Utilization of brown coals for coal gasification as coal/water slurry

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INTRODUCTION

It is well known that Australian brown coals, such as Loy Yang and Yallourn, have very high moisture content from 50 to 70%. When these brown coals are used for coal combustion or gasification, this high moisture content is cause of the low thermal efficiency because a part of the energy of coal is used for this water to evaporate. In order to maintain reasonable power plant outputs, large and costly plant is needed and considerable quantities of carbon dioxide are emitted. Furthermore, brown coals must be used at a power plant adjacent to the open cut mines since high moisture raises calorie-based cost of transport and dried coal has spontaneous combustibility.

Several coal-drying technologies have been considered for effective utilization of brown coals [1-8]. Hydrothermal Dewatering (HTD) process is one of the coal-drying technologies [1-6]. In the process, brown coal containing 62% moisture is converted to pumpable slurry containing 50% moisture. The advantages of this process are that latent heat of water vaporization is not expended and that water-soluble inorganic compounds can be removed because the water is removed as a liquid. Obtained slurry can be fired in conventional boilers. Recently, Mechanical Thermal Expression (MTE) process is developed [1,7,8]. The mechanical energy required to remove the water from coal is less than 1% of the thermal energy required for an equivalent drying by evaporation. However, total costs of drying brown coal for HTD and MTE processes are too expensive, because the wastewater treatment is necessary.

KEM Corporation developed a new process which converts brown coal to coal/water slurry (CWS). In this process, brown coals are subjected to somewhat high temperature (< 200°C) and high shear stress (about 1.0 MPa). This strongly interacted water with coal is dissociated by the heat and shear stress. The crush of coal particles and collapse of pores in the coal by high shear stress prevents re-adsorption of water. Brown coals are converted to concentrated slurry having combustion heat equivalent to that of conventional CWS from bituminous coal by removing a part of water during the process. Obtained the slurry is stable because brown coal has hydrophilic property and dissolved organic acid acts as surfactant. However thermal efficiency of coal combustion or gasification is still low since the slurry contains water.

Miyatani [13] suggested that evaporation of water in CWS before coal gasifier increases cold gas efficiency from calculation. The water in CWS should be evaporated before injection to coal gasifier or boiler in order to increase the cold gas efficiency or the thermal efficiency. However, the preheating and in-line vaporization of CWS requires special design to address the needs of handling phase change and multi-phase flow at different pressures. Before, the pre-vaporization was considered and tried, but this failed to cause the line plugging, so the prevailing technology today still uses direct combustion CWS without pre-vaporization.

In the mid-1980s, a research group in General Applied Science Laboratories Inc. in NY, US, proposed and tested thermal preconditioning of CWS to produce coal/steam suspensions as an alternative of conventional atomization of CWS [9,10]. Roffe *et al.* [9] tried to evaporate water in CWS with preheating and found line plugging using CWS of 40-60wt%-coal as feed, but the CWS was successfully fed together with 10wt% of steam flow. CWS vaporizer development was reported in 1987 with useful experimental observations and conclusions [10]. The feature is that the tube of the preheater has extended gradually. Tests for the gas turbine combustor using CWS vaporizer was performed at a CWS flow rate of about 140 kg/h (containing 54-60 % coal) and combustion pressure of 0.8 MPa for the testing-unit gas turbine combustor. The test durations were varied between 10 and 20 min. It appears that this work was not continued. Usui *et al.* [11,12] also tried to feed CWS with steam flow. In their experiment, CWS was continuously fed while coal particles aggregated and ratio of evaporated water was only 16%. Regardless of the above works, no successful demonstration has been reported.

The authors designed and developed the in-line vaporizer that accommodate CWS pressure and flow change as well as phase change in the same transfer line leading the feed from CWS tank to gasifier [14]. In the present paper, the authors introduce brown coal utilization processes using combination of CWS production process licensed by KEM Corporation with CWS in-line vaporizer. Furthermore, pilot plant for CWS in-line vaporizer is designed, and feasibility study is performed based on the plant cost.

EXPERIMENTAL

Firstly, experimental kneader having 5L of vessel (Fig. 1a) was used for confirmation of CWS production. Sample vessel of the kneader, which equipped with oil heater, is high-pressure type. The kneader has two wings that gave small shear stress (about 0.1 to 0.2 MPa).

Indonesian (ID) and Loy Yang (LY) brown coals were used as raw materials, whose elemental compositions are shown in Table 1. Particle sizes for ID and LY coals were < 0.25 and < 5 mm, respectively. 2.5 kg of raw material was heated in a closed sample vessel with kneading. Pressure in the vessel went up to 1.0 MPa-G due to increase in vapor pressure of water at 185°C. After 5 h of maintaining the pressure, sample vessel was cooled down to room temperature. Obtained slurries from ID coal and LY coal were termed ID slurry and LY slurry, respectively.

The large-scale kneader having capacity of about 200 kg, shown in Fig 1b, was used to produce CWS for vaporizer. The kneader has shaft with screw and blade. The kneader can give high shear stress (about 0.5 MPa) to the sample while has no external heater and no pressurized system. LY coal having average particle size of 0.31 mm was introduced into the kneader. LY coal was kneaded for 4.5 h.

Original coals and obtained slurries were subjected to several analyses. Viscosity of obtained slurry was measured with rotary viscometer (shear rate: 6.7–1008 s^{-1}). Distribution of types of water in original coal and obtained slurry were measured using ^{1}H-NMR on the basis of freezing properties of water [15]. ^{1}H-NMR relaxation measurement was performed at temperatures of 20, -5 and -50°C. For the measurement of gas adsorption and desorption, original coal and obtained slurry were dried at 60°C under the vacuum condition for 1 day. The surface area of these was determined with CO_2 adsorption at 0°C. The pore size distribution was measured with Ar adsorption and desorption at -195°C.

The CWS in-line vaporizer having capacity of about 2.0 tons-coal/day [14] used the LY slurry producing with large-scale kneader. Figures 2 and 3 are shown schematic diagram and photographs of the vaporizer, respectively. This apparatus was composed of CWS feed section and CWS heating section. CWS feed section consisted of 200 L of drum-can, a mohno-pump and high-pressure pump having maximum flow rate of about 200 L/h. CWS was heated in a feed tube settled in the three heaters (termed 1st, 2nd or 3rd heater) by heating medium. Diameters and lengths of feed tube were designed to steadily feed CWS and to completely vaporize water in CWS. Flow of steam/coal went to combustion furnace from outlet of 3rd heater, and was burned in the furnace whose temperature is maintained with crude oil burner. Another exhaust line is prepared for start-up with vaporization of water, monitoring condition of coal/steam exhaust, and sampling of dried coal particles.

The diameters and lengths of coils in each heater are schematically shown in Fig. 4. The length of coil in 1st heater was about 70 m which means 80 sec of residence time. Total length of coils in 2nd and 3rd heater was 47.9m and its residence time was < 10 sec. Temperatures and pressures at the outlet of each heater were detected in order to estimate the state of the fluid and to check steadily flowing of the fluid.

RESULTS

Production of CWS from brown coals

Pulverized ID coal having particle size of < 0.25 mm was subjected to CWS production process. ID coal has less moisture than LY coal as shown in Table 1. About 0.5 g-water/g-ID coal of water was added so that the total moisture of slurry was 50%. Figure 5a shows photographs of slurry production for ID coal at start and end of the operation. Smooth and pumpable slurry was obtained by this operation. LY coal having particle size of < 5 mm was also kneaded. Slurry was obtained as shown in Fig. 5b. ID and LY slurries were separately left at rest in buckets. The authors detected no precipitation for 2 or more days after the experiment while the slurries include no surfactant. This characteristic comes from hydrophilic property of brown coals and effect of organic acid dissolved in the water.

The LY slurry was also produced with large-scale kneader having 0.5MPa shear stress. About 180 kg of sample was introduced into the kneader. Despite low temperature and atmospheric pressure, LY slurry was obtained by this operation.

Properties of CWS obtained from brown coals

The viscosities of obtained slurries were measured with a rotary viscometer. The viscosities of ID slurry and LY slurry were 140–1030 mPa·s and 1000-5000 mPa·s, respectively. The viscosity of LY slurry is relatively higher than that of ID slurry since LY coal. This phenomenon originates in the size of the particle of original coal.

Distributions of types of water for LY coal and LY slurry obtained at 170°C for 1 h were measured using ^{1}H-NMR on the basis of freezing properties of water and shown in Fig 6. Free water is identical to bulk water that freezes at around 0°C. Bound water is defined as pore condensed water that freezes at a temperature range of 0 to -50°C. Non-freezable water does not freeze at -50°C. The comparison demonstrates that this CWS production process decreases amount of non-freezable water and increases amount of free water. Fluidity of LY coal might increase with increasing content of free water. Figure 7 compares pore size distributions for LY coal and LY slurry. Figure 7 means qualitative comparison pore size and volume for LY coal with those for LY slurry since drying of brown coal is known to cause of irreversible shrinkage and/or collapse of pores in the coal [15-17].

Preheating and combustion of CWS obtained from LY coal

The CWS vaporizer shown in Fig. 2 was used for drying LY slurry. The slurry produced by large-scale kneader had contained about 10% particles having > 0.5 mm size and had same viscosity of commercialized CWS. Small amount of water was added and large coal particles were removed from the slurry by precipitation before the experiment since minimum diameter of feed tube was 2 mmϕ. This in-line evaporator causes blocking in the first evaporation pipe (2mmϕ) when about ten % coal particle of 0.5mm or more is in CWS. The water content of the slurry became about 75% and viscosity of the slurry was less than commercialized CWS (<1000 mPa・s).

The LY slurry was preheated and exhausted into atmosphere in order to monitor condition of the exhaust and to measure water content of exhausted coal particles. Temperature of heating medium and flow rate of sample were 300°C and 120 L/h, respectively. After vaporization of water, about 5 kg of LY slurry was introduced from the CWS tank and the vaporization of water in CWS exhausted to outside. Figure 8 shows exhaust of steam/coal from the LY slurry. The moisture in obtained coal particles was 5-6 wt%.

The LY slurry was preheated and introduced directly into the combustion furnace. At the experiment, temperature of heating medium and flow rate of sample were 310°C and 120 L/h, respectively. The log data at the experiment is shown in Fig.9. The LY slurry was steadily fed into the combustion furnace for 90 min without plugging of feed tube. Experiment was terminated because all of sample in a CWS tank having volume of about 200 L was completely fed.

From read out the log data, followings were found:

1. Fluid was in a solid/liquid (slurry) phase at the outlet of 1st heater since pressure and temperature of outlet of the heater were 8.5 MPa and 285°C, respectively. (vapor pressure of water is 8.5 MPa, at 300°C)
2. Fluid was in a solid/liquid/gas phase at the outlet of 2nd heater since pressure and temperature of outlet of the heater were 1.7–1.8 MPa and 200°C, respectively. (vapor pressure of water is 1.5 MPa, at 208-210°C)
3. Fluid was in a solid/gas phase at the outlet of 3rd heater since pressure and temperature of outlet of the heater were 0.8 MPa and > 200°C, respectively. (vapor pressure of water is 0.8 MPa, at 176°C)

Temperature in the combustion furnace increased from 530 to 600°C and consumption of crude oil decreased with feeding of LY slurry. This means LY slurry is steadily burned in the furnace. Fire of LY coal could not monitor because the nozzle of the vaporizer was settled to the monitoring window.

SUMMARY

From the above results, LY coal was converted to slurry using their own moisture and without any surfactant. 200 L of product slurry is pumpable and transportable. Water in the slurry was completely evaporated with vaporizer and was burned in the combustion furnace during 1.5 h of experimental period.

ACKNOWLEDGEMENTS

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Table 1. Elemental composition of raw materials

	wt% (as received)		wt% (dry basis)				
	Moist.	Ash	C	H	O	N	S
Indonesian (ID) Coal	22.2	4.93	66.03	5.19	20.59	1.37	0.39
Loy Yang (LY) Coal	59.0	0.37	67.28	4.97	25.34	0.60	0.28

