7	0.648 59	0.649 66	131.52	518.49	650.01	0.3929	1.2829	1.6759	131
132	2.924 8	0.001 071 7	0.630 78	0.631 85	132.54	517.79	650.34	0.3955	1.2780	1.6735	132
133	3.012 3	0.001 072 7	0.613 54	0.614 61	133.56	517.10	650.66	0.3980	1.2732	1.6711	133
134	3.102 0	0.001 073 6	0.596 87	0.597 94	134.59	516.40	650.98	0.4005	1.2683	1.6688	134
135	3.193 8	0.001 074 7	0.580 73	0.581 80	135.61	515.69	651.30	0.4030	1.2635	1.6665	135
136	3.287 7	0.001 075 7	0.565 11	0.566 18	136.63	514.99	651.62	0.4055	1.2587	1.6642	136
137	3.383 9	0.001 076 7	0.549 99	0.551 06	137.65	514.28	651.94	0.4080	1.2539	1.6619	137
138	3.482 4	0.001 077 7	0.535 35	0.536 42	138.68	513.57	652.25	0.4105	1.2491	1.6596	138
139	3.583 2	0.001 078 7	0.521 17	0.522 25	139.70	512.86	652.56	0.4129	1.2443	1.6573	139
140	3.686 3	0.001 079 8	0.507 44	0.508 52	140.73	512.14	652.87	0.4154	1.2396	1.6550	140
141	3.791 8	0.001 080 8	0.494 14	0.495 22	141.75	511.43	653.18	0.4179	1.2349	1.6528	141
142	3.899 7	0.001 081 9	0.481 25	0.482 33	142.78	510.71	653.49	0.4204	1.2302	1.6505	142
143	4.010 0	0.001 082 9	0.468 77	0.469 85	143.81	509.98	653.79	0.4228	1.2255	1.6483	143
144	4.122 9	0.001 084 0	0.456 66	0.457 75	144.83	509.26	654.09	0.4253	1.2208	1.6461	144
145	4.238 3	0.001 085 0	0.444 93	0.446 02	145.86	508.53	654.39	0.4277	1.2161	1.6439	145
146	4.356 3	0.001 086 1	0.433 56	0.434 65	146.89	507.80	654.69	0.4302	1.2115	1.6417	146
147	4.476 9	0.001 087 2	0.422 54	0.423 62	147.92	507.06	654.98	0.4326	1.2069	1.6395	147
148	4.600 2	0.001 088 3	0.411 84	0.412 93	148.95	506.32	655.27	0.4351	1.2022	1.6373	148
149	4.726 1	0.001 089 4	0.401 47	0.402 56	149.98	505.58	655.56	0.4375	1.1976	1.6352	149
150	4.854 9	0.001 090 5	0.391 41	0.392 50	151.01	504.84	655.85	0.4399	1.1931	1.6330	150
152	5.120 8	0.001 092 7	0.372 18	0.373 27	153.07	503.35	656.42	0.4448	1.1839	1.6287	152
154	5.398 2	0.001 095 0	0.354 07	0.355 16	155.14	501.84	656.98	0.4496	1.1749	1.6245	154
156	5.687 5	0.001 097 3	0.337 00	0.338 09	157.21	500.32	657.53	0.4544	1.1658	1.6203	156
158	5.989 1	0.001 099 6	0.320 90	0.322 00	159.28	498.79	658.07	0.4592	1.1569	1.6161	158
160	6.303 3	0.001 102 0	0.305 72	0.306 82	161.36	497.24	658.60	0.4640	1.1480	1.6120	160
162	6.630 4	0.001 104 4	0.291 38	0.292 49	163.44	495.69	659.12	0.4688	1.1391	1.6079	162
164	6.971 0	0.001 106 8	0.277 84	0.278 95	165.52	494.11	659.63	0.4735	1.1303	1.6039	164
166	7.325 3	0.001 109 3	0.265 05	0.266 16	167.60	492.53	660.13	0.4783	1.1216	1.5998	166
168	7.693 7	0.001 111 7	0.252 95	0.254 06	169.69	490.93	660.62	0.4830	1.1128	1.5958	168
170	8.076 7	0.001 114 3	0.241 50	0.242 62	171.78	489.32	661.10	0.4877	1.1042	1.5919	170
172	8.474 6	0.001 116 8	0.230 67	0.231 78	173.87	487.69	661.57	0.4924	1.0956	1.5880	172
174	8.887 9	0.001 119 4	0.220 41	0.221 53	175.97	486.05	662.02	0.4971	1.0870	1.5841	174
176	9.317 0	0.001 122 0	0.210 69	0.211 81	178.07	484.40	662.47	0.5017	1.0785	1.5802	176
178	9.762 2	0.001 124 7	0.201 47	0.202 60	180.18	482.73	662.90	0.5064	1.0700	1.5764	178
180	10.234	0.001 127 4	0.192 73	0.193 86	182.28	481.04	663.33	0.5110	1.0616	1.5726	180
182	10.703	0.001 130 1	0.184 44	0.185 57	184.40	479.34	663.74	0.5156	1.0532	1.5688	182
184	11.199	0.001 132 9	0.176 57	0.177 70	186.51	477.63	664.14	0.5203	1.0448	1.5650	184
186	11.714	0.001 135 7	0.169 09	0.170 23	188.63	475.89	664.52	0.5248	1.0365	1.5613	186
188	12.246	0.001 138 6	0.161 99	0.163 13	190.76	474.14	664.90	0.5294	1.0282	1.5576	188
190	12.798	0.001 141 4	0.155 24	0.156 38	192.88	472.38	665.26	0.5340	1.0199	1.5539	190
192	13.368	0.001 144 4	0.148 81	0.149 96	195.02	470.59	665.61	0.5386	1.0117	1.5503	192
194	13.959	0.001 147 3	0.142 70	0.143 85	197.15	468.79	665.94	0.5431	1.0035	1.5466	194
196	14.569	0.001 150 4	0.136 88	0.138 03	199.29	466.97	666.27	0.5477	0.9954	1.5430	196
198	15.201	0.001 153 4	0.131 34	0.132 50	201.44	465.14	666.58	0.5522	0.9872	1.5394	198
200	15.853	0.001 156 5	0.126 07	0.127 22	203.59	463.28	666.87	0.5567	0.9791	1.5358	200

