CHAPTER VII

AN INVESTIGATION OF THE THERMAL SYSTEM

Introduction

The thermal system studied concerns the generation and utilization of steam, as shown in Figure 7.1. Analysis of the system as well as energy conservation measures for both production and utilization sides of this system will be described in the following sections.

Steam Production system

Two water-tube boilers which run alternatively have been employed as steam generators in the plant. The current capacity of each boiler is about 3.0 tons per hour, which is 55 % of its nameplate capacity, at a steam pressure of 9 kg/cm^2g. The boiler is fired with heavy fuel oil and consumes 4.0 to 4.2 kiloliters per day. Before entering the combustion chamber, the fuel is preheated by both steam and electric heater to raise its temperature to 88°c. Boiler's water is fed from the deaerator by two boiler-feed-water pumps which take turns operating. This boiler water, with temperature of 82°c, is a mixture of make up water, condensate and steam. Blowdown from the boiler is done automatically as well as manually. The automatic method is set to blow 60 liters of boiler water every 7.5 minutes. The manual method, however, is a human adjustment and done once every 2 hours. The heating surface area of 129 square meters in the combustion chamber is cleaned once or twice a year for the waste gas side and several times a year for the water side. Flue gas temperature, measured

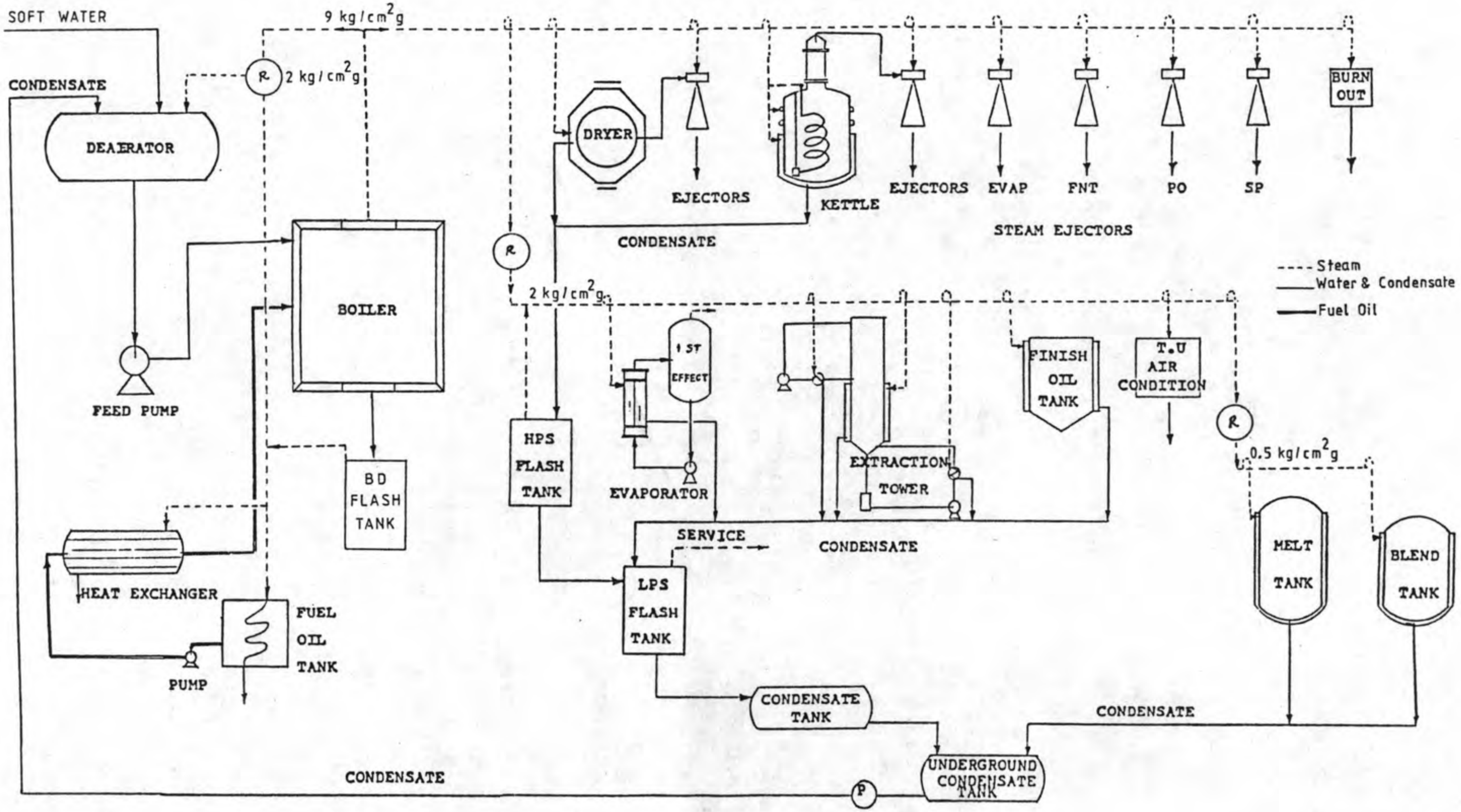

Figure 7.1 Schematic Diagram for the Thermal System of the Plant

by a stack thermocouple, is about 232°c (450°F). A combustion indicator was used, in the auditing stage to determine the percentage of CO_2 in the flue gas and it was found that the CO_2 was about 12.5% at normal firing.

Steam Boiler Heat Balance Determination

In this study, the approximate procedure will be employed using the data collected during November, 1985. The data for the previous months cannot be taken into consideration since no complete record was available. A schematic diagram for the boiler is shown in Figure 7.2.

1. Heat Input to the Boiler

Under the conditions described above, the heat input to the boiler are as follows. (See Appendix I.1 for more details.)

1.1 Chemical heat in the fuel "as fired," Q_{fc}, is 1,732,500 kcal per hour.

1.2 Heat credit supplied by feedwater, Q_w, is 156,900 kcal per hour.

1.3 Heat credit supplied by preheated fuel oil, Q_{fp}, is 5481 kcal per hour.

2. Heat Output of the Boiler.

The calculations, illustrated in Appendix I.2, give the following results:

2.1 Heat of steam produced, Q_s, is 1,652,892 kcal per hour.

2.2 Heat loss due to dry flue-gas, Q_g, is 169,824 kcal per hour.

2.3 Heat loss due to blowdown, Q_b, is 62,878 kcal per hour.

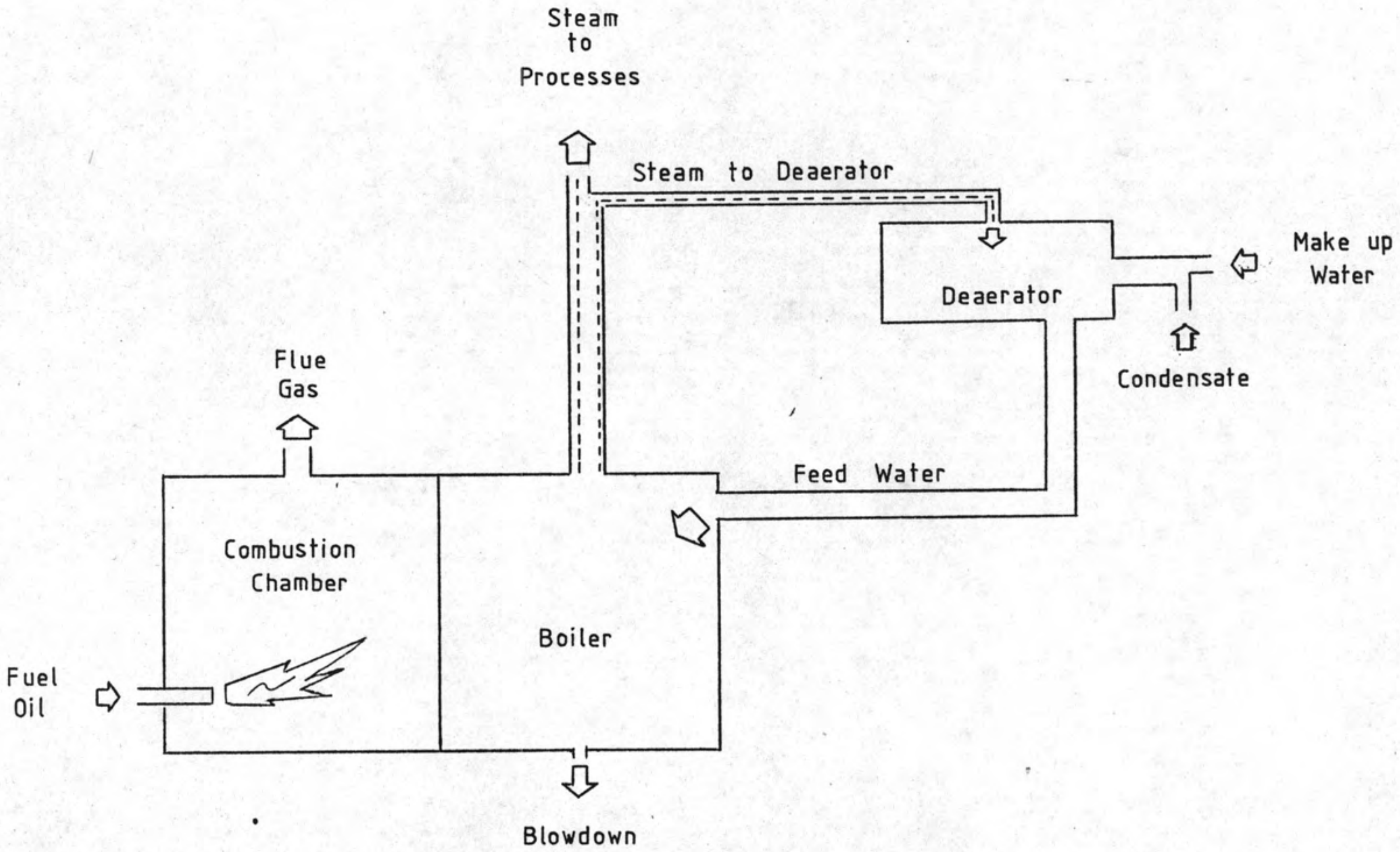

Figure 7.2 Schematic Diagram of the Steam Production System

Table 7.1 Average Daily Data Observed During November, 1985.

Item	Average data	Condition
1. Heavy fuel oil	4,342 liters/day	$88^{\circ}c$
2. Make up water	42,512 liters/day	$22^{\circ}c^{*}$
3. Condensate	32,818 liters/day	$82^{\circ}c^{*}$
4. Blowdown	10,164 liters/day	$179^{\circ}c^{**}$
5. Steam	72,308 kg/day	$9\ kg/cm^{2}g$

Remarks: *This figure is measured at the outlet of the deaerator.

**Blowdown is saturated water, in this case, boiling under pressure of $9\ kg/cm^{2}g$.

Source: Utility department logsheets.

Table 7.2 Steam boiler heat balance (30°C, H_1, per 1 kg of fuel oil)*

Input	kcal per kg of fuel	%		Output	kcal per kg of fuel	%
1. Heat of fuel as fired	9,900	91.7	Effective	1. Heat of steam produced	9,674	89.6
				Subtotal	9,674	89.6
2. Sensible heat of feedwater	867	8.0	Losses	2. Heat loss due to dry flue-gas	970	9.0
3. Sensible heat of preheated fuel oil	31	0.3		3. Other losses due to radiation, etc.	154	1.4
				Subtotal	1,124	10.4
Grand Total	10,798	100		Grand Total	10,798	100

Remark: *Entries within the parenthesis are temperature, low-heat value and unit of fuel oil used as references in this analysis.