(a) Experimental kneader

(b) Large-scale kneader

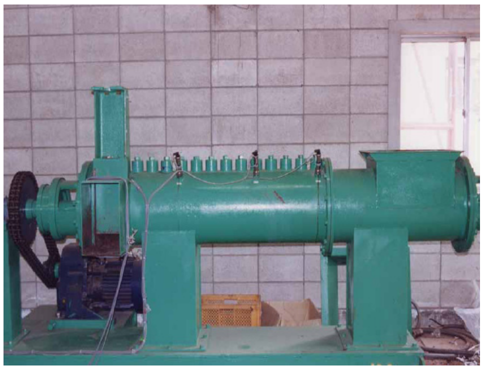


Figure 1 Photographs of experimental (a) and large-scale (b) kneader

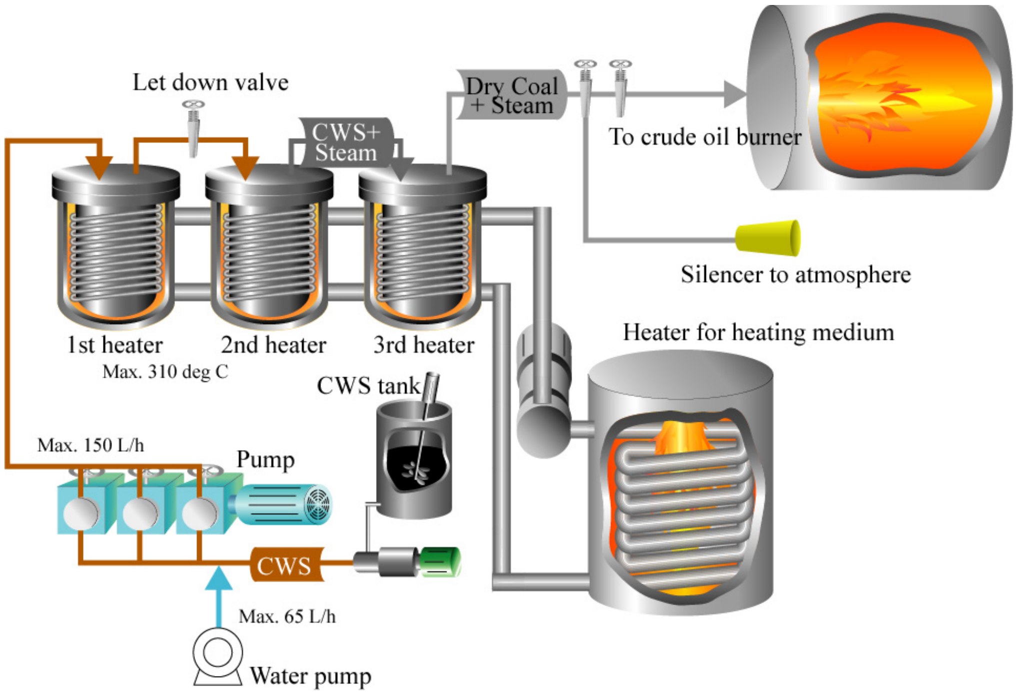


Figure 2. Schematic diagram of CWS vaporizer

Figure 3. Photographs of CWS vaporizer system

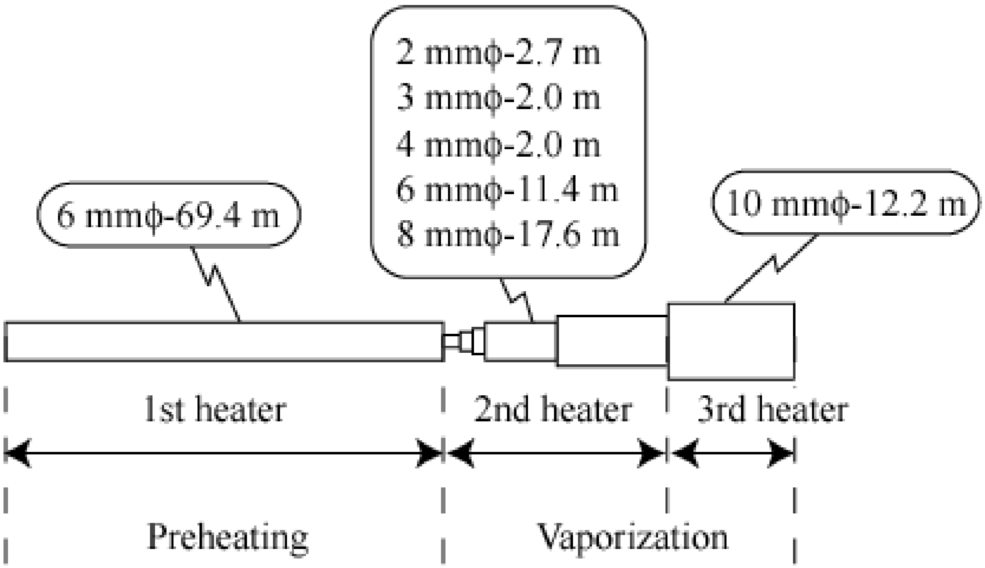


Figure 4. Diameters and lengths of coils

(a) ID coal

Start of operation

End of operation

(b) LY coal

Start of operation

End of operation

Figure 5. Photographs of CWS production at start and end of operation

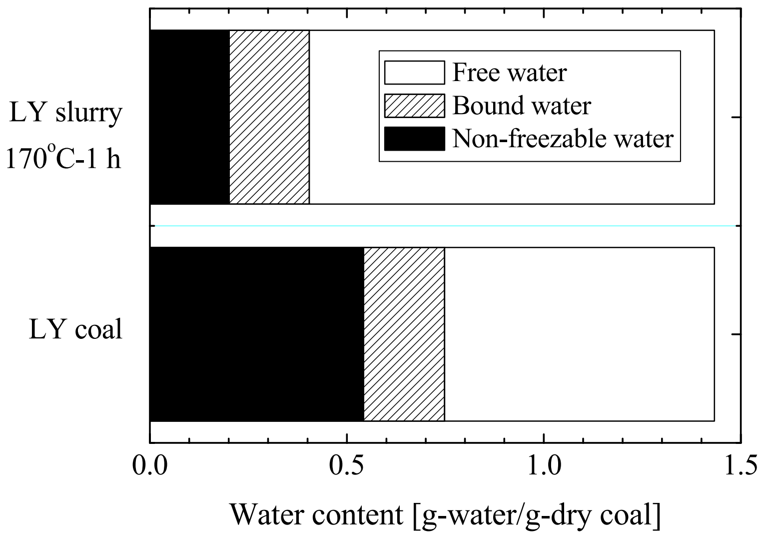


Figure 6 Freezing properties of water in LY coal and LY slurry

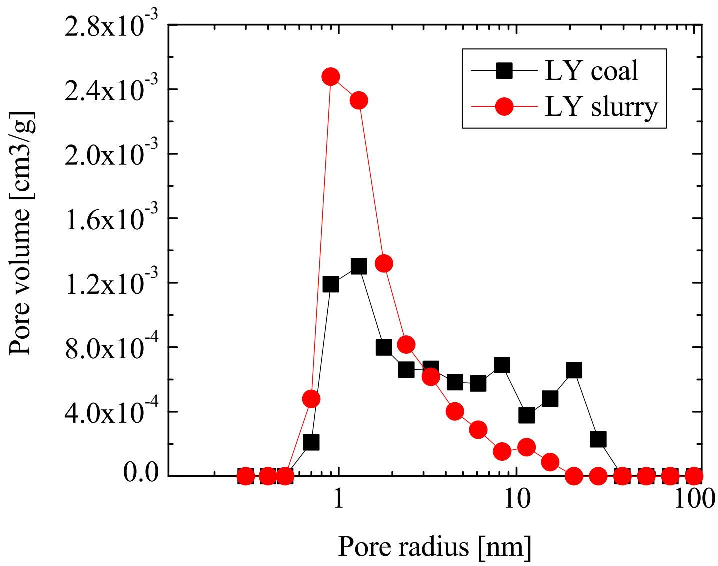
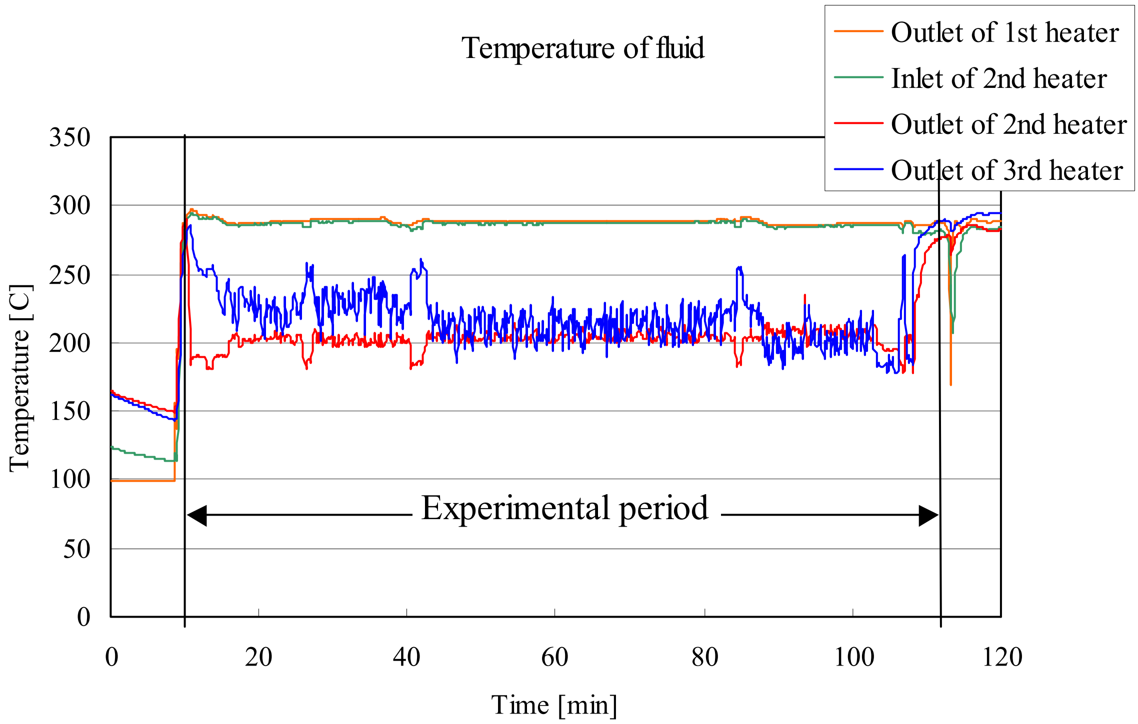


Figure 7 Pore size distribution of dried LY coal and LY slurry

Figure 8 Exhaust of steam/coal from LY slurry



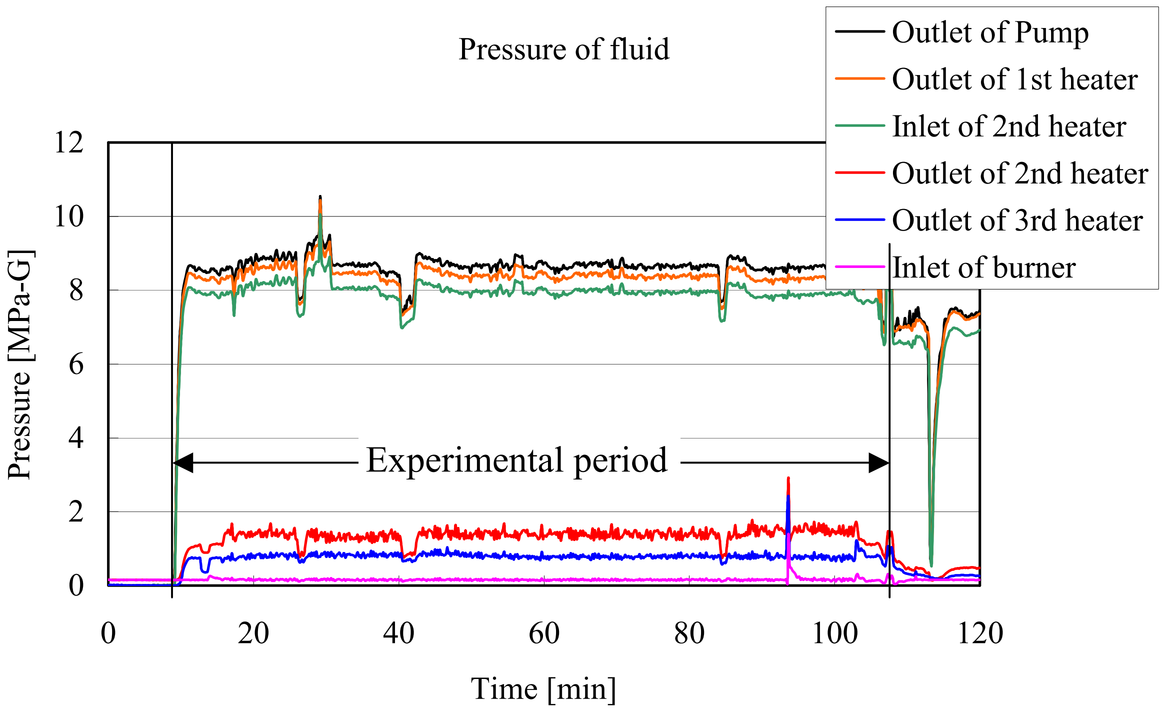


Figure 9 Log data of preheating of LY slurry

Evaluation of Brown Coal Power Plant using CWS System

1 Evaluation of CWS preheating system

1.1 Conditions

Processing ability: 300 t/d-dry coal

Type of vaporizer: race track

Heating medium: Molten salt (340ºC, 1 m/s)

1.2 Material

CWS from brown coal: 65wt%-CWS (35% water+65% dried coal)

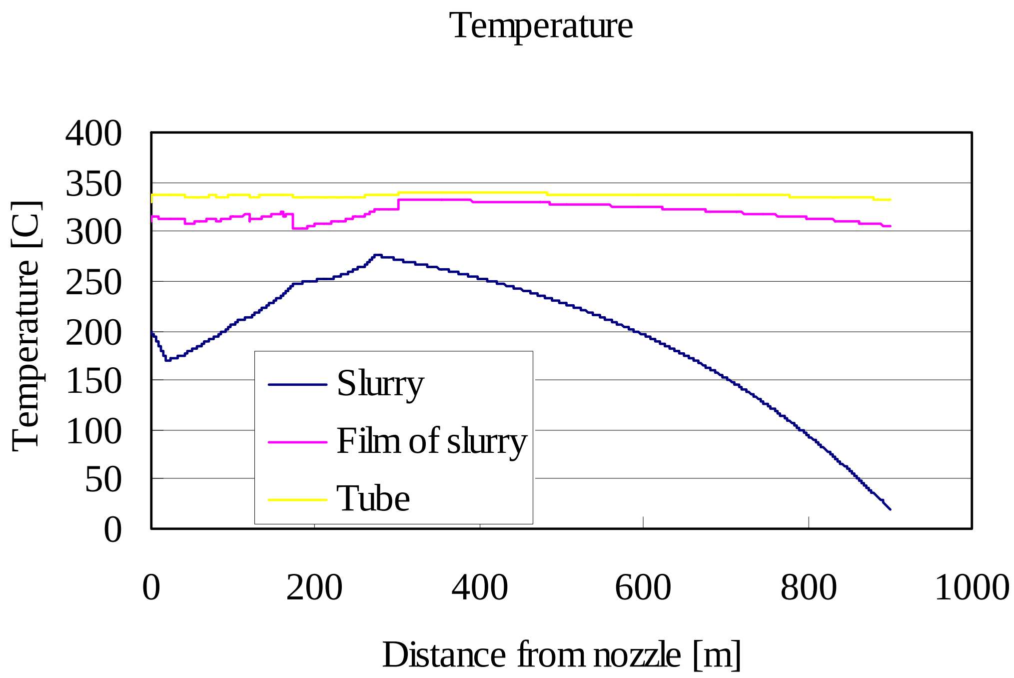
1.3 Design

Number of feed tube: 1

Design of feed tube:

Design of tube	
Inner diameter [mm]	Length [m]
85.4	500
25	40
32.9	20
38.4	20
49.5	20
62.3	40
85.4	40
120.8	40
143.2	40
190.9	40

Prediction of temperature, ratio of water evaporation, pressure, and velocity for large-scale CWS preheater are shown in Figure 1.3-1. Left side and right side of these figures indicate outlet and inlet of CWS preheater, respectively.



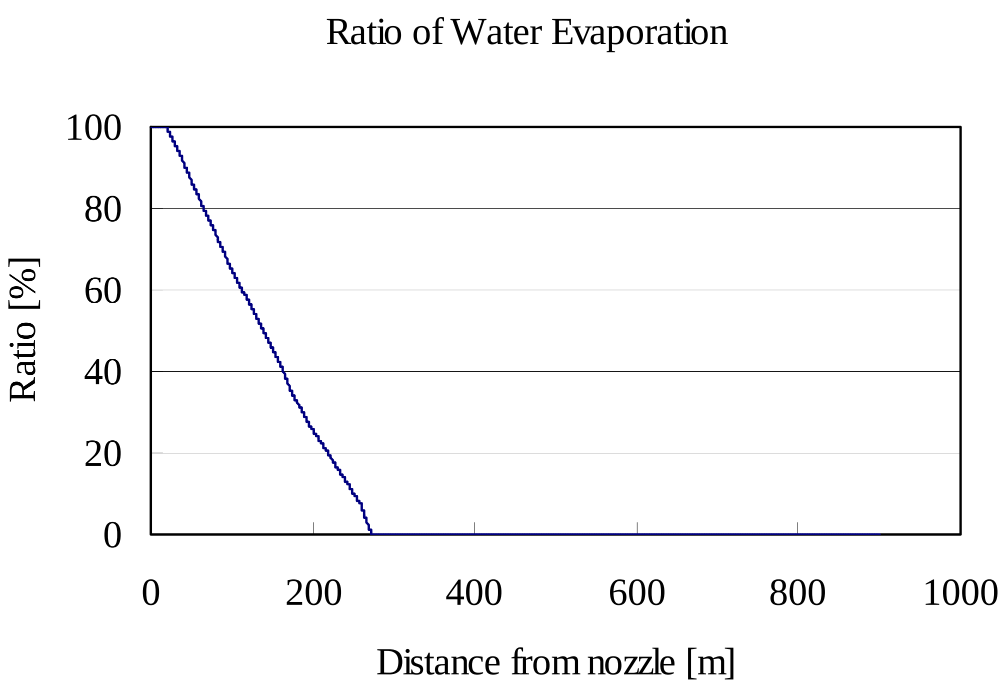
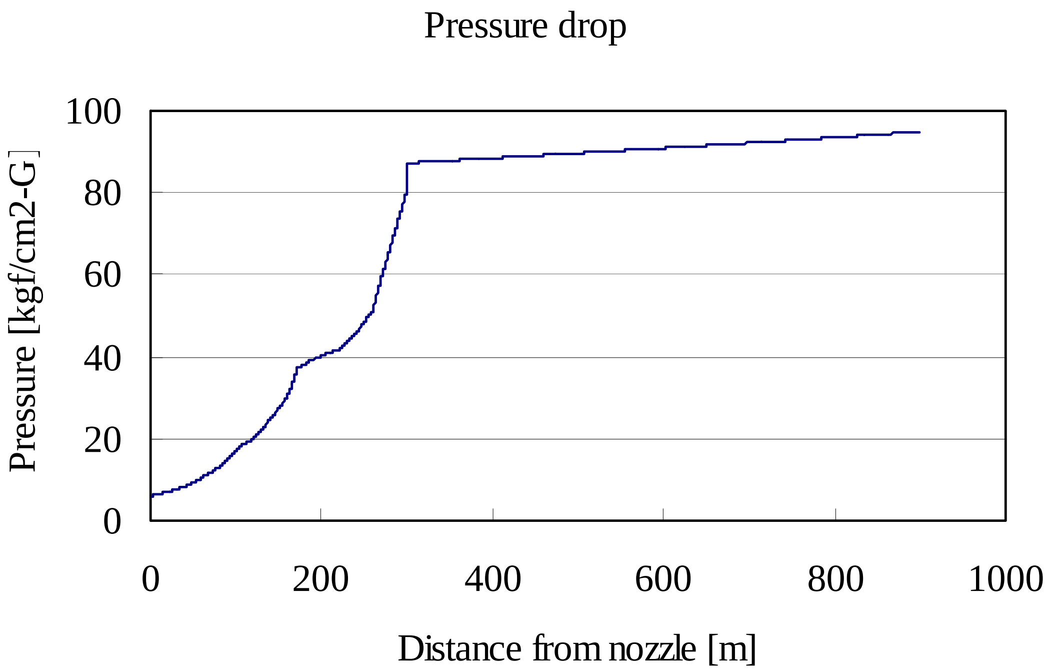