2. Boiler heat balance practice

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◆ Measurement result in table

		Unit	Measured value	Note
Exterior temperature		℃	15	
Interior temperature		℃	35	
Fuel	Name	-	B-C	Use sulfur 0.3%
	Used amount	ℓ/h	2,940	Fuel ratio :0.95
	Providing temperature	℃	85	
Water supply	Water supply amount	ℓ/h	43,386	
	Water supply temperature	℃	90	
Steam	Evaporation amount	Kg/h	40,622	
	Evaporation pressure	$Kg/cm^2 \cdot g$	7	Steam quality:0.98 applied
Air for combustion	Temperature before APH	℃	35	
	Temperature after APH	℃	159	
Exhaust gas	APH exit temperature	℃	200	
	O2 composition	%	8	
Blow Down		kg/h	1,000	
Atomizing steam		Kg/h	265	Used custom Steam
Theoretically combusted air		Nm^3/kg-fuel	10.709	
Theoretically exhaust gas		Nm^3/kg-fuel	11.443	

2. Boiler heat balance practice

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◆ Basic computation

A) Consumed fuel

= measure fuel amount(ℓ/h) × density(kg/ℓ)× volume correction factor

= 2,940 ℓ/h × 0.95 kg/ℓ × 0.954 = 2,666 kg/h

Note) diesel oil volume correction factor= 0.9754 – 0.0006×(temperature before flow meter -50)=0.954

B) Supplied water

= Measured supplied water (ℓ/h) ÷ specific volume of the supplied water (ℓ/kg)

= 43,386 ÷ 1.03579 = 41,887 kg/h

C) Generated steam

= Supplied water(kg/h) – Blow Down (kg/h) – Atomizing steam inside the furnace (kg/h)

= 41,887 – 1,000 – 265 = 40,622 kg/h

D) Generated steam per 1kg fuel

= Generated steam(kg/h) ÷ consumed fuel (kg-fuel/h)

