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Environmental Assessment of Power Generation From Bagasse at a Sugar Factory in Thailand

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ABSTRACT

Bagasse, the waste from sugar processing, is one of the biomass residues used as fuel. It can thus be a useful renewable resource for energy which also promises to avoid the environmental emissions of power generation from fossil fuels. Nevertheless, it should be confirmed that power production from bagasse is friendly for the environment. Life Cycle Assessment (LCA) is a very useful tool for such an evaluation. In this study, the LCA methodology is used for the environmental assessment of energy production from bagasse at Ratchasima Sugar Mill, Thailand. The sugar mill processes 30,000 tons of sugarcane per day. The power plant, attached to the sugar mill, is of cogeneration type. The energy and water balance show that 272 tons of bagasse can produce 342 tons of steam at 420 C used in the sugar process and about 25.5 MWh of electricity. Since the carbon in bagasse is part of the global carbon cycle, the CO_2 emission from the combustion of bagasse does not contribute to global warming. Therefore, the study focuses on the acidifying gases, NO_x and SO_x, which are also of concern in fossil-based power generation. A low amount of nitrogen (1.82%) and sulphur (<1%) in bagasse and low combustion temperatures contribute to low NO_x and SO_2 formation. Consequently, bagasse can be an environmentally-friendly raw material for power generation and has high potential as an alternate, renewable source of energy.

1. INTRODUCTION

Environmental issues are becoming more significant than in the past especially in the energy sector since it is a large emitter of pollutants [1]. The environmental constraints are leading to a rising interest in methods of improving efficiency of the energy sector [2]. Thailand's government has been concerned the management and development of indigenous resources and environment. The Electricity Generating Authority of Thailand (EGAT) has adjusted its strategic planning and implementation to enhance sustainable development by efficient use of natural energy resource, adopting advanced, cleaner and more efficient technologies for power plants, and also maximizing non-utility generation by encouraging small power producers (SPPs) to supply the power system with electricity fuelled with agricultural and industrial wastes [3].

Alternative energy is expected to reduce the import of conventional energy resources. Renewable energy is an option which may be indigenous as well as environmentally sound. Solar energy has been developed in Thailand but the application processes are limited, primarily due to the high initial cost. Nevertheless, research, development and demonstration of solar thermal equipment and systems should be supported. Wind energy in Thailand is used mainly for water pumping, roof ventilation and generating electricity. Unfortunately, wind energy for electricity generation is limited to some coastal areas and the central plain of Thailand [4]. Biomass energy is defined as energy from crops, agricultural residues and municipal solid waste. Thailand has high potential to utilize agricultural waste for electricity generation. Biomass is as important renewable source of energy for the region and since its combustion practically generates no net carbon dioxide emission, its development and utilization has been more rigorously promoted in the region. The preferably residue types identified are bagasse, rice husk, waste wood, etc.

Bagasse is one of the most viable biomass fuels. Thailand has about 50 sugar factories which are the resource of this material. Bagasse is utilized presently by sugar mills as boiler fuel or as fiber material for attached medium density fiberboard (MDF) and particleboard factories [5]. Although, biomass energy is reported to be better for the environment when compared with fossil fuels, environmental assessment should conducted for verification. The objectives of this study are to calculate the energy and water balance and analyze the environmental impact of power generation from bagasse by using life cycle methodology.

2. SUGARCANE PRODUCTION IN THAILAND

Thailand has a climate suitable for cane cultivation. However, sugar cane cultivation, and thus processing, is seasonal. The season lasts about 5 months per year, and the rest of the year the sugar mills are closed for maintenance. According to the Office of Agricultural Economics, agricultural production increased about 1.9 percent in 2000. The primary factors responsible were the weather, the global recession and the relatively lower increase in the agricultural price index than in the consumer price index [6]. Table 1 shows sugarcane's area and production by region of Thailand in the years 1998-2000. Thailand is the world's sixth largest sugar producer and the twelfth largest consumer. Thai sugar production in 1999/2000 was a record 5.72 million tons. Moreover, as per the 5-year strategic plan (2004/08) for the sugar industry, developed recently to strengthen industrial competitiveness, the production target aims to improve cane yield from the current 60 tons per hectare to 88 tons per hectare [7].