Figure 1.3-1 Prediction of CWS flowage and heat transfer



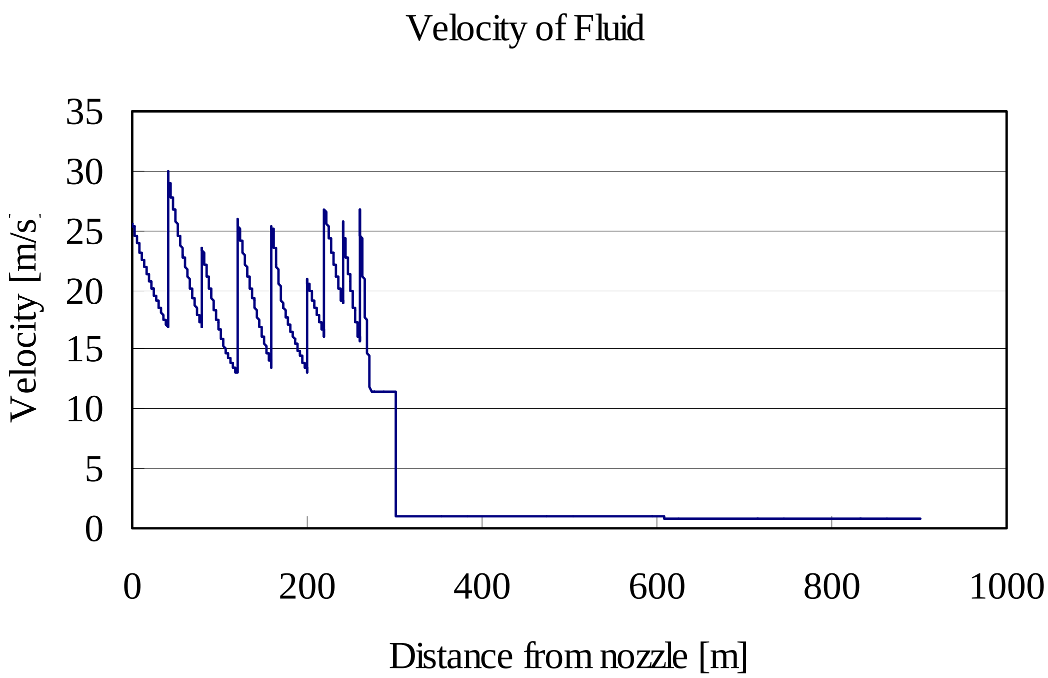


Figure 1.3-1　Continued

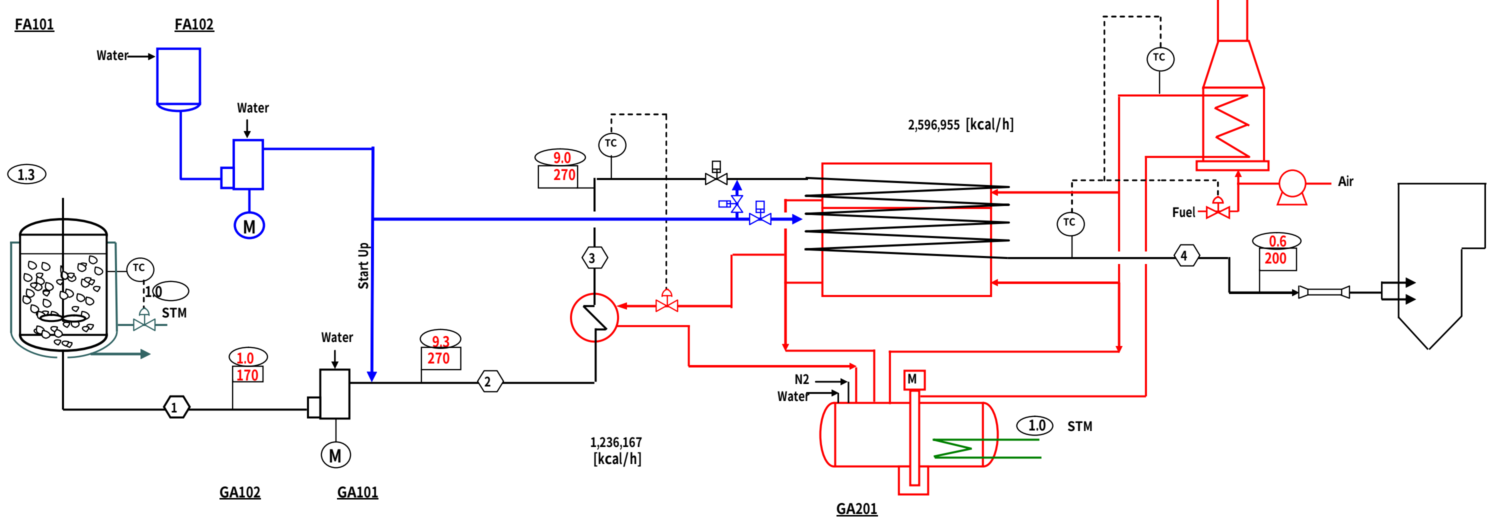
1.4 General representation of CWS preheating system

Process flow diagram, equipment list, and engineering flow diagram for CWS preheating system are shown in Fig.1.4-1, Table 1.4-1, and Fig.1.4-2, respectively.

CWS produced with CWS kneader is supplied to CWS tank (FA101) at temperature of 170ºC and pressure of 1.0 MPa-G. The CWS is pressurized with CWS pump (GA101) to 10.0 MPa-G, and is fed to preheater (EA101). The CWS is heated up to 270ºC with EA101.
Water in the CWS vaporizes with the vaporizer (EA102A and EA102B). At the initial of EA102A, water in the CWS is in a saturated state. The water vaporizes through EA102A and EA102B having different inner diameters of feed tube. The CWS is completely converted to coal/steam mixture and is fed into boiler.

Molten salt is heated to 340ºC with molten salt heater (BA201). The molten salt gives heat for each unit (EA101, EA102A and EA102B), and goes back to BA201 through molten salt tank (FA201) with pump (GA201)

CWM Weight Density 63%
Coal Flow Rate 12,500 [kg/h]
CWM Flow Rate 20,833 [kg/h]



Stream			1	2	3	Saturated	4
Flow Rate	Coal	[kg/h]	12,500	12,500	12,500	12,500	12,500
	Water	[kg/h]	7,448	8,333	8,333	0	0
	Steam	[kg/h]	0	0	0	8,333	8,333
Density	Coal	[kg/m3]	1,400	1,400	1,400	1,400	1,400
	Water	[kg/m3]	948	948	948	-	-
	Steam	[kg/m3]	-	-	-	3.5	3.2
Volume Flow	Coal	[m3/h]	8.9	8.9	8.9	8.9	8.9
	Water	[m3/h]	7.9	8.8	8.8	-	-
	Steam	[m3/h]	-	-	-	2,402	2,594
Temperature		[°C]	170	170	170	165	200
Pressure		[MPaG]	1.0	9.3	8.8	0.6	0.6
Vapor Pressure		[MPaG]	0.7	0.7	0.7	0.6	1.5

(ellipse) : MPaG
(rectangle) : C

CUSTOMER	Ø TOYO ENGINEERING CORPORATION					
LOCATION -	TOKYO JAPAN					
PLANT Preheating System of Brown Coal Slurry	PROCESS FLOW SHEET					
DWG. NO.		Rev	DATE	MADE	CHKD	AUTH. DESCRIPTION

Figure 1.4-1 Process flow diagram

PLANT		TOYO ENGINEERING CORPORATION	MADE BY		DATE	
SECTION	**Preheating System of Brown Coal Slurry**		CHECK BY		DATE	
JOB No.		**Equipment List CLASS "D" "F" Tower、Tank**	APPR. BY		DATE	

Rev	Item No.	Service Name	No. Req'd	Fluid Name	Type	Specifications			Materials	Design Conditions		Operating Conditions		Accessories	Code	Insula -tion	Remarks
						I.D. (mm)	T-T Length (mm)	Volume (m^3)		Temp. (℃)	Pressure (MPaG)	Temp. (℃)	Pressure (MPaG)				
0	FA101	CWM Tank	1	Brown Coal Slurry 63 wt.%	Vertial Cylindrical with Jacket	3,300	4,270	40.0	C.S.	198/203	1.1/1.1	170/175	1.0/1.0	Agitator	—	H	CWM for 2 hours (35.4)→80～90%
0	FA102	Water Tank	1	Water	Vertial Cylindrical	2,000	2,350	8.0	C.S.	60	Full Liquid	20	ATM	-	-	-	Preheating Line*1.2
0	FA201	Molten-salt Tank	1	Molten-salt	Horizontal Cylindrical	3,100	5,950	50.0	C.S.	374/203	0.6/1.1	340/175	0.3/1.0	Steam Coil	-	H	

Table 1.4-1 Equipment list

PLANT		TOYO ENGINEERING CORPORATION	MADE BY		DATE	
SECTION	Preheating System of Brown Coal Slurry		CHECK BY		DATE	
JOB No.		Equipment List CLASS "E" Heat Exchanger	APPR. BY		DATE	

Rev	Item No.	Service Name	No. Req'd		Fluid Name	Type	Surface Area (m^2)	Specifications DIA. (mm)	Length (mm)	Tube No.	Materials	Design Conditions Temp. (℃)	Pressure (MPaG)	Operating Conditions Temp. (℃)	Pressure (MPaG)	Duty (W)	Code	Insula-tion	Remarks
0	EA101	Preheater	1	T	CWM	V-AEU	27	15.9			C.S.	298	13.2	270	9.3	Nor.	-	H	
				S	Molten-salt			300	9,000	61	C.S.	371	0.6	338/308	0.3	1,437,403		H	
0	EA102A	Vaporizer	2	T	CWM	Coil	*1	*1			304SS	308	13.2	280	8.8	Nor.	-	H	*1 See Datasheet
				S	Molten-salt				*1	*1	C.S.	374	0.6	340/338	0.3	752,829		H	
0	EA102B	Vaporizer	2	T	CWM	Coil	*1	*1			304SS	278	13.2	250	4.0	Nor.	-	H	*1 See Datasheet
				S	Molten-salt				*1	*1	C.S.	374	0.6	340/331	0.3	3,019,715		H	

Table 1.4-1　Continued

PLANT		TOYO ENGINEERING CORPORATION	MADE BY		DATE	
SECTION	Preheating System of Brown Coal Slurry		CHECK BY		DATE	
JOB No.		Equipment List CLASS "G" Pump	APPR. BY		DATE	

Rev	Item No.	Service Name	No. Req'd	Fluid Name	Type	Specifications Capacity (m^3/h)	Specifications Head (m)	Pressure Suc./Dis. (MPaG)	Density (kg/m3)	Viscosity (cP)	Vapor Pressure (kPa)	Operating Temp. (℃)	Material	Motor Rating (kW)	Code	Remarks
0	GA101	CWM Pump	1	Brown Coal Slurry 63 wt.%	Reciprocating	16.8	1,010	1.0/12.0	1,189	3.8	690.7	170	S.S.	B.V.	-	Pulsation Prevention Safety Valve
0	GA102	Water Pump	1	Water	Reciprocating	16.8	1,200	0.0/12.0	1,000	1	2.3	20	S.S.	B.V.	-	Pulsation Prevention Safety Valve
0	GA201	Molten-salt Pump	1	Molten-salt	Centrifugal	2,300	30	0.0/0.3	1,831	2.6	-	340	S.S.	B.V.	-	

PLANT		TOYO ENGINEERING CORPORATION	MADE BY		DATE	
SECTION	Preheating System of Brown Coal Slurry		CHECK BY		DATE	
JOB No.		Equipment List Others	APPR. BY		DATE	

Rev	Item No.	Service Name	No. Req'd	Fluid Name	Type	Volume	Specifications	Materials	Design Conditions Temp. (℃)	Design Conditions Pressure (MPaG)	Operating Conditions Temp. (℃)	Operating Conditions Pressure (MPaG)	Code	Insula-tion	Remarks
0	BA201	Molten-salt Heating System	1	Molten-salt	-	Duty *1) 4,480,554 kcal/h		C.S.	374	0.6	340	0.3	-	-	*1) Heat loss and burner efficiency are not expecting