= 40,622 ÷ 2,666 = 15.28 kg/kg-fuel

E) Excess air ratio

= 21 ÷ (21 -8) = 1.62

2. Boiler heat balance practice

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◆ Heat input

A) Heat value of the fuel

= 9,870 kcal/kg-fuel

B) Fuel's sensible heat

= Specific heat of the fuel(kcal/kg·℃) × (supply temperature – exterior temperature)(℃)

= 0.45 × (85 -15) =31.5 kcal/kg-fuel

C) Air's sensible heat

= theoretical combustion air amount (Nm3/kg-fuel) ×excess air ratio × specific heat(kcal/Nm^3·℃)

×(APH entrance temperature – exterior temperature)(℃)

= 10.709 × 1.62 × 0.31 × (35 -15)

= 107.3 kcal/kg-fuel

D) Total heat input

= Heat value of the fuel + fuel's sensible heat + air's sensible heat

= 9,870 + 31.5 + 107.3

= 10,009 kcal/kg-fuel

2. Boiler heat balance practice

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◆ Heat output

A) Heat absorption of the generated steam

= Evaporated fuel per 1kg(kg/kg-fuel) × (steam enthalpy – water supply enthalpy)(kcal/kg)

= 15.28 × (651-90) = 8,572 kcal/kg-fuel

Note) steam enthalpy = water supply sensible heat + latent heat× vapor quality

B) Exhaust gas heat loss

= {Theoretical exhaust gas amount + (excess air ratio-1)×theoretical combustion air amount}(Nm^3/kg-fuel)

× specific heat(kcal/Nm^3·℃) × (APH exit temperature – entrance temperature)(℃)

= {11.443 + (1.62 -1.0)×10.709}×0.33×(200-15) = 1104 kcal/kg-fuel

C) Blow Down emission calories

= Blow down per 1kg (kg/kg-fuel) × (blow down water enthalpy – water supply enthalpy)(kcal/kg)

= 0.375 × (171.5 -90) =30.5 kcal/kg-fuel

D) Atomizing steam heat loss inside the furnace

= Atomizing steam per 1kg ×(steam enthalpy after APH – water supply enthalpy)

= 0.1 × (666.6 -90) = 57.3 kcal/kg-fuel

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◆ Heat output

E) Radiant heat, electric heat, and other heat losses

= Input heat total – (heat absorption of the generated steam + exhaust gas heat loss + Blow Down emission calories + Atomizing steam heat loss inside the furnace)

= 10,009 –(8,572 + 1,104+ 30.5 + 57.3)

= 245 kcal/kg-fuel

2. Boiler heat balance practice

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◆ Performance

A) Boiler load factor

= (Generated evaporation amount ÷ maximum continuous evaporation amount) × 100

= (40,622 ÷ 60,000) × 100

= 67.7 %

B) Boiler efficiency by input and output heat (%)

= (Absorption heat of the generated steam ÷ total heat input) × 100

= (8,572 ÷ 10,009) × 100

= 85.6 %

C) Boiler efficiency by heat loss (%)