Table 1 Sugar cane: Area and production by regions of Thailand, 1998 – 2000

Region	Planted area (1,000 rai*)			Production (1,000 tons)		
	1998	1999	2000	1998	1999	2000
Northern	1,322	1,288	1,181	11,391	12,097	10,392
North-Eastern	2,068	2,064	1,994	18,8596	20,342	18,153
Central Plain	2,344	2,292	2,245	20,081	21,054	20,525
Thailand (total)	5,735	5,645	5,421	50,332	53,494	49,070

* 6.25 rai = 1 ha

Note: Adapted from Thailand, Office of Agricultural Economics, Food and Agriculture Organization of the United Nations)

3. BAGASSE

Bagasse is the solid fibrous material which leaves the delivery opening of the last mill of the tandem, after extraction of the juice. It is the residue from the milling of cane. Physical composition of bagasse varies between rather narrow limits. Its moisture content most frequently is 45 to 50% and around 50% of fibre content. The quantity of the bagasse varies between 24 and 30% by weight of cane [8]. Bagasse is usually used as a combustible material in furnaces to produce steam, which in turn is used to generate power. It is also used as the raw material for production of paper and as feed stock for cattle.

Composition of bagasse from the Ratchasima Sugar Factory has been analyzed by using CHONS analyzer. The physical properties such as moisture content and calorific value have also mean measured and are shown in Table 2.

Table 2 Ultimate analysis of bagasse sample of Ratchasima Sugar Factory's power plant

Component Name	Value	Moisture content, m (%)	Calorific value,(GJ/t)
Carbon, C (%)	41.54	53	7.32
Hydrogen, H (%)	5.40		
Oxygen, O (%)	33.14		
Nitrogen, N (%)	1.83		
Sulphur, S (%)	*<1*		

4. SITE STUDY

Based on the data available for the Ratchasima Sugar Factory in Nakorn Ratchasima, Thailand, the mill capacity is 30,000 tons of sugarcane per day every day during the crushing season. The power plant is cogeneration type with 2 water-tube boilers (each of capacity 300 ton/hour) and 2 steam turbines (each of capacity 15 MW). The power plant stores bagasse from the milling process for utilization in power processes appropriate for the 8 months and for the remaining 4 months they buy other residues such as rice husk, wood waste to generate electricity.

Demineralized water is used in the boilers at start-up operation and condensate water from sugar processes is reused thereafter. Therefore, water consumption for this power plant is closed-loop, recycling water. Normally, the factory has to make-up water less than one time per year. Steam generated in the boilers is used in the sugar processes and steam turbines. This power plant generally operates at 24 MW, utilizing 16 MW for the sugar factory and power plant itself and selling the excess 8 MW to the grid under the SPP scheme.

Wastewater from the power plant is only the blow down water, which is about 5% of feed water, is sent to wastewater pond. Oxidation pond is used to manage all of wastewater of the factory. Heat from the flue gas is utilized in air-preheater and economizer. A multi-cyclone collects dust and fly ash from the final flue gas before releasing it from the stack. Bottom and fly ash from combustion goes to the landfill.

5. RESULTS AND DISCUSSION

An LCA includes four phases, viz., (1) goal & scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. The results follow the format of the life cycle methodology. However, the impact assessment stage is not considered in this paper since useful interpretation can be drawn directly by analyzing the inventory results.

5.1 Goal and Scope Definition

The goal of the study is to evaluate the environmental impact of power generation from bagasse of Ratchasima Sugar Factory's power plant in the crushing season (180 days). Energy and material balances are carried out to check the consistency of the collected data and also to compute the efficiency of the power plant. The overall power production scheme is shown in Fig. 1. The materials requirement for water treatment for using in boilers and wastes treatment; including air, wastewater and solid waste management, are not included in the system boundaries as they are anticipated to be quite less. Energy requirement for these processes is however included as part of the demand for the power plant.