Table 1.4-1 Continued

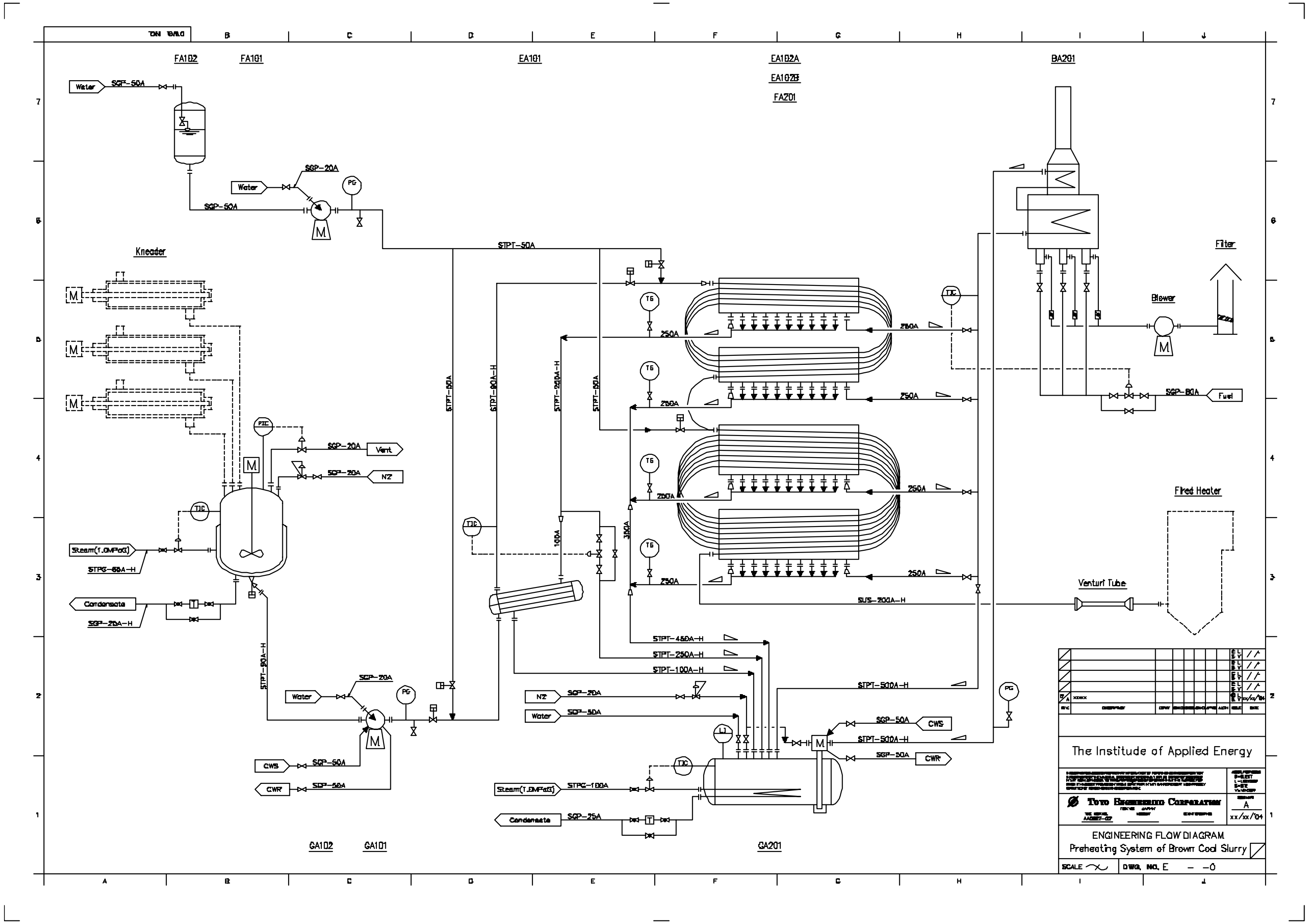


Figure 1.4-2 Engineering flow diagram

1.5 Data sheet for main equipments

	TOYO ENGINEERING CORPORATION TOKYO JAPAN					HEAT EXCHANGER SPECIFICATION SHEET					
1	CUSTOMER					REV.	DATE	MADE	CHKD.	AUTH.	LINE NO.
2	PLANT LOCATION										
3	WORK NO.	ITEM NO. EA101									
4	SERVICE OF UNIT	CASE									
5		Preheater									
6	NO. REQ'D WORKING 1	STANDBY 0	TOTAL 1								

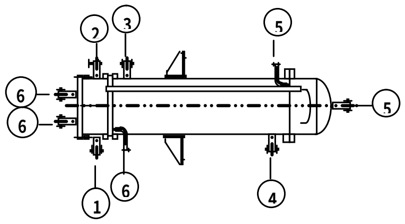
7	SIZE	TYPE V-AEU	CONNECTED IN	PARALLEL	SERIES	
8	SURF - m2	SHELLS PER UNIT	SURFACE PER SHELL	27.1	m2	

PERFORMANCE OF ONE UNIT

			SHELL SIDE		TUBE SIDE	
	FLUID ALLOCATION		SHELL SIDE		TUBE SIDE	
10	FLUID NAME		Molten-salt		CWM	
11	FLUID QUANTITY TOTAL	kg/h	107,825	x 1.0	19,948	x 1.00
12	VAPOR	kg/h	IN.	OUT.	IN.	OUT.
13	LIQUID	kg/h	107,825	107,825	19,948	19,948
14	STEAM	kg/h				
15	WATER	kg/h				
16	NON-CONDENSABLE	kg/h				
17	TEMPERATURE	`C	338	308	170	270
18	DENSITY V/L	kg/m3	/	/	/	
19	VISCOSITY V/L	mPa.s	/	/	/	
20	MOLECULAR WEIGHT-VAPORS					
21	MOLECULAR WEIGHT-NONCON.					
22	THERMAL CONDUCT. V/L	W/m.`K	/	/	/	
23	SPECIFIC HEAT V/L	KJ/kg`K	/	/	/	
24	LATENT HEAT	KJ/kg				
25	OPERATING PRESSURE	KPaG			9200	
26	VELOCITY	m/s				
27	PRESSURE DROP,ALLOW./CALC.	KPaA	50	/	100	/
28	FOULING RESISTANCE	m2.`K/W	0.00086		0.00086	
29	HEAT EXCHANGED		1,437,403 x 1.00 W		M.T.D(CORRECTED)	`C
30	TRANSFER RATE-SERVICE				CLEAN	W/m2.`K

CONSTRUCTION OF ONE SHELL — SKETCH(BUNDLE/NOZZLE ORIENTATION)

			SHELL SIDE	TUBE SIDE
31	DESIGN PRESSURE	KPaG	600 &	13200 &
32	TEST PRESSURE	KPaG		
33	DESIGN TEMPERATURE	`C	371 &	298 &
34	NO.PASSES PER SHELL			
35	CORROSION ALLOWANCE	mm	3.0	3.0
36	INSULATION		H	H
37	CONNECTIONS	IN	③100A /	①90A /
38	SIZE	OUT	④100A /	②90A /
39	/	Drain	⑤20A /	⑤20A /
40	RATING	Vent	⑥20A /	⑥20A /



41	TUBES NO. O.D mm THK	mm LENGTH 9,000 mm	PITCH mm	30 60 90 45
42	TUBES TYPE PLAIN		MATERIAL CS	
43	SHELL CS	I.D. 300 mm	SHELL COVER	
44	CHANNEL		CHANNEL COVER	
45	TUBESHEET-STATIONARY		TUBESHEET-FLOATING	
46	FLOATING HEAD COVER		IMPINGEMENT BAFFLE	YES NO
47	BAFFLES-CROSS	TYPE H.V.45'	%CUT(DIAM/AREA)	SPACING mm
48	BAFFLE-LONG	SEAL TYPE		
49	SUPPORTS-TUBE	U-BEND	TYPE	
50	BYPASS SEAL ARRANGEMENT			
51	GASKETS-SHELL	CHANNEL	FLOATING HEAD	
52	CODE REQUIREMENTS		TEMA CLASS	R B C
53	WEIGHT-EACH SHELL kg	FILLED WITH WATER kg	BUNDLE kg	
54	REMARKS			
55				
56				
57				
58				
59				

TOYO ENGINEERING CORPORATION
TOKYO JAPAN

HEAT EXCHANGER
SPECIFICATION SHEET

1	CUSTOMER				REV.	DATE	MADE	CHKD.	AUTH.	LINE NO.
2	PLANT LOCATION									
3	WORK NO.	ITEM NO. EA102A								
4	SERVICE OF UNIT	CASE								
5		Vaporizer								
6	NO. REQ'D WORKING 2	STANDBY 0	TOTAL 2							
7	SIZE	TYPE Coil	CONNECTED IN	PARALLEL	SERIES					
8	SURF -	m2 SHELLS PER UNIT	SURFACE PER SHELL *1	m2						

PERFORMANCE OF ONE UNIT

			SHELL SIDE		TUBE SIDE	
	FLUID ALLOCATION		SHELL SIDE		TUBE SIDE	
10	FLUID NAME		Molten-salt		CWM	
11	FLUID QUANTITY TOTAL	kg/h	824,116	x 1.0	19,948	x 1.00
12	VAPOR	kg/h	IN.	OUT.	IN. 0	OUT. 19,948
13	LIQUID	kg/h	824,116	824,116	19,948	
14	STEAM	kg/h				
15	WATER	kg/h				
16	NON-CONDENSABLE	kg/h				
17	TEMPERATURE	`C	340	338	280	250
18	DENSITY V/L	kg/m3	/	/	/	
19	VISCOSITY V/L	mPa.s	/	/	/	
20	MOLECULAR WEIGHT-VAPORS					
21	MOLECULAR WEIGHT-NONCON.					
22	THERMAL CONDUCT. V/L	W/m.`K	/	/	/	
23	SPECIFIC HEAT V/L	KJ/kg`K	/	/	/	
24	LATENT HEAT	KJ/kg				
25	OPERATING PRESSURE	KPaG			8800	
26	VELOCITY	m/s				
27	PRESSURE DROP,ALLOW./CALC.	KPaA	50	/	*1	/
28	FOULING RESISTANCE	m2.`K/W	0.00086		0.00086	
29	HEAT EXCHANGED	752,829 x 1.00 W	M.T.D(CORRECTED)			`C
30	TRANSFER RATE-SERVICE		CLEAN			W/m2.`K

CONSTRUCTION OF ONE SHELL

			SHELL SIDE	TUBE SIDE
31	DESIGN PRESSURE	KPaG	600 &	13200 &
32	TEST PRESSURE	KPaG		
33	DESIGN TEMPERATURE	`C	374 &	308 &
34	NO.PASSES PER SHELL			
35	CORROSION ALLOWANCE	mm	3.0	3.0
36	INSULATION		H	H
37	CONNECTIONS	IN	200A /	25A /
38	SIZE	OUT	200A /	50A /
39	/	LIQ.OUT	/	/
40	RATING	INTERMEDIATE	/	/

SKETCH(BUNDLE/NOZZLE ORIENTATION)

See Attachment

41	TUBES NO. O.D mm THK mm LENGTH *1 mm PITCH mm	30 60 90 45	
42	TUBES TYPE PLAIN	MATERIAL 304 SS	
43	SHELL CS I.D. *1 mm	SHELL COVER	
44	CHANNEL	CHANNEL COVER	
45	TUBESHEET-STATIONARY	TUBESHEET-FLOATING	
46	FLOATING HEAD COVER	IMPINGEMENT BAFFLE	YES NO
47	BAFFLES-CROSS TYPE H.V.45'	%CUT(DIAM/AREA) SPACING	mm
48	BAFFLE-LONG	SEAL TYPE	
49	SUPPORTS-TUBE	U-BEND	TYPE
50	BYPASS SEAL ARRANGEMENT		
51	GASKETS-SHELL	CHANNEL	FLOATING HEAD
52	CODE REQUIREMENTS	TEMA CLASS	R B C
53	WEIGHT-EACH SHELL kg	FILLED WITH WATER kg	BUNDLE kg
54	REMARKS		
55	*1: See Attachment		
56			
57			
58			
59			

TOYO ENGINEERING CORPORATION TOKYO JAPAN	HEAT EXCHANGER SPECIFICATION SHEET					
1 CUSTOMER	REV.	DATE	MADE	CHKD.	AUTH.	LINE NO.
2 PLANT LOCATION						
3 WORK NO. ITEM NO. EA102B						
4 SERVICE OF UNIT CASE						
5 Vaporizer						
6 NO. REQ'D WORKING 2 STANDBY 0 TOTAL 2						

7	SIZE	TYPE Coil	CONNECTED IN	PARALLEL SERIES
8	SURF - m2	SHELLS PER UNIT	SURFACE PER SHELL *1	m2

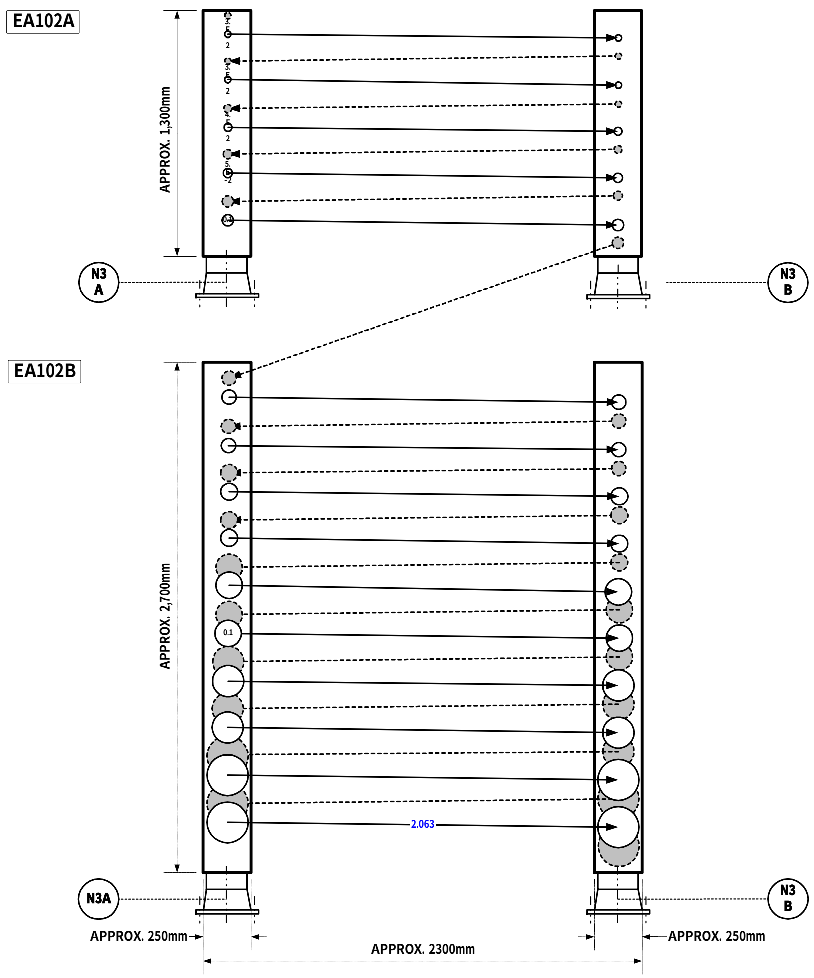
PERFORMANCE OF ONE UNIT

	FLUID ALLOCATION		SHELL SIDE		TUBE SIDE	
10	FLUID NAME		Molten-salt		CWM	
11	FLUID QUANTITY TOTAL	kg/h	824,116	x 1.0	19,948	x 1.00
12	VAPOR	kg/h	IN.	OUT.	IN. 5442	OUT. 19,948
13	LIQUID	kg/h	824,116	824,116	14,506	
14	STEAM	kg/h				
15	WATER	kg/h				
16	NON-CONDENSABLE	kg/h				
17	TEMPERATURE	`C	340	331	250	200
18	DENSITY V/L	kg/m3	/	/	/	
19	VISCOSITY V/L	mPa.s	/	/	/	
20	MOLECULAR WEIGHT-VAPORS					
21	MOLECULAR WEIGHT-NONCON.					
22	THERMAL CONDUCT. V/L	W/m.`K	/	/	/	
23	SPECIFIC HEAT V/L	KJ/kg`K	/	/	/	
24	LATENT HEAT	KJ/kg				
25	OPERATING PRESSURE	KPaG			4000	
26	VELOCITY	m/s				
27	PRESSURE DROP,ALLOW./CALC.	KPaA	50	/	*1	/
28	FOULING RESISTANCE	m2.`K/W	0.00086		0.00086	
29	HEAT EXCHANGED		3,019,715 x 1.00 W		M.T.D(CORRECTED)	`C
30	TRANSFER RATE-SERVICE				CLEAN	W/m2.`K