= (1- heat loss total/total heat input) ×100

= (1-(1,104+30.5+57.3+245)/10,009) × 100

= 85.6 %

2. Boiler heat balance practice

[Reference] Heat loss of flue boiler

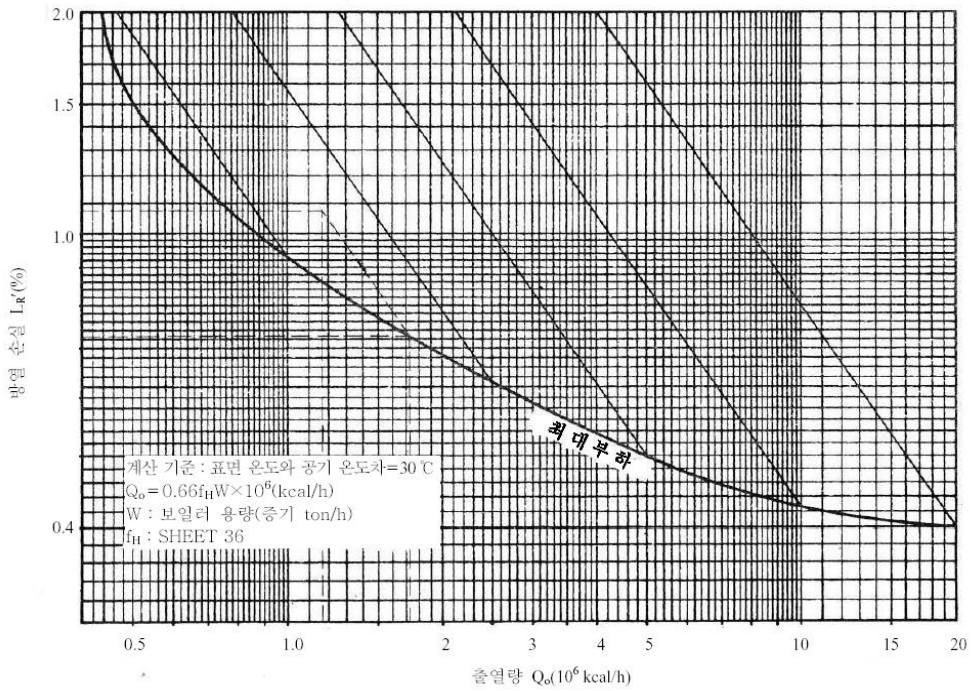

그림 4 노통 연관식 보일러의 방열 손실

[Reference] Heat loss of water tube boiler

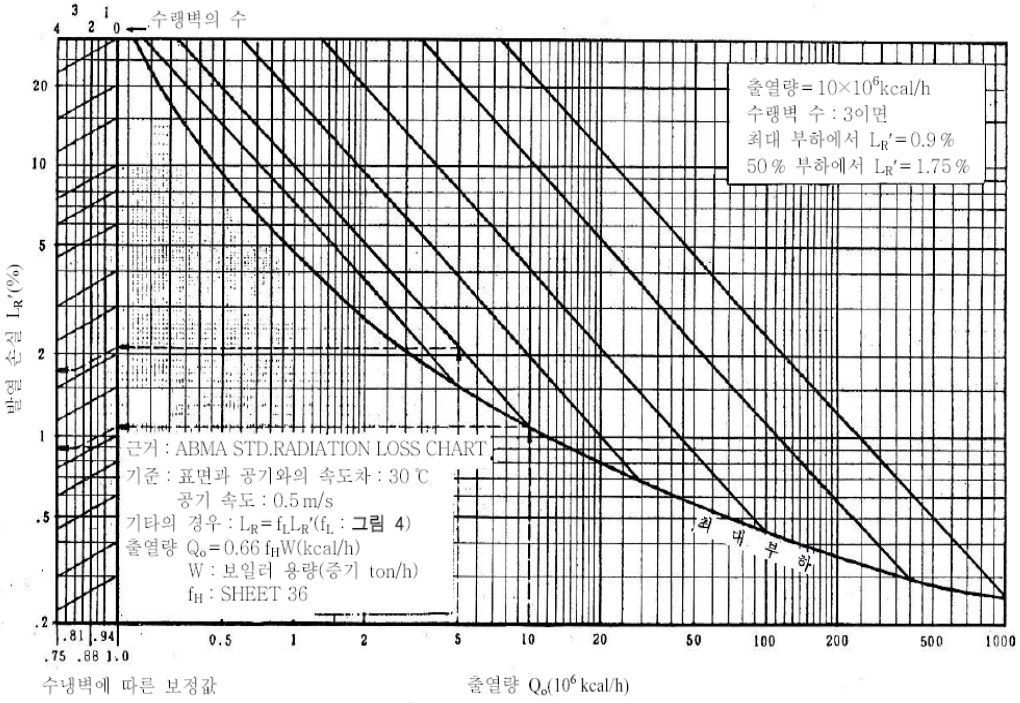

그림 5 수관식 보일러의 방열 손실

2. Boiler heat balance practice

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◆ Heat balance table and performance

[열 정 산 표]