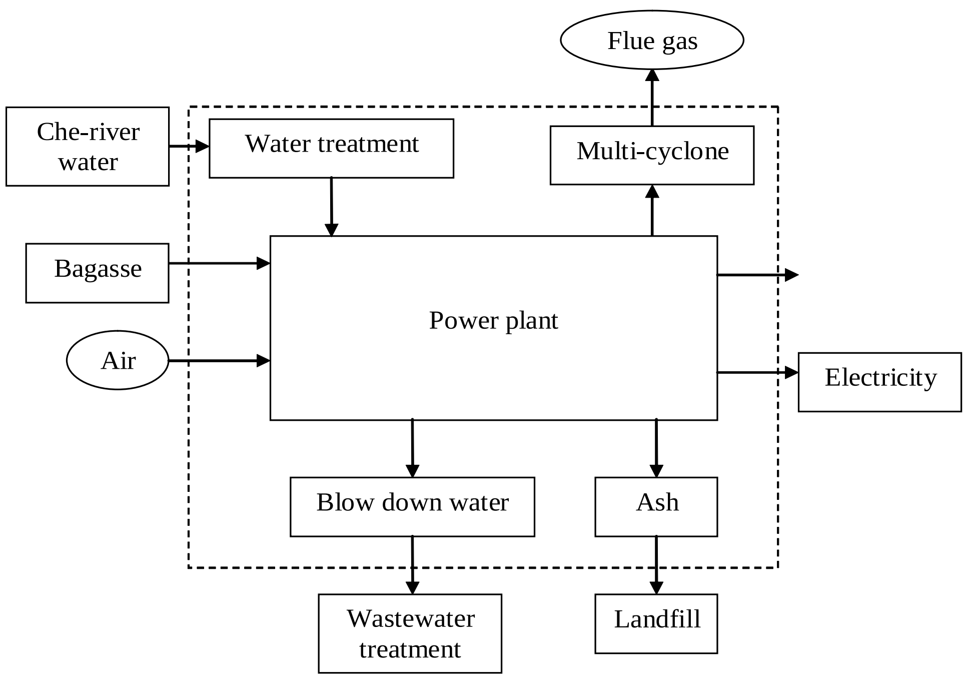

Fig. 1 System boundaries of the study

5.2 Functional Unit (FU)

The functional unit is defined for quantifying the function of the product, process or service under consideration, which will be used for normalising the data in the inventory. Since this study concerns energy generation from bagasse, the products are steam and electricity. To normalize the data the functional unit has been set as 1 MWh of electricity.

5.3 Inventory Analysis

Data was collected from the Ratchasima Sugar Factory's power plant for computing the energy balance, water balance, and emissions. The power plant is cogeneration system comprising 2 water-tube boilers and 2 steam turbines having capacity 300 ton/hr and 15 MW each, respectively. Flow diagram of the studied power plant is shown in Fig. 2.