CONSTRUCTION OF ONE SHELL — **SKETCH(BUNDLE/NOZZLE ORIENTATION)**: See Attachment

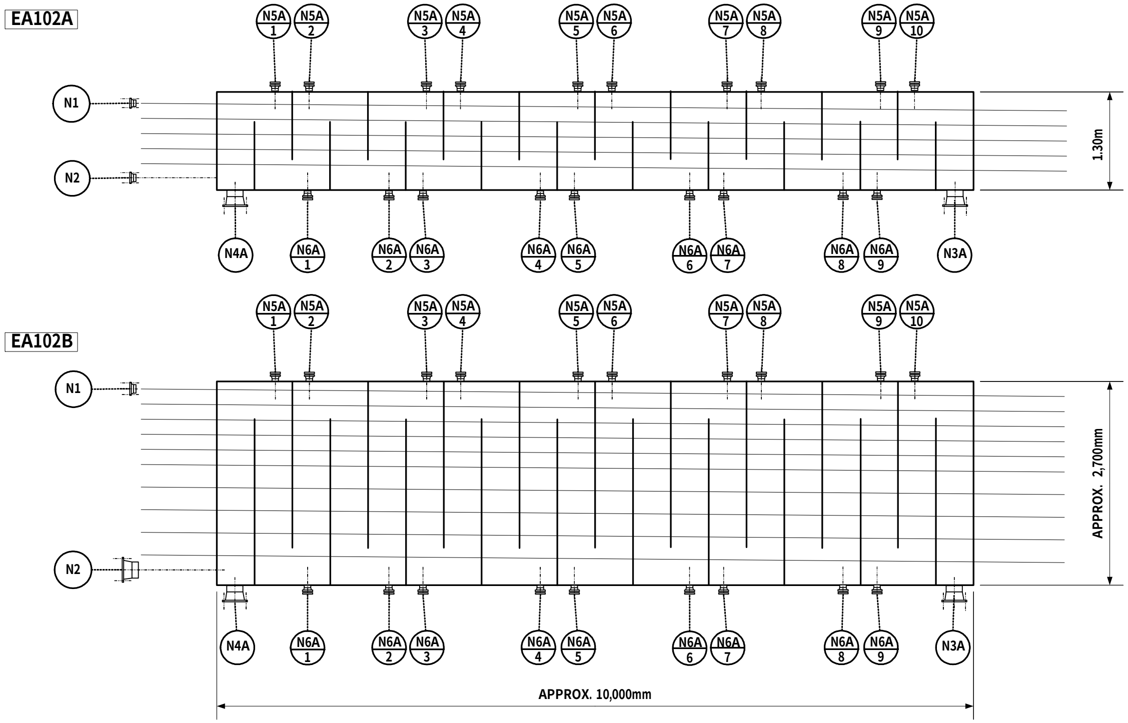
				SHELL SIDE	TUBE SIDE
31	DESIGN PRESSURE		KPaG	600 &	13200 &
32	TEST PRESSURE		KPaG		
33	DESIGN TEMPERATURE		`C	374 &	278 &
34	NO.PASSES PER SHELL				
35	CORROSION ALLOWANCE		mm	3.0	3.0
36	INSULATION			H	H
37	CONNECTIONS	IN		200A /	65A /
38	SIZE	OUT		200A /	200A /
39	/	LIQ.OUT		/	/
40	RATING	INTERMEDIATE		/	/

41	TUBES NO. O.D mm THK mm LENGTH *1 mm PITCH mm 30 60 90 45	
42	TUBES TYPE PLAIN	MATERIAL 304 SS
43	SHELL CS I.D. *1 mm	SHELL COVER
44	CHANNEL	CHANNEL COVER
45	TUBESHEET-STATIONARY	TUBESHEET-FLOATING
46	FLOATING HEAD COVER	IMPINGEMENT BAFFLE ◎ YES ◎ NO
47	BAFFLES-CROSS TYPE H.V.45'	%CUT(DIAM/AREA) SPACING mm
48	BAFFLE-LONG SEAL TYPE	
49	SUPPORTS-TUBE U-BEND	TYPE
50	BYPASS SEAL ARRANGEMENT	
51	GASKETS-SHELL CHANNEL	FLOATING HEAD
52	CODE REQUIREMENTS	TEMA CLASS ◎ R ◎ B ● C
53	WEIGHT-EACH SHELL kg FILLED WITH WATER	kg BUNDLE kg
54	REMARKS	
55	*1: See Attachment	
56		
57		
58		
59		



	Mark	Q'ty	Size (A)	Service	Coil	Coil Conditions
E102A					E102A	E102A
	3A	1	200	Salt Inlet	Piping(Sch80) Size (A) / Length (m) 25 / 40 32 / 20 40 / 20 50 / 20	Operating Press. 8.8 MPaG Temp. 280 °C Design Press. 13.2 MPaG Temp. 308 °C
	3B	1	200	Salt Inlet		
E102B					E102B	E102B
	3A	1	200	Salt Inlet	Piping(Sch80) Size (A) / Length (m) 65 / 40 90 / 40 125 / 40 150 / 40 200 / 40	Operating Press. 4.0 MPaG Temp. 250 °C Design Press. 13.2 MPaG Temp. 278 °C
	3B	1	200	Salt Inlet		

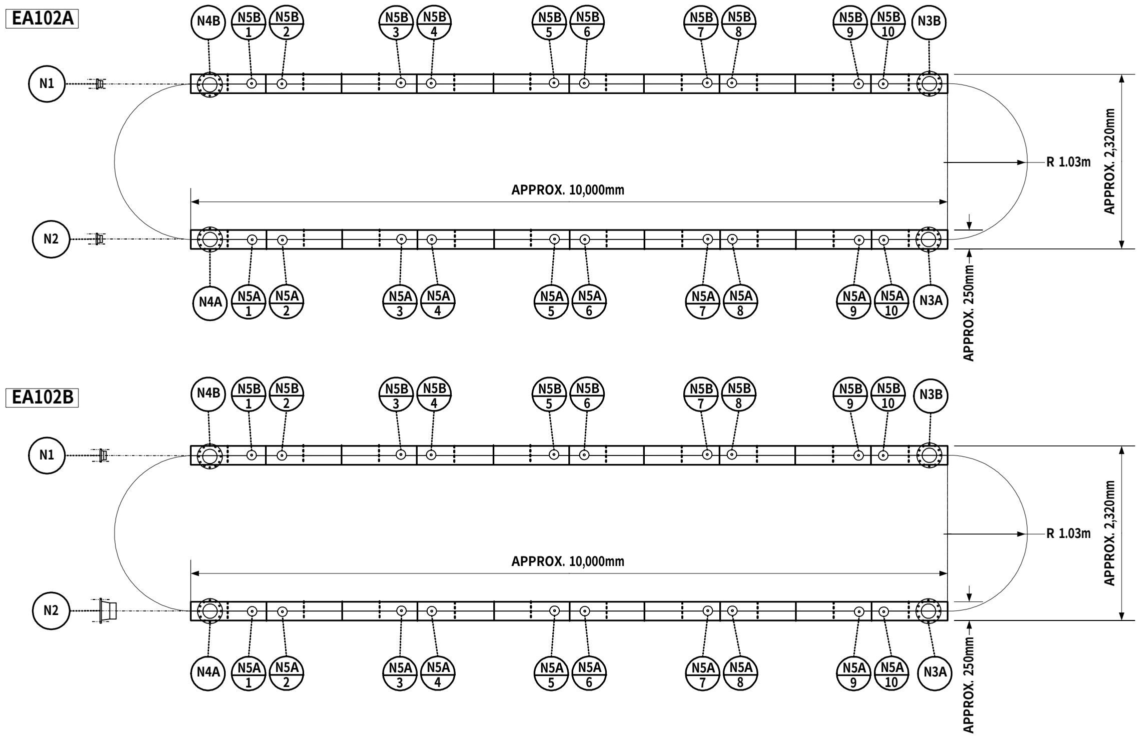
VAPORIZER EA102A／B	Preheating System of Brown Coal Slurry
	TOYO ENGINEERING CORPORATION TOKYO JAPAN
	Size: / FSCM Number: / Drawing Number: / Rev.:
	Scale 1 : 20 / Sheet 1 / 3



Coil	Coil Conditions
E102A	E102A
Piping(Sch80) Size (A) / Length (m) 25 / 40 32 / 20 40 / 20 50 / 20	Operating Press. 8.8 MPaG Temp. 280 °C Design Press. 13.2 MPaG Temp. 308 °C
E102B	E102B
Piping(Sch80) Size (A) / Length (m) 65 / 40 90 / 40 125 / 40 150 / 40 200 / 40	Operating Press. 4.0 MPaG Temp. 250 °C Design Press. 13.2 MPaG Temp. 278 °C

	Mark	Q'ty	Size (A)	Service
E102A				
	1	1	25	CWM Inlet
	2	1	50	CWM Outlet
	3A	1	200	Salt Inlet
	4A	1	200	Salt Outlet
	5A	10	25	Vent
	6A	9	25	Drain
E102B				
	1	1	65	CWM Inlet
	2	1	200	CWM Outlet
	3A	1	200	Salt Inlet
	4A	1	200	Salt Outlet
	5A	10	25	Vent
	6A	9	25	Drain

VAPORIZER EA102A／B	Preheating System of Brown Coal Slurry			
	TOYO ENGINEERING CORPORATION TOKYO JAPAN			
	Size	FSCM Number	Drawing Number	Rev.
	Scale 1 : 50		Sheet 2 / 3	



Coil	Coil Conditions
E102A	E102A
Piping(Sch80) Size (A) Length (m) 25 40 32 20 40 20 50 20	Operating Press. 8.8 MPaG Temp. 280 °C Design Press. 13.2 MPaG Temp. 308 °C
E102B	E102B
Piping(Sch80) Size (A) Length (m) 65 40 90 40 125 40 150 40 200 40	Operating Press. 4.0 MPaG Temp. 250 °C Design Press. 13.2 MPaG Temp. 278 °C

Mark	Q'ty	Size (A)	Service
E102A			
N1	1	25	CWM Inlet
N2	1	50	CWM Outlet
N3A	1	200	Salt Inlet
N3B	1	200	Salt Inlet
N4A	1	200	Salt Outlet
N4B	1	200	Salt Outlet
N5A	10	25	Vent
N5B	10	25	Vent
E102B			
N1	1	65	CWM Inlet
N2	1	200	CWM Outlet
N3A	1	200	Salt Inlet
N3B	1	200	Salt Inlet
N4A	1	200	Salt Outlet
N4B	1	200	Salt Outlet
N5A	10	25	Vent
N5B	10	25	Vent

VAPORIZER EA102A／B	Preheating System of Brown Coal Slurry TOYO ENGINEERING CORPORATION TOKYO JAPAN
	Size · FSCM Number · Drawing Number · Rev.
	Scale 1 : 50 · Sheet 3 / 3

1.6 Utilities and cost of equipment

Service Name		Industrial Water (t/h)	10k Steam (t/h)	Cooling Water (t/h)	Nitrogen (Nm^3/h)	Electricity (kWh)	Fuel (MMkcal/h)
FA101	CWS tank	—	0.09	—	Gas replacement	—	—
FA102	Water tank	0.84*	—	—	—	—	—
FA201	Molten salt tank	Molten salt adjustment	Shut down	—	Gas replacement	—	—
GA101	CWS pump	0.84	—	0.17	—	106	—
GA102	Water pump	0.84*	—	—	—	106*	—
GA201	Molten salt pump	—	—	0.17	Sealing	206	—
BA201	Molten salt heater	—	—	—	—	61	4.8

Consumption pre hour	Industrial Water (t/h)	10k Steam (t/h)	Cooling Water (t/h)	Nitrogen (Nm^3/h)	Electricity (kWh)	Fuel (MMkcal/h)
Total	0.84	0.09	0.34	Null	373	4.8

Consumption per year (8000 hours per year)	Industrial Water (t/y)	10k Steam (t/y)	Cooling Water (t/y)	Nitrogen (Nm^3/y)	Electricity (kWh)	Fuel (MMkcal/y)
Total	6,720	720	2,720	Null	2,984,000	38,400

* Start up

Cost of equipment	9,375,000 AUS$

2 Comparison of cost and technology for Loy Yang power and CWS system

Technologies for CWS production process and CWS in-line vaporizer have been developed and confirmed. In this section, we compared technology and cost of electricity for conventional Loy Yang power and CWS system (CWS kneader and CWS preheater).

2.1 Crushing and drying

Loy Yang

Wet brown coal is dried with hot flue gas (1010ºC) taken from boiler combustion chamber, and then converted to fine particles in primary beater and mill. Moisture of the coal decreases from 67 to 33%.

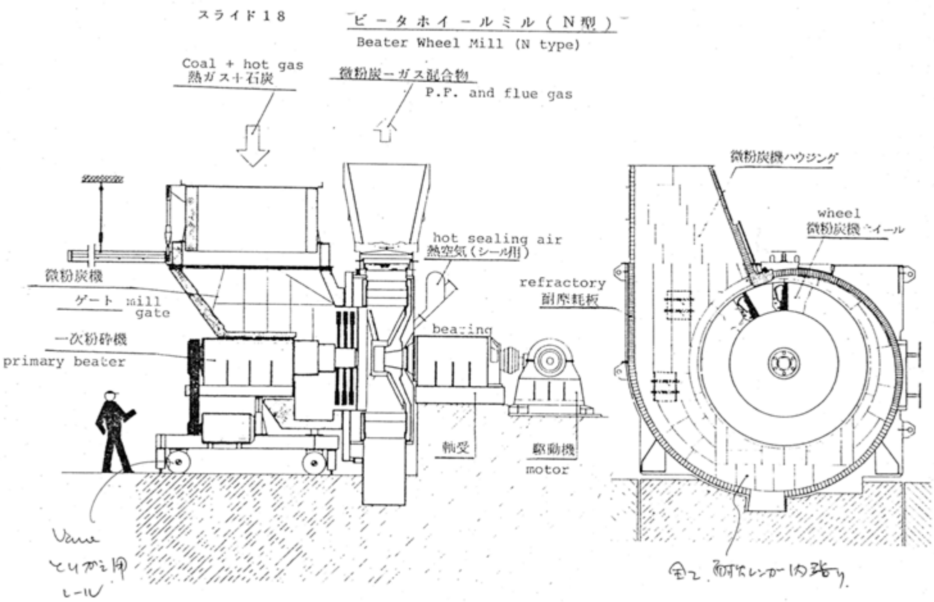


Figure 2.1-1 Wheel Mill

CWS system

Wet brown coal introduced into CWS kneader is converted to CWS with shear stress of 1.0 MPa and temperature of 175ºC. In this process, about 37% of moisture is removed from the coal. CWS is converted to dried coal and steam with CWS preheater.

2.2 Steam classifier

Loy Yang

Coal/steam mixture exhausted from wheel mill is introduced into the steam classifier. Data from Yallourn power said that 80% of coal is contained in high concentrated coal/steam mixture and 20% of coal is in the low concentrated mixture.