열정산기준: 1.연료의 저위발열량
2.외기 온도
3.연료 1kg당

항목	기호	입열		출열	
		kcal/kg	%	kcal/kg	%
연료의발열량	HL	9,870.0	98.6		
연료의현열	Q_1	31.5	0.3		
공기의현열	Q_2	107.3	1.1		
로내분입증기의입열	Q_4	-	-		
발생증기의흡수열	Q_5			8,569.5	85.6
배가스손실열	L_1			1,100.9	11.0
로내분입증기손실열	L_2			57.5	0.6
불완전연소의손실열	L_3			-	-
블로우 다운수 손실열	L_4			30.7	0.3
방열및기타손실열	L_5			250.2	2.5
합 계	Qi,Li	10,008.8	100.0	10,008.8	100.0

6 페이지

[성 능 치]

항 목	결 과 치	단 위
보 일 러 효 율	85.6	%
부 하 율	67.7	%
매 시 환 산 증 발 량	43,022	kg/h
환 산 증 발 배 수	16.2	kg/kg-연료
보 일 러 전 열 면 열 부 하	#DIV/0!	kcal/m²h
전 열 면 환 산 증 발 률	#DIV/0!	kg/m²h
연 료 원 단 위	65.45	kg/ton

2. Boiler heat balance practice

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- Is exhaust gas temperature appropriate?
- Is boiler’s excess air ratio is properly maintained?
- Is there a way to raise supplied water’s temperature?
- Is amount of Blow Down appropriate? Is waste heat properly recovered?
- Is there a leakage in air preheater?
- Is there an unshielded area such as valves?
- Is steam trap properly installed?
- Is the retrieval method of steam condensed water appropriate?
- Is the operating pressure of supplied water pump appropriate?

2. Boiler heat balance practice

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◆ Recovery ideas

• **Installing ECONOMIZER**	▪ When using gaseous fuel, ▪ Be considered preferentially when installed location is narrow ▪ Substitute existing GAH (additional heat recovery)
• **Installing air preheater**	▪ Check if exhaust gas can cause corrosion ▪ Make sure installation space is adequate
• **Prevent leak for air preheater**	▪ Check existing heat exchanger ‘s air-leak status and sealing
• **Installing corrosion-resistance heat exchanger**	▪ Additional installation at the back of existing heat exchanger (strengthen heat recovery) ▪ Be applicable in incinerator, etc.

Ⅲ. Calculating boiler energy saving expected effect

3. Calculating boiler energy saving expected effect

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◆ Adjusting excess air ratio

- Appropriate excess air ratio is different by structure of the boiler, used fuel, burner operating characteristic, operating load condition, etc.
- Decide proper degree considering Boiler's combustion device operating characteristic, control method and condition, operation load condition, operating log comprehensively.
- Introduce O2 triming system, use air-fuel ratio control device to move the location of the level position.

◆ Measurement point

- Use gas analyzer in the exit of the main body to find out concentration of O2%, CO2 %, CO in the exhaust gas.

3. Calculating boiler energy saving expected effect

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◆ Calculating method of expected effect

• Saved calories (Q)

$$Q = (m1 - m2) \times Ao \times Ca \times (tg - ta)$$

m1 : excess air ratio before improvement

m2 : excess air ratio after improvement

Ao : theoretical combustion air amount (N㎥/kg-fuel)

Ca : specific heat of the air (kcal/N㎥·℃)

tg : exhaust gas temperature (℃)

ta : exterior air temperature (℃)

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

- Question) Find out fuel economy effect when boiler's excess air ratio changes from current 8% to 4%.

  (Input calories 10,009 kcal/kg-fuel, theoretical combustion air amount Ao:10.709 Nm3/kg,

  Specific heat of air: 0.31kcal/Nm^3·℃, annual fuel usage amount:22,394,000ℓ/yr, unit fuel price: 0.9$/ℓ)

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

◆ Solution)

1)Excess air ratio before improvement: 1.615= 21/(21-8)

2)Excess air ratio after improvement: 1.235=21/(21-4)

3)Q(Saved calories) = (m1 - m2) × Ao × Ca × (tg - ta)

208kcal/kg-fuel = (1.615 – 1.235)×10.709 Nm3/kg-fuel×0.31kcal/Nm^3 ×(200℃ - 35℃)