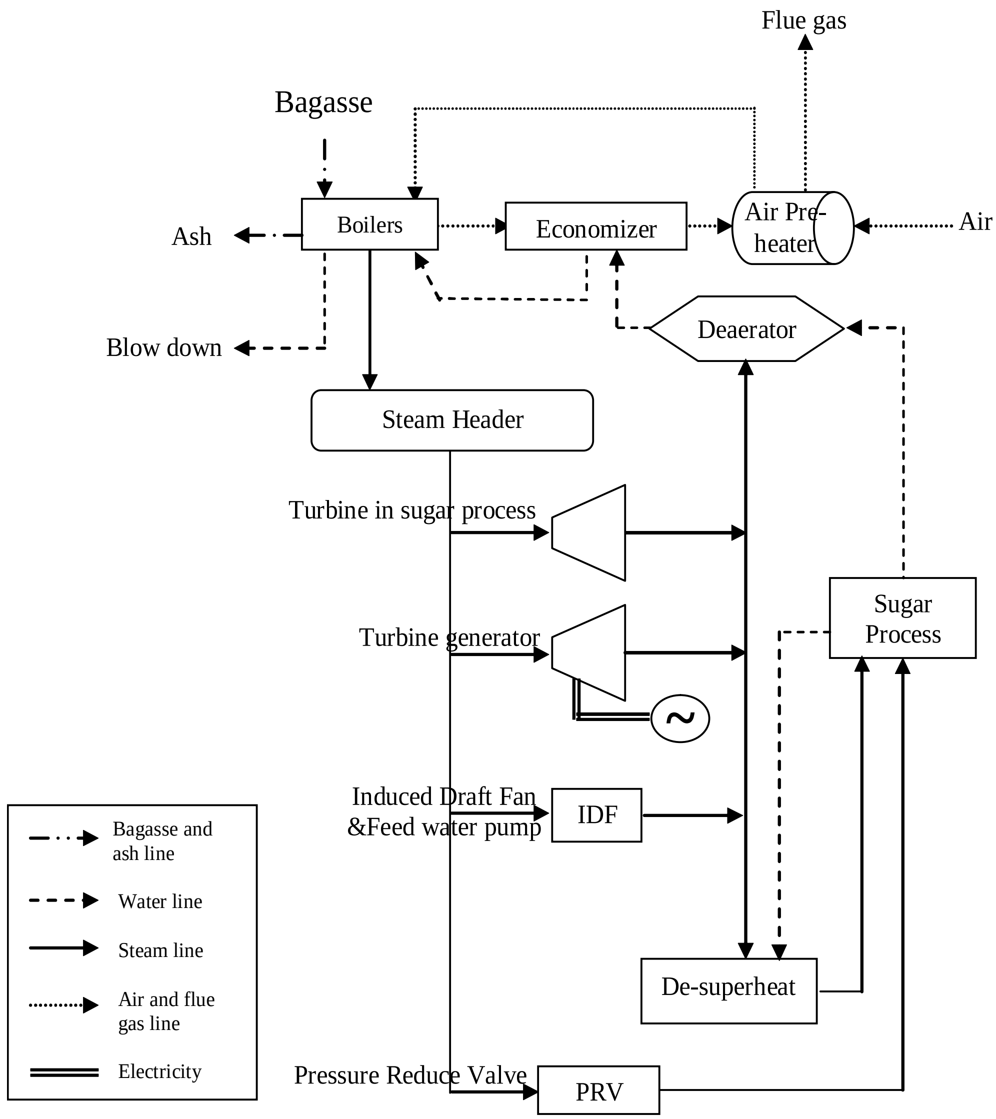

Fig. 2 Flow diagram of Ratchasima Sugar Factory's power plant

Energy and water balances are shown in Fig. 3. Bagasse combustion at the rate of 272 ton/h results in energy production of 1991.05 GJ/h. This energy is utilized in the boilers to produce 605 ton/h steam at 420ºC. 342 ton/h steam at 420ºC goes to the process in the sugar mill and 263 ton/h goes for power generation (turbine generator and induced draft fan). 637 ton/h of condensate water from sugar processes is returned to the power plant.

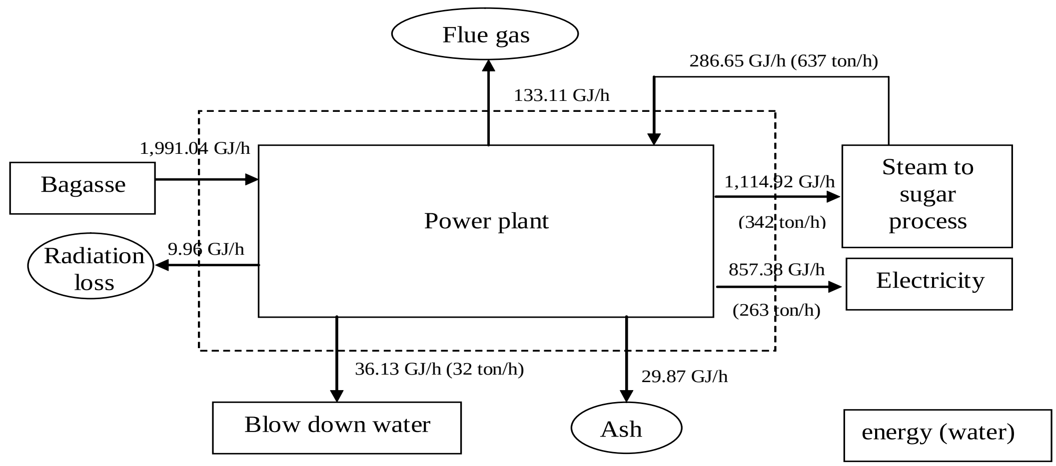

Fig. 3 Energy and water balance in Ratchasima sugar factory's power plant

Energy balance calculation followed the first law of thermodynamics. From Fig. 3, the total input energy is 1,972.3 GJ/h and the total output energy (excluding estimated losses) is 2,181.37 GJ/h. Estimated energy losses from the power plant are about 209.07 GJ/h or about 9.2 % with blow down water, flue gas, ash and radiation. The remaining 96.32 GJ/h, which is about 4% of the total input energy, is unaccounted loss. The power plant efficiency is about 86-92% as calculated below.

The boiler efficiency has been calculated below by two methods (1) Input-output and (2) Heat loss. The boiler efficiency is calculated in two ways as shows below. Further details are presented in the Appendix.