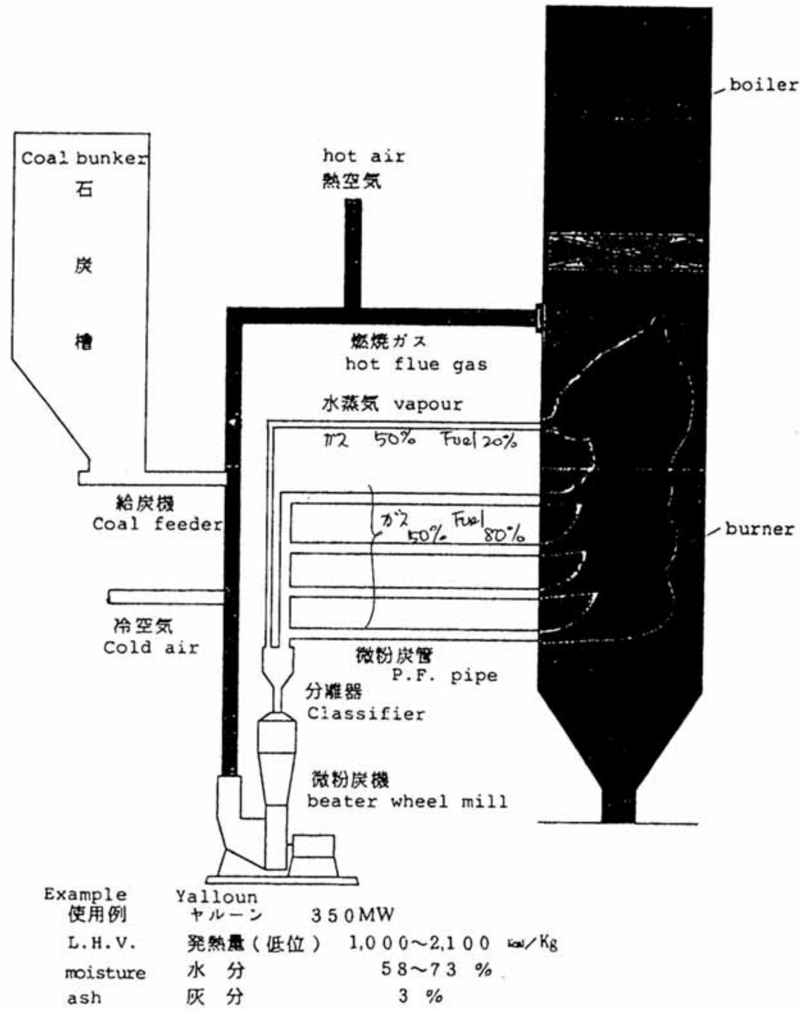


Figure 2.2-1 Simple overview of powdered coal boiler

CWS system

Classification is not needed since coal in CWS is concentrated during CWS production process.

2.3 Comparison of ability

2.3.1 Processing ability of CWS system

Prerequisite is that one CWS production kneader having processing ability of 144 ton/d-raw coal. Mass balance for one kneader is following.

Raw coal: 6.0 t/h Moisture: 59%	→	CWS kneader 175ºC, 0.9 MPa	→	65wt%CWS 3.8 ton/h
		↓		
		Recovered water: 2.2 t/h		

Figure 2.3-1 Mass balance for one kneader

CWS production ratio is 3.8 / 6.0 = 63.3%.

2.3.2 Characteristics of CWS

Characteristics of CWS are listed in Table 2.3-1. Heating value is calculated from that of dried Loy Yang (LY) coal of 6380 kcal/kg. 4147 kcal/kg of heating value for CWS is used for consumption of LY coal.

Table 2.3-1 Characteristics of CWS

Coal concentration (wt%)	65.0
Viscosity (cp@25℃)	600
Ash content (%/coal)	0.46
Sulfur (%/coal)	0.17
Heating value (kcal/kg-CWM)	4,147

2.3.3 Production of electricity

Theoretical value of production of electricity for Loy Yang power is calculated from consumption of LY coal in Loy Yang power (public report). The value for CWS system is calculated with same consumption of LY coal. From Table 2.3-2, CWS system increases the theoretical electricity by 10%.

Table 2.3-2 Production of electricity

Year		2000 (Loy Yang)	CWS system	2001 (Loy Yang)	CWS system
Consumption of brown coal	ton	20,577,000	—	19,151,858	—
Consumption of CWS	ton	—	13,032,100	—	12,129,510
Heating value	kcal/kg	2,374	4,147	2,383	4,147
Amount of heat (theoretical)	GJ	204,537,545	226,271,818	191,064,921	210,600,463
Production of electricity (theoretical)	GWh	56,816	62,853	53,074	58,500

2.3.4 Power generation efficiency for CWS system

Conventional steam-power generation has following heat balance

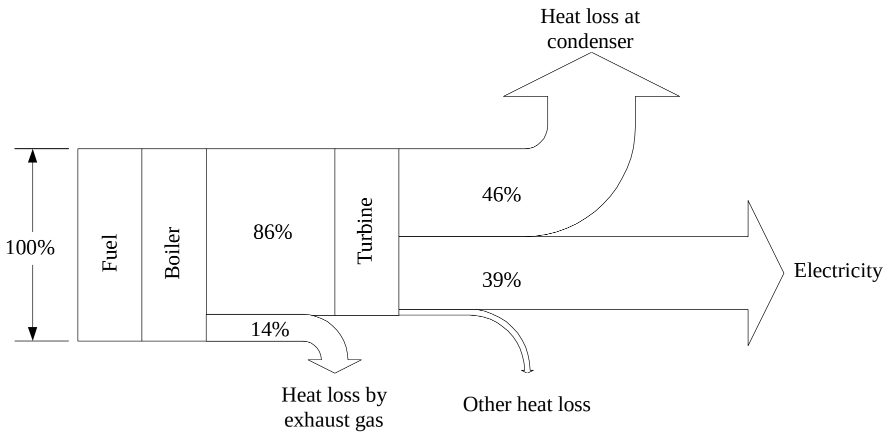


Figure 2.3-2 Heat balance for conventional steam-power generation

Power generation efficiency for Loy Yang power is about 30% calculated from consumption of brown coal and production of electricity. This low efficiency comes from drying brown coal by hot flue gas (1010ºC). Energy consumption used for drying brown coal is calculated from latent heat of water evaporation as 440 kcal/kg. Brown coal has heating value of 2374 kcal/kg 18.5% of which is used for drying brown coal. Fig. 2.3-3 shows heat balance for Loy Yang power.

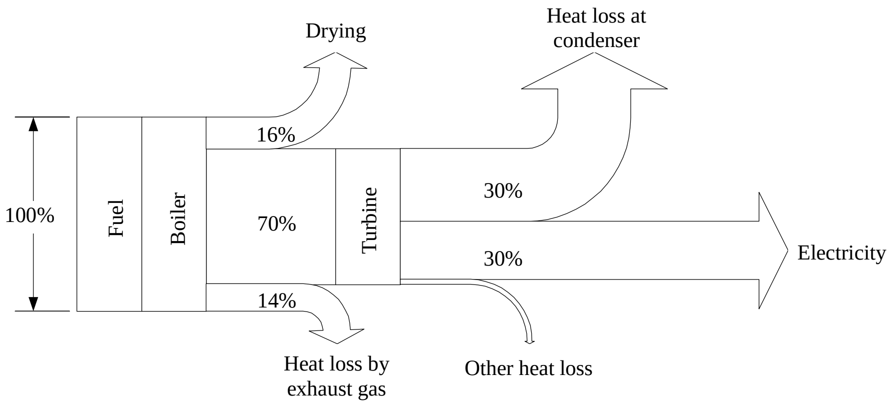


Figure 2.3-3 Heat balance for Loy Yang power

Power generation efficiency for CWS system is considered as 39% since it has drying system before coal injection to boiler. Production of electricity is estimated from the efficiency and data in Table 2.3-2.

Table 2.3-3 Production of electricity for Loy Yang power and CWS system

		Loy Yang 2000 year	CWS system	Loy Yang 2001 year	CWS system
Production of electricity (theoretical)	GWh	56,816	62,853	53,074	58,500
Production of electricity	GWh	16,945	24,513	16,317	22,815

CWS system can generate more electricity than Loy Yang power by 40%.

2.3.5 Scale-up of CWS system

We calculated consumption of LY coal for CWS system. Production of electricity for CWS system is conformed to that for Loy Yang power. Number of kneaders is calculated from the consumption of LY coal and the processing ability of CWS kneader.

Table 2.3-4 Number of CWS kneaders

	2000 year	2001 year
Consumption of brown coal for CWS system (t/year)	14,308,077	13,365,623
Consumption of brown coal for CWS system (t/h)	1,670	1,587
Number of CWS kneader	279	265

Number of the kneaders for one power unit is 70 since Loy Yang power has 4 power units having 500 MW of production of electricity. 8 units of CWS kneaders are needed for one burner assuming 500 MW boiler has 8 burners. Followings are assumptions for CWS in-line vaporizer and molten salt system;

a. Vaporizer

Number of CWS tank is 8 for overall power generation plant (2 for 500 MW boiler). The tank is shared for 35 units of CWS kneaders. One CWS pump and one vaporizer is settled for one burner. One backup CWS pump is settled for one CWS tank.

b. Molten salt system

Numbers of molten salt tanks and of molten salt heaters are 8 for overall power generation plant. 4 vaporizers are in one molten salt system.

c. Water start-up system

One sequence of water start-up system is settled for 4 CWS pumps.

Figure 2.3-4 shows schematic diagram for CWS system combined with boiler

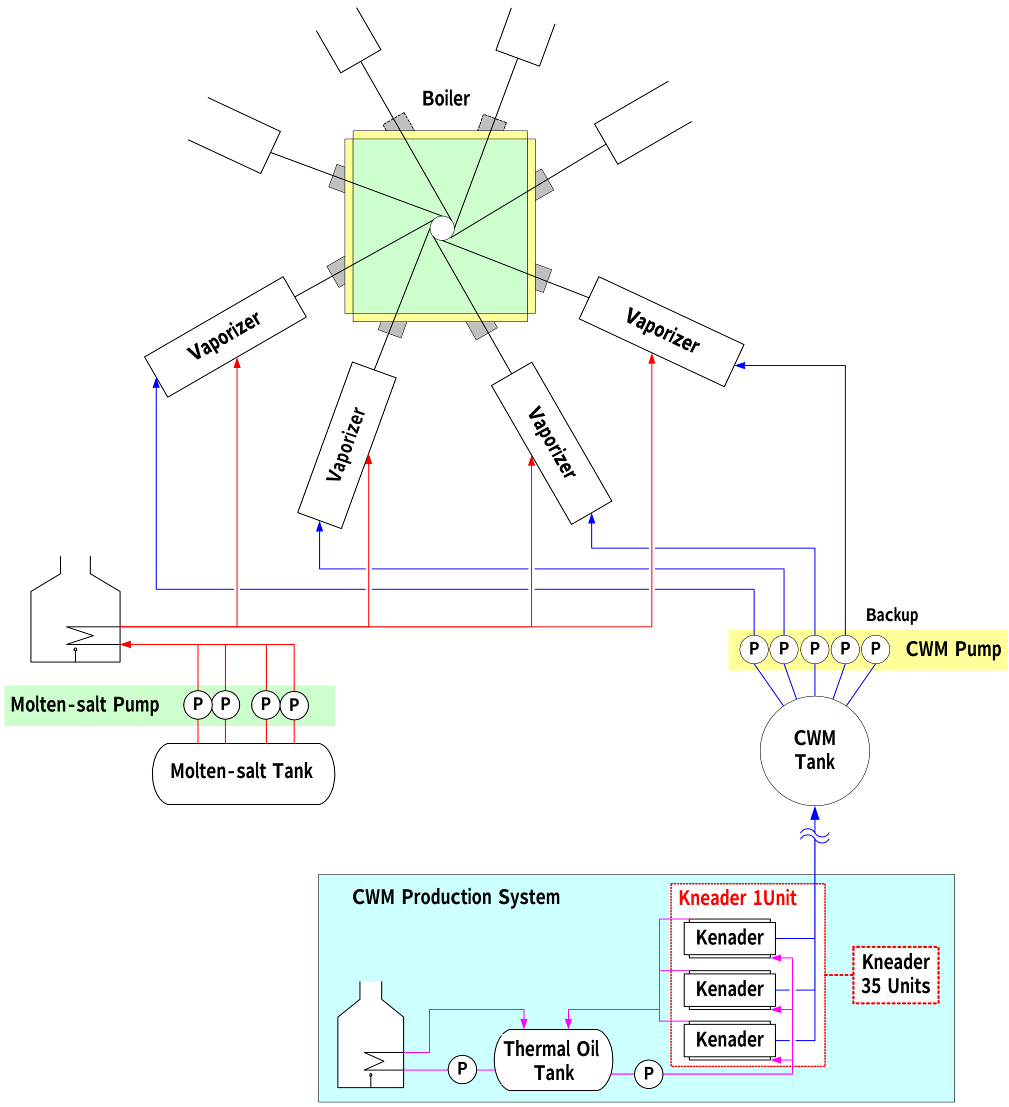


Figure 2.3-4 Schematic diagram for CWS system combined with boiler

2.4 Variable cost

2.4.1 Annual cost for CWS system

Annual cost for CWS system is calculated from annual costs for CWS production process and that for in-line vaporizer.

Construction cost for CWS production process is 46 billion yen (575 million AUS$) for 280 units of CWS kneaders. Construction cost for preheating system is 50 billion yen (625 million AUS$).

Condition of estimation

Lifetime is 25 years.

Employment cost for temporary employee is decided as 87,500 AUS$ from following table.

Table 2.4-1 Average employment cost for Loy Yang power

	2001 year	2002 year
Total personnel cost	56,900,000 AUS$	56,600,000 AUS$
Employees	535	532
Average personnel cost	106,355 AUS$	106,390 AUS$

Manpower for preheating system is diverted from that for CWS production system.

Electricity used for preheater is diverted from that produced by the power plant.

Table 2.4-2 Annual costs for CWS system

			CWM Production System			Preheating System		
Construction Cost			4,600,000 x10^4 yen			5,000,000 x10^4 yen		
	Item	Unit Cost	Budget		Annual Cost x10^4 yen	Budget		Annual Cost x10^4 yen
			Hourly	Per Annum		Hourly	Per Annum	
Variable Cost	1 Utility							
	Industrial Water	13.75 円/ton				215 ton	1,720,320 ton	2,365
	Fuel	200 円/10^6kcal	264.0 x10^6 kcal	2,112,000 x10^6 kcal	42,240	1,216 x10^6 kcal	9,728,000 x10^6 kcal	194,560
	Cooling Water	5 円/ton				46 ton	371,667 ton	186
	Steam	3000 円/ton				23 ton	184,320 ton	55,296
	2 Chemicals	30,000 円/ton	0.08 ton	640 ton	1,920			
	3 Electric Power	0.00 円/kW				47,401 kW・h	379,205,349 kW・h	0
	Total Variable Cost				44,160			252,407
Constant Cost	1 Manpower Cost	7,000 x10^3yen/p・y		150 people	105,000			
	2 Capital Charge							
	Depreciation	6.16%	Construction Cost	4,600,000 x10^4 yen	283,410	Construction Cost	5,000,000 x10^4 yen	308,054
	Interest	4.0%						
	Repair Cost	3.0%	Construction Cost	4,600,000 x10^4 yen	138,000	Construction Cost	5,000,000 x10^4 yen	150,000
	Insurance	0.77%	Book Cost	2,530,000 x10^4 yen	19,481	Book Cost	2,750,000 x10^4 yen	21,175
	Property Tax	1.4%	Book Cost	2,530,000 x10^4 yen	35,420	Book Cost	2,750,000 x10^4 yen	38,500
	3 Administrative expense	20.0%	Labor Cost	105,000 x10^4 yen	21,000			
	Total Constant Cost				602,311			517,729
Total Annual Cost					646,471			770,136

CWS production system = 6.46 billion yen/year (80.7 million AUS$/year)

Preheating system = 7.70 billion yen/year (96.4 million AUS$/year)

Total annual costs for CWS system is 14.16 billion yen/year (177.0 million AUS$/year)

2.4.2 Comparison of variable costs

Condition of estimation

Data for 2000 year are used.

Unit cost of LY coal is 2.5 AUS$/ton.

Unit cost of electricity is 33.6 AUS$/MWh.