4)Fuel saving rate=saved fuel/heat input

0.02=208kcal/kg-fuel ÷ 10,009 kcal/kg-fuel

5)Fuel saving amount= fuel saved amount x annual fuel usage amount

465,376ℓ/yr = 0.02 × 22,394,000ℓ/yr

6)Fuel saved cost = fuel saved amount × unit fuel price

418,838 $/yr=465,376ℓ/yr × 0.9$/ℓ

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

◆Ideas for raising supplied water temperature

- Install Economizer, heat recovery device of exhaust gas, and preheat supplied water

(Decide installing location and raising supplied water available condition by considering used fuel condition, corrosion causing factor at low temperature, composition and space condition of the device)

- Recover condensed water(Steam Drain) as much as possible

- Recover waste heat generated by the process to preheat supplied water.

- Recover evaporating steam of the open tank as much as possible, make water supply tank to pressure tank

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

◆ Calculating method of expected effect

• Calculate saved calories (Q)

$$Q = \{Go + (m - 1) \times Ao\} \times Cg \times (tg1 - tg2)\}$$

Go : theoretical exhaust gas (N㎥/kg-fuel)

Ao : theoretical combustion air (N㎥/kg-fuel)

m : excess air ratio

Cg : average specific heat of exhaust gas (kcal/N㎥.℃)

tg1 : exhaust gas temperature before improvement (℃)

tg2 : exhaust gas temperature after improvement (℃)

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

◆ Question) Calculate fuel economy effect if heat exchanger is installed and heat recovered boiler's exhaust gas from current 200℃ to 150℃

(Heat input 10,009 kcal/kg-fuel, theoretical combustion air Ao:10.709 Nm3/kg, theoretical exhaust gas Go:11.494Nm3/kg, excess air ratio after improvement 1.235, specific heat of exhaust gas: 0.33kcal/Nm^3·℃, annual fuel usage:22,394,000ℓ/yr, fuel unit price: 0.9$/ℓ)

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

◆ Solution)

1)Q(saved calories) = {Go + (m - 1) × Ao} × Cg × (tg1 - tg2)}

231kcal/kg-fuel={11.494 Nm3/kg-fuel+(1.235-1)×10.709 Nm3/kg-fuel}×0.33kcal/Nm^3

× (200℃ - 150℃)

2)Fuel saving rate=saved calories/heat input

0.023=208kcal/kg-fuel ÷ 10,009 kcal/kg-fuel

3)Fuel saving amount = fuel saving rate x annual fuel usage amount

515,062ℓ/yr = 0.023 × 22,394,000ℓ/yr

4)Fuel saved cost = fuel saving amount × unit fuel price

418,838 $/yr=465,376ℓ/yr × 0.9$/ℓ

3. Calculating boiler energy saving expected effect

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◆ Calculating Economizer heating surface area

- Calculating Economizer heating surface area
- Q = U×A×LMTD, so

  A= Q/(U×LMTD)

Q : Recovered heat in exhaust gas (kcal/h)

U : Economizer total heating coefficient (kcal/m^2·h·℃)

where, 50 kcal/m^2·h·℃ applied

LMTD : Algebraic average temperature (℃)

where, LMTD=$(\Delta T_1-\Delta T_2)\div \ln(\Delta T_1/\Delta T_2)$

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

- Question) Find out heating surface area of the supplied water if heat exchanger is installed and recover exhaust gas heat from 200℃ to 150℃.
  (Exhaust gas recovery ratio: 0.9, total heating coefficient of the supplied water heat exchanger: 50 kcal/m^2·h·℃, specific heat of the supplied water: 1kcal/kg·℃)

3. Calculating boiler energy saving expected effect

KOREA ENERGY AGENCY

◆ Solution)

1) Exhaust gas recovered calories = recovered calories × 0.9

207.9kcal/kg-fuel=231kcal/kg-fuel ×0.9

2)Available raising boiler supplied water temperature (℃)

=Exhaust gas recovered calories (kcal/kg-fuel)×fuel usage (kg-fuel/h)

÷{(supplied water(kg/h)×specific heat of the supplied water(kcal/kg·℃)