1. *Efficiency by Input-output method*

$$\frac{(M_s \times H_s) + (M_{bw} \times H_{bw}) - (M_w \times H_w)}{(M_b \times H_b)} \times 100 = \% Efficiency$$

where, M_s = Mass of steam generated = 605 t/h,
H_s = Enthalpy of steam generated at pressure 38 kg/cm^2 and temperature 420ºC = 3.26 GJ/t,
M_{bw} = Mass of blow down water = 32 t/h,
H_{bw} = Enthalpy of blow down water at 258ºC = 1.13 GJ/t,
M_w = Mass of feed water = 637 t/h,
H_w = Enthalpy of feed water at 108ºC = 0.45 GJ/t,
M_b = Quantity of bagasse consumption = 272 t/h, and
H_b = Low heating value of bagasse = 7.32 GJ/t.

Therefore, boiler efficiency works out to 86.48 %.

2. Efficiency by Heat loss method

Concerning percentage of energy loss from flue gas, radiation and ash based on working experience of plant engineer,

$$E_0 - L_{fl} - L_r - L_{ash} = \%\ Efficiency$$

where, E_0 = Percentage of boiler efficiency without loss,
L_{fl} = Percentage of loss from flue gas,
L_r = Percentage of loss from radiation, and
L_{ash} = Percentage of loss from ash.

Therefore, boiler efficiency is;

$$100 - 6.69 - 0.5 - 1.5 = 91.31\ \%$$

Flue gas emissions from this power plant comprise of CO_2, CO, NO_2, SO_2 and TSP at 141.5 °C at flow rate of 833,981.1 m^3/h. Since this power plant generates steam which is used both in the sugar processes as well as for electricity production, the emissions due the flue gas must be allocated according to the steam usage for the two cases. Steam consumption of electricity production of power plant is 263 ton/h from the total steam generated, 605 tons/h. Therefore, only 43.5 % of the emissions associated with the flue gas are allocated to electricity production.

The collected data of emissions is shown in Table 3. The table shows that the emissions of SO_2 and NO_2 are very small amount, as anticipated from the low amount of nitrogen and sulphur in the biomass and low combustion temperatures. Carbon dioxide emission from the power plant is not considered since the carbon in the sugar cane (and hence, bagasse) is a part of global carbon cycle and hence, does not contribute to global warming. Table 4 shows the emission intensities (in kg/MWh) of CO_2, CO, NO_2, SO_2, and TSP from coal-fired, oil-fired and natural gas power plants. The overall emissions per MWh of electricity produced from all the three types of power plant are also computed. The comparison of the selected emissions from fossil-based power plant and bagasse-based electricity production from Ratchasima sugar factory's power plant are shown in Table 5.

Table 3 Emission data from the stack of Ratchasima sugar factory's power plant

Parameter	Amount	Mass flow rate (kg/h)	Mass per FU (kg/MWh)
SO_2	0.615 mg/m^3	0.22	0.009
NO_2	5.13 mg/m^3	1.86	0.07
CO	564.25 ppmv	255.7	10.03
TSP	306.12 mg/m^3	110.98	4.35

Note: Stack property : Diameter 5.2 m., temperature 141.5°C, velocity 5.44 m/s, density 1.1798 kg/m^3, and flow rate is 833,981.1 m^3/h Only 43.5 % of the emissions associated with the flue gas are allocated to electricity production.

Table 4 Emission intensities of each substance from power stations in Thailand in fiscal year 2001 [10]

Types	Electricity production, MWh	CO_2		CO	
		Tons	Kg/MWh	Tons	Kg/MWh
Coal	17,338,580	22,011,748	1,269.52	3,421	0.197
Oil	12,947.2	10,521	812.61	3.52	0.27
Gas	56,247,083.1	31,997,720	568.88	11,070	0.197
Combined*	73,598,610	54,019,989	733.98	14,495	0.197

Types	SO_2		NO_2		TSP	
	Tons	Kg/MWh	Tons	Kg/MWh	Tons	Kg/MWh
Coal	48,005	2.77	101,212	5.84	633	0.037
Oil	16.6	1.28	37	2.86	12	0.927
Gas	19	0.0003	76,634	1.36	2042	0.036
Combined*	48,041	0.65	177,883	2.42	2686	0.036

* Weighted average of Coal, oil and gas-fired power plants

Table 5 Comparison of selected emissions

Parameter	RSFPP[1] (kg/MWh)	Coal Power Plant (kg/MWh)[10]	Oil Power Plant (kg/MWh)[10]	Natural gas Power Plant (kg/MWh)[10]	Combined (kg/MWh) [10]
SO_2	0.009	2.77	1.28	0.0003	0.65
NO_2	0.07	5.84	2.86	1.36	2.42
CO_2	(non-fossil)	1,269.52	812.61	568.88	733.98
CO	10.03	0.197	0.27	0.197	0.196
TSP	4.35	0.037	0.927	0.036	0.036