Electrical consumption for Loy Yang is calculated from 1380kW of motor for pulverizing mill.

Table 2.4-3 Comparison of variable costs (cost of brown coal is 2.5 AUS$/ton)

Item	Unit Cost		Loy Yang		CWM Preheating System	
			Consumption	Budget	Consumption	Budget
Brown Coal（t）	**200**	yen/ton	20,577,000	411,540	14,308,077	286,162
Industrial Water（t）	13.75	yen/ton	—	—	1,720,320	2,365
Fuel（MMkcal）	200	yen/MMkcal	—	—	11,840,000	236,800
Cooling Water（t）	5	yen/ton	—	—	371,667	186
Steam（t）	3,000	yen/ton	—	—	184,320	55,296
Chemicals（t）	30,000	yen/ton	—	—	640	1,920
Sub Total（x10^{4}yen）			**411,540**		**582,729**	
Electric Power(MWh)	2,688	yen/MW	49,067	13,189	379,205	101,930
Total（x10^{4}yen）			**424,729**		**684,659**	
Total（AUS$）			**53,091,125**		**85,582,375**	

In the above table, cost of LY coal is expense price. Variable cost is calculated with sales price of LY coal and shown in Table 2.4-4.

Table 2.4-4 Comparison of variable costs (cost of brown coal is 5.3 AUS$/ton)

Item	Unit Cost		Loy Yang		CWM Preheating System	
			Consumption	Budget	Consumption	Budget
Brown Coal (t)	**424**	yen/ton	20,577,000	872,465	14,308,077	606,662
Industrial Water (t)	13.75	yen/ton	—	—	1,720,320	2,365
Fuel (MMkcal)	200	yen/MMkcal	—	—	11,840,000	236,800
Cooling Water (t)	5	yen/ton	—	—	371,667	186
Steam (t)	3000	yen/ton	—	—	184,320	55,296
Chemicals (t)	30,000	yen/ton	—	—	640	1,920
Sub Total (x10^{4}yen)				**872,465**		**903,230**
Electric Power(MWh)	2,688	yen/MW	49,067	13,189	379,205	101,930
Total (x10^{4}yen)				**885,654**		**1,005,160**
Total (AUS$)				**110,706,750**		**125,645,000**

In the above table, variable cost except electricity for CWS system is close to that for Loy Yang power.

Tables 2.4-5 and 2.4-6 are effect of cost of LY coal on the total variable cost.

Table 2.4-5 Comparison of variable costs (case 1)

Item	Unit Cost		Loy Yang		CWM Preheating System	
			Consumption	Budget	Consumption	Budget
Brown Coal (t)	**473**	yen/ton	20,577,000	973,448	14,308,077	676,881
Industrial Water (t)	13.75	yen/ton	—	—	1,720,320	2,365
Fuel (MMkcal)	200	yen/MMkcal	—	—	11,840,000	236,800
Cooling Water (t)	5	yen/ton	—	—	371,667	186
Steam (t)	3000	yen/ton	—	—	184,320	55,296
Chemicals (t)	30,000	yen/ton	—	—	640	1,920
Sub Total (x10^{4}yen)				**973,448**		**973,448**
Electric Power(MWh)	2,688	yen/MW	49,067	13,189	379,205	101,930
Total (x10^{4}yen)				**986,638**		**1,075,378**
Total (AUS$)				**123,329,750**		**134,422,250**

Table 2.4-6 Comparison of variable costs (case 2)

Item	Unit Cost		Loy Yang		CWM Preheating System	
			Consumption	Budget	Consumption	Budget
Brown Coal（t）	**615**	yen/ton	20,577,000	1,264,730	14,308,077	879,422
Industrial Water（t）	13.75	yen/ton	—	—	1,720,320	2,365
Fuel（MMkcal）	200	yen/MMkcal	—	—	11,840,000	236,800
Cooling Water（t）	5	yen/ton	—	—	371,667	186
Steam（t）	3000	yen/ton	—	—	184,320	55,296
Chemicals（t）	30,000	yen/ton	—	—	640	1,920
Sub Total（x10^{4}yen）				**1,264,730**		**1,175,989**
Electric Power(MWh)	2,688	yen/MW	49,067	13,189	379,205	101,930
Total（x10^{4}yen）				**1,277,919**		**1,277,919**
Total（AUS$）				**159,739,875**		**159,739,875**

Variable costs except electricity for both systems are same in the case 1 (cost of coal is 473 yen/ton = 5.9 AUS$/ton). Total variable costs for both systems are same in the case 2 (cost of coal is 615 yen/ton = 7.7 AUS$/ton).

2.5 Ash disposal cost

2.5.1 Ash disposal cost for Loy Yang power

According to Loy Yang power Public Report 2000, amount of ash was 213,973 m^3 (13 m^3/GWh). It is reported that costs for power station precipitators and ash disposal are 1,333,563 AUS$ and 1,145,103 AUS$, respectively. Ash disposal cost for unit volume of ash is 11.6 AUS$/$m^3$.

2.5.2 Advantage of CWS system

CWS system can reduce consumption of brown coal by 30.5%. The system can save 756,000 AUS$/year of cost of ash disposal

Table 2.5-1 Variable costs including ash disposal cost

Item	Loy Yang Budget（x10^4yen）	CWM Preheating System Budget（x10^4yen）
Variable Cost（Brown Coal=2.5AUS$/t）	424,729	684,659
Ash Treatment	19,829	13,781
Total	**444,558**	**698,440**
Total (AUS$)	**55,569,750**	**87,305,000**
Variable Cost（Brown Coal=5.3AUS$/t）	885,654	1,005,160
Ash Treatment	19,829	13,781
Total	**905,483**	**1,018,941**
Total (AUS$)	**113,185,375**	**127,367,625**

2.6. Estimation of emission of carbon dioxide

CWS system can reduce consumption of brown coal by 30.5%. This section evaluates effect of the reduction of coal consumption on the emission of carbon dioxide.

2.6.1 Cost of reduction of CO_2

According to Loy Yang power Public Report 2000, amount of emission of carbon dioxide is following.

Table 2.6-1 CO_2 Gas Emissions for Loy Yang power

Fuel	CO_2 Gas Emissions（t）	CO_2 Gas Emissions（t/GWh）	CO_2 Gas Emissions（kg/MMkcal）
Brown Coal	19,143,975	1,225	390
Gas	1,995	0.1	246

For CWS system, amount of reduction of CO_2 is 5,838,912 ton. CO_2 generation from CWS vaporizer is calculated as following.

Fuel consumption (MMkcal) :	10,530,041
CO_2 Gas Emissions (t) :	2,590,390
↓	
Reduction of CO_2 Gas Emissions (t) :	3,248,522

Construction cost of CWS system is 91 billion yen (1137.5 million AUS$). Cost needed for reduction of CO_2 is 1137.5 million AUS$/3.248 million ton = 350 AUS$/ton-$CO_2$.

Emissions trading are estimated from variable cost including ash disposal (Table 2.5-1) and constant cost (Table 2.4-2), and are listed in Table 2.6-2. Constant cost for Loy Yang power is calculated from cost of pulverizing mill.

Table 2.6-2　Emissions trading and variable cost

Item	Loy Yang Budget（x10^4yen）	CWM Preheating System Budget（x10^4yen）
Variable Cost（Brown Coal=2.5AUS$/t）	444,558	698,440
Constant Cost（x10^4yen）	101,970	1,120,039
CO_2 Gas Emissions（t）	—	3,248,522
Trading Value（yen/t）	—	3,951
Trading Value（AUS$/t）		**49.4**
Environmental Interst（x10^4yen）	—	-1,271,952
Total	546,528	546,528
Variable Cost（Brown Coal=5.3AUS$/t）	905,483	1,018,941
Constant Cost（x10^4yen）	101,970	1,120,039
CO_2 Gas Emissions（t）	—	3,248,522
Trading Value（yen/t）	—	3,483
Trading Value（AUS$/t）		**43.5**
Environmental Interst（x10^4yen）	—	-1,131,528
Total	1,007,453	1,007,453

2.7 Heat recovery system

In this section, introduction of heat pump into CWS production process is evaluated.

2.7.1 Heat pump system

Flow diagram of CWS production process is shown in Fig. 2.7-2. Heating medium is used for heat source and the medium is heated with furnace. Steam exhausted from kneader is compressed to 2.45 MPa-G and is converted into superheated steam of 333ºC. Heating medium is heated by the steam from 220 to 247ºC. The medium is further heated to 260ºC with furnace.

Heat balance for 64 units of CWS kneaders is shown in the following figure.

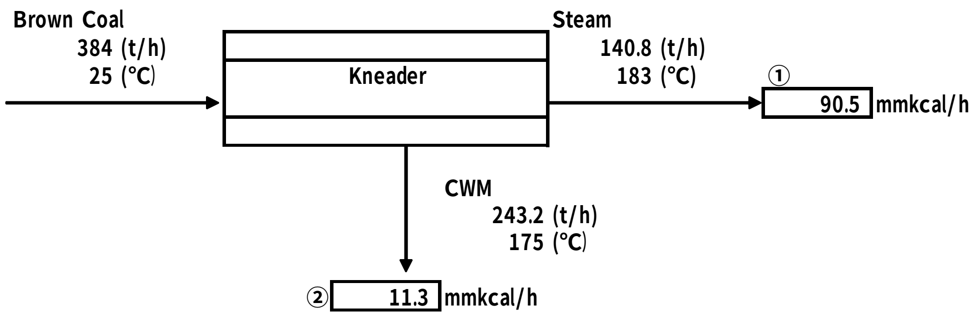
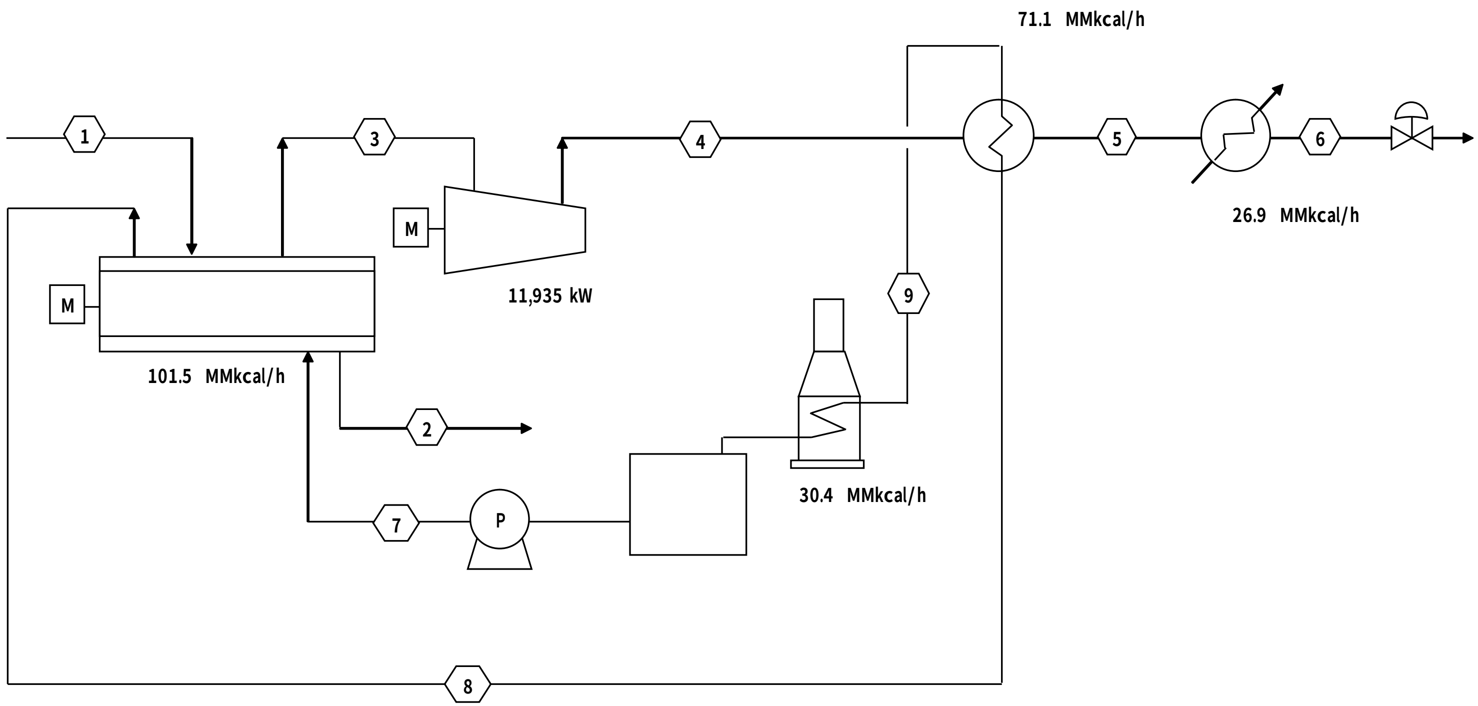


Figure 2.7-1 Heat balance



		1 Brown Coal	2 CWM	3 Steam	4 Superheated Steam	5 Saturated Water	6 Waste Water	7 Heat Medium	8 Heat Medium	9 Heat Medium
Fluid Flow	t/h	384	243	140.8	140.8	140.8	140.8	5073.9	5073.9	5073.9
Pressure	kg/cm2G	0	10	10	26	26	0			
Tempreture	°C	25	175	183	333	225	40	260	220	247

CUSTOMER	TOYO ENGINEERING CORPORATION					
LOCATION -						
PLANT **Heat Pump System**	TOKYO JAPAN					
	PROCESS FLOW SHEET					
DWG. NO.		Rev	DATE	MADE	CHKD	AUTH. DESCRIPTION

Figure 2.7-2 Flow diagram of heat pump system

2.7.2 *Cost merit for heat pump system*

Table 2.7-1 Cost for heat pump system

			Heat Pump System		
Construction Cost			210,000 x10^4 yen		
	Item	Unit Cost	Budget		Annual Cost x10^4 yen
			Hourly	Per Annum	
Variable Cost	1 Utility				
	Industrial Water	13.75 円/ton			
	Fuel	200 円/10^6kcal	-356 x10^6 kcal	-2,844,336 x10^6 kcal	-56,887
	Cooling Water	5 円/ton			
	Steam	3000 円/ton			
	2 Chemicals	30,000 円/ton			
	3 Electric Power	0.00 円/kW	47,738 kW・h	381,905,365 kW・h	0
	Total Variable Cost				-56,887
Constant Cost	1 Manpower Cost	7,000 x10^3yen/p・y			
	2 Capital Charge				
	Depreciation	6.16%	Construction Cost	210,000 x10^4 yen	12,938
	Interest	4.0%			
	Repair Cost	3.0%	Construction Cost	210,000 x10^4 yen	6,300
	Insurance	0.77%	Book Cost	115,500 x10^4 yen	889
	Property Tax	1.4%	Book Cost	115,500 x10^4 yen	1,617
	3 Administrative expense	20.0%			
	Total Constant Cost				21,745
Total Annual Cost					-35,142

2.8 Construction cost of power plant and cost of electricity

In this section, cost of electricity is calculated assuming construction of new power plant. Estimated results are shown in Tables 2.8-1 and 2.8-2. In case 1, costs of electricity for Loy Yang power and CWS system are same with changing environmental interest. In case 2, environmental interest is fixed at 5000 yen/t-CO_2 (62.5 AUS$/t-$CO_2$).