13.23℃ = 207.9kcal/kg-fuel×2,666kg-fuel/h ÷{(41,887kg/h×1 kcal/kg·℃)}

3) Algebraic average temperature(LMTD)=$(\Delta T_1-\Delta T_2)\div \ln(\Delta T_1/\Delta T_2)$

97℃ = (146.77℃- 60℃)÷In(146.77℃/60℃)

where, ΔT_1=Economizer exhaust gas temperature at the front – Economizer supplied water temperature at the back

ΔT_2=Economizer exhaust gas temperature at the back – Economizer supplied water temperature at the front

4)Heating surface area= Exhaust gas recovered calories÷ (Economizer total heating coefficient ×LMTD)

114.3m^2 = 207.9kcal/kg-fuel×2,666kg-fuel/h÷(50 kcal/m^2·h·℃ × 97℃)

3. Calculating boiler energy saving expected effect

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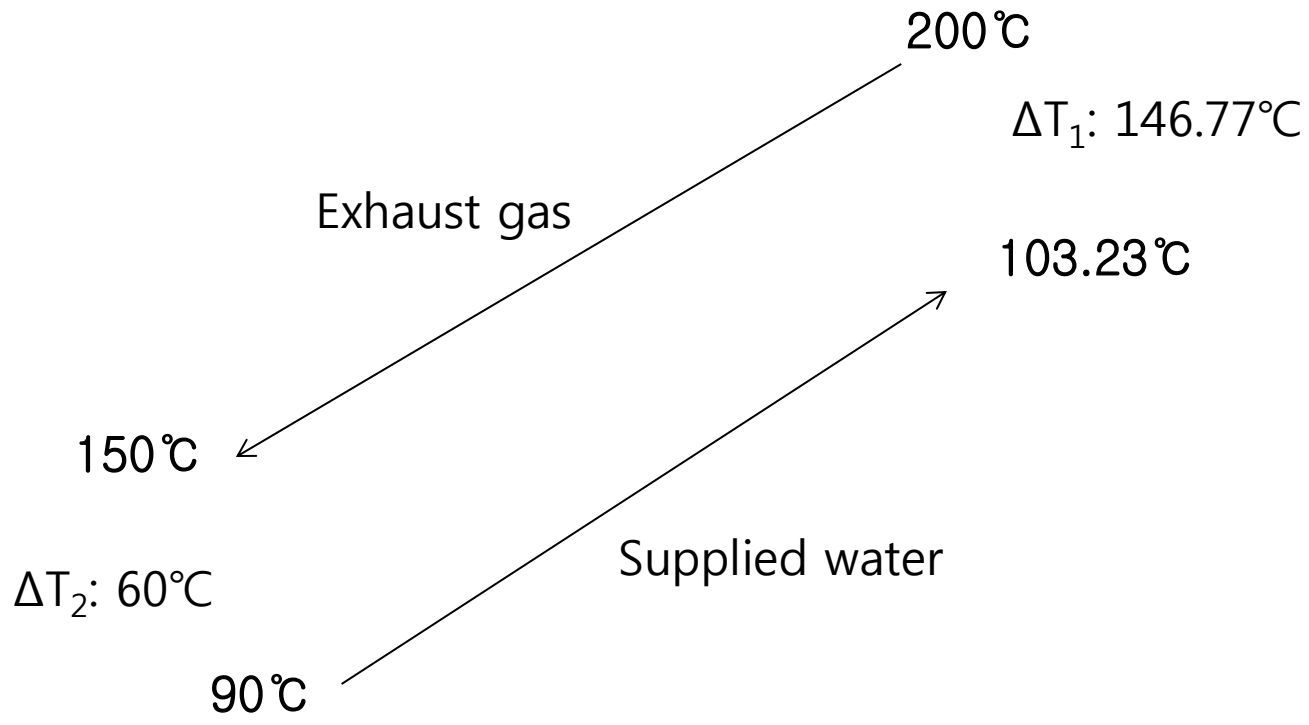
◆ Solution)

Algebraic average temperature (LMTD): exponential value of the average temperature difference which is used to calculate heat exchanging calories for heat exchanger.



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Question & Answer