The information, heat credits and heat losses, mentioned above and the remaining computations are summarized in Table 7.2.

In carrying out this analysis, it should always be realized that error in numerical values do occur due to instrumentation and human factors. It is recommended that the results be reviewed as soon as reliable data are available.

Steam Utilization system

In this section, steam consumed by various equipment in the factory system is investigated. The first law of thermodynamics is employed in the estimation process to disclose the quantity of steam required by each equipment. The calculations are performed in Appendix I.3 to accomplish these estimates.

Table 7.3 provides a summary of steam utilization by each equipment of the plant. To highlight the distribution pattern, a plot of the consumption is illustrated in Figure 7.3

Energy Conservation Opportunities (ECOs)

A walk-through audit and energy analysis conducted in this plant revealed several opportunities to save energy in the existing thermal system. In this section, energy saving for both production and utilization sides of the steam system will be discussed.

1. The ECOs in Steam Production System

The thermal efficiency of the boiler and variation in boiler output, or load factor are the two important, interrelated, factors in minimizing steam expenses. The current operating condition may be improved by the following measures.

Table 7.3 Ranking of Equipment by Steam Usage

Equipment	Steam consumption kg/hr	percentage of steam produced
1. The Vacuum Dryers	805	26.7
2. The First Effect Heat Exchanger	766	25.4
3. The Deaerator	298	9.9
4. The Extraction Towers	258	8.6
5. The FNT Ejectors	192	6.4
6. The Take-Up Air Washer	122	4.1
7. The Distillation Kettle	98	3.3
8. The Steam Ejector of the Second Effect	96	3.2
9. The Melting Tank	57	1.9
10. The Oil Preheater	16	0.5
11. The Burn Out Furnace	8	0.3
12. The Take Up Finish Oil Tank	4	0.1
13. The Blending Tank	3	0.1
14. Others (Spinning Ejector, Polymerization Ejector, Piping, leakage, etc.)	289	9.5
Total	3012	100.0

Note : FNT stands for "Finishing Tower."