Table 2.8-1 Cost of electricity (case 1)

			Brown Coal Thermal Power Generation(Loy Yang)			Brown Coal Slurry Thermal Power Gneration		
Construction Cost			30,000,000 x10^4 yen			39,900,000 x10^4 yen		
	Item	Unit Cost	Budget		Annual Cost	Budget		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Variable Cost	1 Brown Coal(Wet Base)	400 yen/ton	2,415 ton	19,321,675 ton	772,867	1,679 ton	13,435,196 ton	537,408
	2 Utility							
	Industrial Water	13.75 yen/ton				215 ton	1,720,320 ton	2,365
	Fuel	200 yen/10^6kcal				1,295 x10^6 kcal	10,361,600 x10^6 kcal	207,232
	Cooling Water	5 yen/ton				46 ton	371,667 ton	186
	Steam	3000 yen/ton				23 ton	184,320 ton	55,296
	3 Chemicals	30,000 yen/ton				0.08 ton	640 ton	1,920
	4 Electric Power	0.00 yen/kW	200,000 kW･h	1,600,000,000 kW･h		295,139 kW･h	2,361,110,713 kW･h	
	Total Variable Cost				772,867			804,407
Constant Cost	1 Manpower Cost	7,000 x10^3yen/p･y		120 people	84,000		150 people	105,000
	2 Capital Charge							
	Depreciation	6.16%	Construction Cost	30,000,000 x10^4 yen	1,848,323	Construction Cost	39,900,000 x10^4 yen	2,458,270
	Interest	4.0%						
	Repair Cost	3.0%	Construction Cost	30,000,000 x10^4 yen	900,000	Construction Cost	39,900,000 x10^4 yen	1,197,000
	Insurance	0.77%	Book Cost	16,500,000 x10^4 yen	127,050	Book Cost	21,945,000 x10^4 yen	168,977
	Property Tax	1.4%	Book Cost	16,500,000 x10^4 yen	231,000	Book Cost	21,945,000 x10^4 yen	307,230
	3 Administrative expense	20.0%	Labor Cost	84,000 x10^4 yen	16,800	Labor Cost	105,000 x10^4 yen	21,000
	Total Constant Cost				3,207,173			4,257,476
Total Annual Cost					3,980,040			5,061,883
	Item	Unit Cost	Production Volume		Annual Cost	Production Volume		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Benefit	1 Power Price	円/kW	1,800,000 kW	14,400,000,000 kW･h	5,271,752	1,753,928 kW	14,031,422,620 kW･h	5,132,040
	2 Patent Fee	-0.05 円/kW						-70,157
	3 Environmental Interest	-3,976 円/t-CO2	406 t/h	3,249,111 ton	-1,291,712			
	Total Benefit				5,271,752			5,132,040
Electric Power Production Unit Cost（yen/kW）					3.66			3.66

Electric power production unit costs for both systems are 45.75 AUS$/MW.

Table 2.8-2 Cost of electricity (case 2)

			Brown Coal Thermal Power Generation(Loy Yang)			Brown Coal Slurry Thermal Power Gneration		
Construction Cost			30,000,000 x10^4 yen			39,900,000 x10^4 yen		
	Item	Unit Cost	Budget		Annual Cost	Budget		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Variable Cost	1 Brown Coal(Wet Base)	400 yen/ton	2,415 ton	19,321,675 ton	772,867	1,679 ton	13,435,196 ton	537,408
	2 Utility							
	Industrial Water	13.75 yen/ton				215 ton	1,720,320 ton	2,365
	Fuel	200 yen/10^6kcal				1,295 x10^6 kcal	10,361,600 x10^6 kcal	207,232
	Cooling Water	5 yen/ton				46 ton	371,667 ton	186
	Steam	3000 yen/ton				23 ton	184,320 ton	55,296
	3 Chemicals	30,000 yen/ton				0.08 ton	640 ton	1,920
	4 Electric Power	0.00 yen/kW	200,000 kW･h	1,600,000,000 kW･h		295,139 kW･h	2,361,110,713 kW･h	
	Total Variable Cost				772,867			804,407
Constant Cost	1 Manpower Cost	7,000 x10^3yen/p･y		120 people	84,000		150 people	105,000
	2 Capital Charge							
	Depreciation	6.16%	Construction Cost	30,000,000 x10^4 yen	1,848,323	Construction Cost	39,900,000 x10^4 yen	2,458,270
	Interest	4.0%						
	Repair Cost	3.0%	Construction Cost	30,000,000 x10^4 yen	900,000	Construction Cost	39,900,000 x10^4 yen	1,197,000
	Insurance	0.77%	Book Cost	16,500,000 x10^4 yen	127,050	Book Cost	21,945,000 x10^4 yen	168,977
	Property Tax	1.4%	Book Cost	16,500,000 x10^4 yen	231,000	Book Cost	21,945,000 x10^4 yen	307,230
	3 Administrative expense	20.0%	Labor Cost	84,000 x10^4 yen	16,800	Labor Cost	105,000 x10^4 yen	21,000
	Total Constant Cost				3,207,173			4,257,476
Total Annual Cost					3,980,040			5,061,883
	Item	Unit Cost	Production Volume		Annual Cost	Production Volume		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Benefit	1 Power Price	円/kW	1,800,000 kW	14,400,000,000 kW･h	5,604,595	1,753,928 kW	14,031,422,620 kW･h	5,132,040
	2 Patent Fee	-0.05 円/kW						-70,157
	3 Environmental Interest	-5,000 円/t-CO2	406 t/h	3,249,111 ton	-1,624,555			
	Total Benefit				5,604,595			5,132,040
Electric Power Production Unit Cost（yen/kW）					3.89			3.66

Electric power production unit cost for Loy Yang power is 48.6 AUS$/MW.

Electric power production unit cost for CWS system is 45.8 AUS$/MW.

Construction cost and cost of electricity

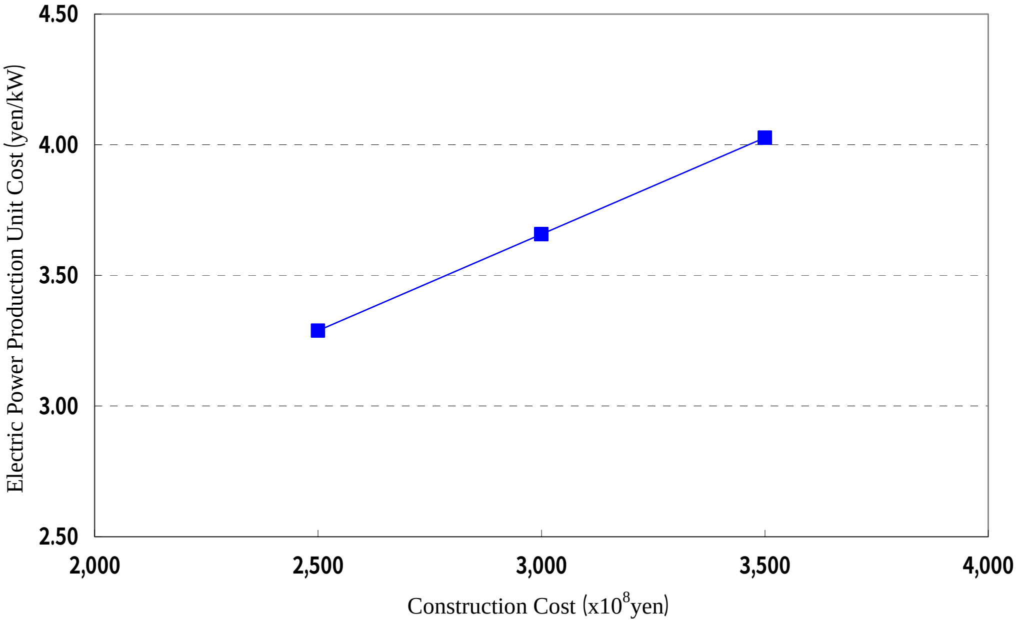


Figure 2.8-1 Construction cost and cost of electricity

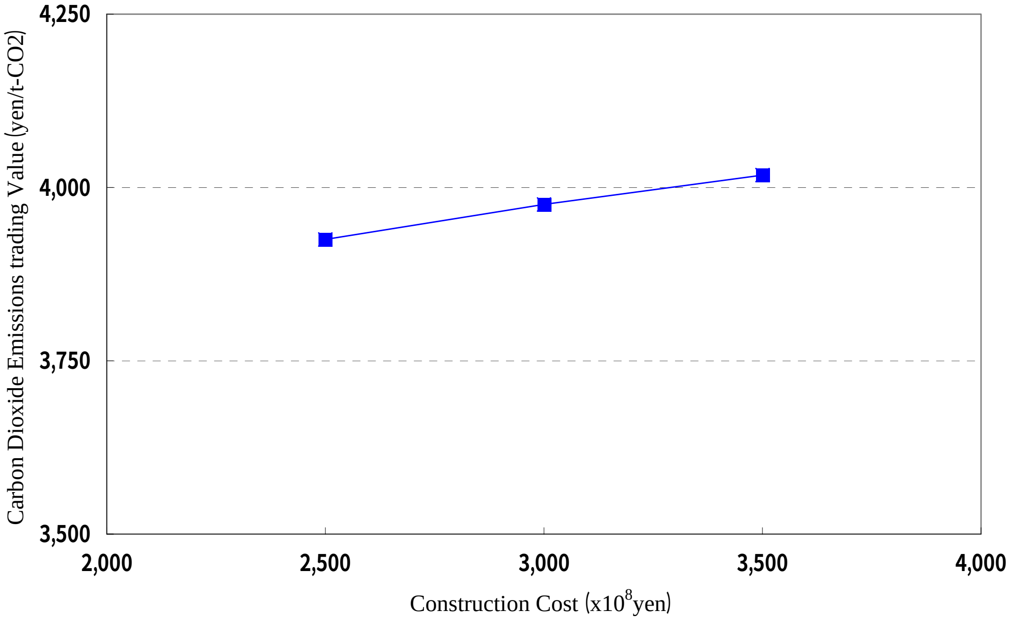


Figure 2.8-2 Construction cost and CO_2 trading value

Table 2.8-3 Cost of electricity (construction cost is 250 billion yen = 3125 million AUS$)

			Brown Coal Thermal Power Generation(Loy Yang)			Brown Coal Slurry Thermal Power Gneration		
Construction Cost			25,000,000 x10^4 yen			34,900,000 x10^4 yen		
	Item	Unit Cost	Budget		Annual Cost	Budget		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Variable Cost	1 Brown Coal(Wet Base)	400 yen/ton	2,415 ton	19,321,675 ton	772,867	1,679 ton	13,435,196 ton	537,408
	2 Utility							
	Industrial Water	13.75 yen/ton				215 ton	1,720,320 ton	2,365
	Fuel	200 yen/10^{6}kcal				1,295 x10^6 kcal	10,361,600 x10^6 kcal	207,232
	Cooling Water	5 yen/ton				46 ton	371,667 ton	186
	Steam	3000 yen/ton				23 ton	184,320 ton	55,296
	3 Chemicals	30,000 yen/ton				0.08 ton	640 ton	1,920
	4 Electric Power	0.00 yen/kW	200,000 kW・h	1,600,000,000 kW・h		295,139 kW・h	2,361,110,713 kW・h	
	Total Variable Cost				772,867			804,407
Constant Cost	1 Manpower Cost	7,000 x10^{3}yen/p・y		120 people	84,000		150 people	105,000
	2 Capital Charge							
	Depreciation	6.16%	Construction Cost	25,000,000 x10^4 yen	1,540,269	Construction Cost	34,900,000 x10^4 yen	2,150,216
	Interest	4.0%						
	Repair Cost	3.0%	Construction Cost	25,000,000 x10^4 yen	750,000	Construction Cost	34,900,000 x10^4 yen	1,047,000
	Insurance	0.77%	Book Cost	13,750,000 x10^4 yen	105,875	Book Cost	19,195,000 x10^4 yen	147,802
	Property Tax	1.4%	Book Cost	13,750,000 x10^4 yen	192,500	Book Cost	19,195,000 x10^4 yen	268,730
	3 Administrative expense	20.0%	Labor Cost	84,000 x10^4 yen	16,800	Labor Cost	105,000 x10^4 yen	21,000
	Total Constant Cost				2,689,444			3,739,747
Total Annual Cost					3,462,311			4,544,154
	Item	Unit Cost	Production Volume		Annual Cost	Production Volume		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Benefit	1 Power Price	円/kW	1,800,000 kW	14,400,000,000 kW・h	4,737,600	1,753,928 kW	14,031,422,620 kW・h	4,614,311
	2 Patent Fee	-0.05 円/kW						-70,157
	3 Environmental Interest	-3,925 円/t-CO2	406 t/h	3,249,111 ton	-1,275,289			
	Total Benefit				4,737,600			4,614,311
Electric Power Production Unit Cost（yen/kW）					3.29			3.29

Table 2.8-4 Cost of electricity (construction cost is 350 billion yen = 4375 million AUS$)

			Brown Coal Thermal Power Generation(Loy Yang)			Brown Coal Slurry Thermal Power Gneration		
Construction Cost			35,000,000 x10^4 yen			44,900,000 x10^4 yen		
	Item	Unit Cost	Budget		Annual Cost	Budget		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Variable Cost	1 Brown Coal(Wet Base)	400 yen/ton	2,415 ton	19,321,675 ton	772,867	1,679 ton	13,435,196 ton	537,408
	2 Utility							
	Industrial Water	13.75 yen/ton				215 ton	1,720,320 ton	2,365
	Fuel	200 yen/10^{6}kcal				1,295 x10^6 kcal	10,361,600 x10^6 kcal	207,232
	Cooling Water	5 yen/ton				46 ton	371,667 ton	186
	Steam	3000 yen/ton				23 ton	184,320 ton	55,296
	3 Chemicals	30,000 yen/ton				0.08 ton	640 ton	1,920
	4 Electric Power	0.00 yen/kW	200,000 kW･h	1,600,000,000 kW･h		295,139 kW･h	2,361,110,713 kW･h	
	Total Variable Cost				772,867			804,407
Constant Cost	1 Manpower Cost	7,000 x10^{3}yen/p･y		120 people	84,000		150 people	105,000
	2 Capital Charge							
	Depreciation	6.16%	Construction Cost	35,000,000 x10^4 yen	2,156,377	Construction Cost	44,900,000 x10^4 yen	2,766,323
	Interest	4.0%						
	Repair Cost	3.0%	Construction Cost	35,000,000 x10^4 yen	1,050,000	Construction Cost	44,900,000 x10^4 yen	1,347,000
	Insurance	0.77%	Book Cost	19,250,000 x10^4 yen	148,225	Book Cost	24,695,000 x10^4 yen	190,152
	Property Tax	1.4%	Book Cost	19,250,000 x10^4 yen	269,500	Book Cost	24,695,000 x10^4 yen	345,730
	3 Administrative expense	20.0%	Labor Cost	84,000 x10^4 yen	16,800	Labor Cost	105,000 x10^4 yen	21,000
	Total Constant Cost				3,724,902			4,775,205
Total Annual Cost					4,497,769			5,579,612
	Item	Unit Cost	Production Volume		Annual Cost	Production Volume		Annual Cost
			Hourly	Per Annum	x10^4 yen	Hourly	Per Annum	x10^4 yen
Benefit	1 Power Price	円/kW	1,800,000 kW	14,400,000,000 kW･h	5,803,200	1,753,928 kW	14,031,422,620 kW･h	5,649,769
	2 Patent Fee	-0.05 円/kW						-70,157
	3 Environmental Interest	-4,018 円/t-CO2	406 t/h	3,249,111 ton	-1,305,431			
	Total Benefit				5,803,200			5,649,769
Electric Power Production Unit Cost（yen/kW）					4.03			4.03