[1] RSFPP: Ratchasima Sugar Factory's Power Plant

5.4 Interpretation

Main part of bagasse is carbon and oxygen. There are small amounts of nitrogen (1.82%) and sulphur (less than 1%) in bagasse. This combined with the fact that combustion temperatures are low, results in low SO_2 and NO_2 formation. Thus, the SO_2 emissions of the bagasse power plant are much lesser than coal and oil-fired power plants. They are higher than natural gas power plants. However, even though about 76% of the electricity is produced from natural gas, the SO_2 emissions from the bagasse power plant are lesser than the combined electricity production from all three types of conventional fuels. For the case of NO_2, the emissions from the bagasse power plant are much lesser than all three types of conventional fuel plants. It must also be pointed out that even though the conventional fuel power plants have facilities for SO_X and NO_X removal whereas the bagasse power plant does not, the emissions of these gases are lower for the latter. Since both SO_2 and NO_2 contribute to acidification and NO_2 also contributes to photochemical ozone formation, these impacts will be mitigated.

As stated earlier, since the CO_2 from biomass combustion can be recycled in photosynthesis during the growth of sugar cane, this emission does not contribute to global warming. This is a clear advantage of the bagasse power plant since there are substantial emissions of CO_2 from all the three types of conventional fuel plants.

The CO emissions from the bagasse power plant are very high compared to the conventional power plants. This may partly be due to incomplete combustion. Also, upsets in combustion conditions can cause increases in emission of CO. This may also imply a need for improving the combustion technology for biomass. However, since these are primary data, these values should be checked again.

Total suspended particulates (TSP) are also emitted in much higher amounts as compared to the conventional power plants. Particulate matter in bagasse-fired boilers is caused by the turbulent movement of combustion gases with respect to the burning bagasse and resultant ash. Soil (from cane) characteristics such as particle size can affect the magnitude of particulate matter emitted from the boiler. Cane that is improperly washed or incorrectly prepared can also influence the bagasse ash content. These may be possible reasons for the high emissions of TSP. Also, the RSFPP has only multi-cyclone for pretreatment of flue gas before releasing to the atmosphere. Adding other dust removal equipment such as Electrostatic Precipitator (ESP) would reduce TSP emitted from the stack.

Overall, bagasse may be friendlier for the environment impact than fossil fuels as discussed above. However, the issues of improving combustion and dust removal need to be addressed to realize the potential adequately.

6. ACKNOWLEDGEMENTS

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8. APPENDIX

Energy Balance Calculation

1. Fuel bagasse input	Flow		272	ton/h
	Low heating value		1,750	kcal/kg
		=	7.32	GJ/t
Total heat input	272 x 7.32	=	1,991.04	GJ/h
2. Steam				
Steam generated	Flow		605	ton/h
(38 kg/cm^2,420ºC)	Enthalpy (superheat)		3.26	GJ/t
Steam output from system boundary				
• Steam for Turbine in sugar process	Flow		235	ton/h
• Steam for PRV.	Flow		107	ton/h
(38 kg/cm^2,420ºC)	Enthalpy (superheat)		3.26	GJ/t
Exhaust steam output from system boundary				
• Exh. from TG	Flow		204	ton/h
• Exh. from IDF & Feed water pump	Flow		59	ton/h
(1.5 kg/cm^2,200ºC)	Enthalpy (superheat)		2.87	GJ/t
3. Feed water input	Flow		637	ton/h
	Enthalpy (108ºC)		0.45	GJ/t
4. Blow down water	Flow		32	ton/h
	Enthalpy (258ºC)		1.13	GJ/t
5. Flue gas loss	Gas flow		833,981.1	m^3/h
	Gas temperature		141.5	ºC
	Mean gas specific heat		0.00137	J/m^{3}ºC
	833,981.1 x (141.5-25) x 0.00137	=	133,107.55	MJ/h
		=	133.11	GJ/h
	(133.11/1991.04) x 100	=	6.69	%
6. Radiation loss (from furnace, boiler, air-heater)			0.5 *	%
	0.5% x 1,991.04 GJ/h	=	9.96	GJ/h
7. Ash and other loss (%)			1.5 *	%
	1.5% x 1,991.04 GJ/h	=	29.87	GJ/h

* Based on working experience of plant engineer.