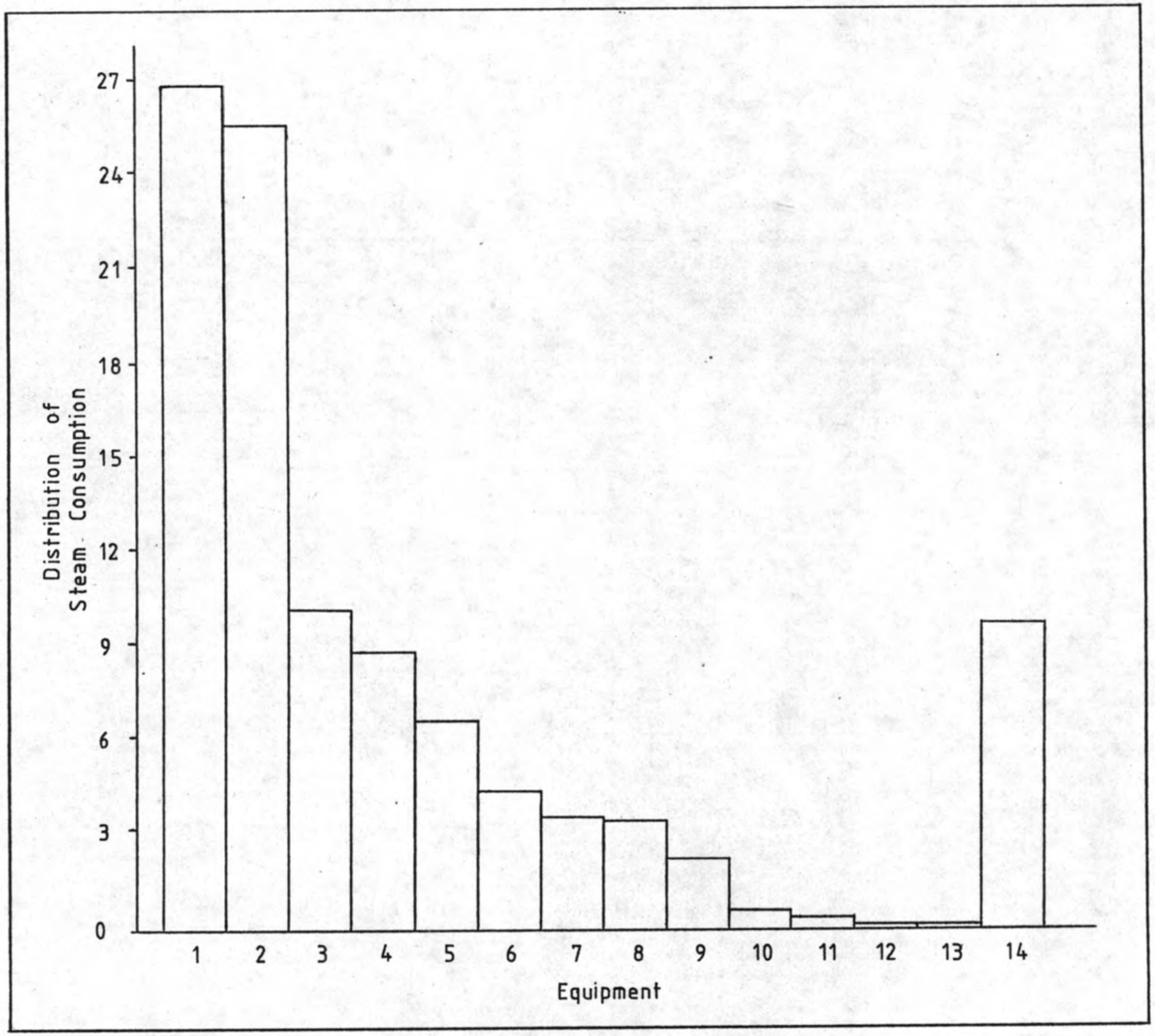

Figure 7.3 Plot of Steam Usage by Equipment

1.1 The boiler is presently operated at about 55% load which is not an efficient practice. A smaller one may be more attractive after some careful evaluation as the new boiler can operate as closely as possible to its designed rating.

1.2 The boiler should be operated at its designed pressure of 17 kg/cm^2g (250 psig). Since its current operating pressure is about 9 kg/cm^2g, an improvement for this boiler can be also expected.

1.3 Heat losses due to dry flue gases can be serious and they should be controlled by minimizing the flue gas temperature as well as the amount of excess air used. For more details, consults The Energy Managers' Handbook (2).

1.4 Tubes and other fire-side heat exchange surfaces should be cleaned regularly or as soon as a predetermined temperature is reached. Cleaning should be thorough.

1.5 Heat losses due to blowdown can be reduced by several methods. Not blowing down any greater volume than necessary and careful control of feedwater treatment are the two possible methods to control such heat losses under current operating condition.

1.6 High thermal efficiency can be maintained by good housekeeping and adequate boilerhouse records. The records obtained may be used to identify trends and changes in boiler conditions. Tests of combustion performance should be carried out at regular intervals to measure the carbon dioxide (or oxygen) content of the flue gases and the flue gas temperature, then, use these values to assess the stack loss.

1.7 Training of all persons involved with the operation and maintenance of boiler is of paramount important to perform their duties safely and effectively.

2. The ECOs in Steam Utilization System

The potential for heat loss is great in all types of distribution and utilization systems. Followings are some guidances that can reduce such losses and improve the overall efficiency of the thermal system.

2.1 Regular inspection and maintenance schedules should be developed for all forms of heat distribution including valves, traps, gauges and joints as well as the pipes themselves.

2.2 Whenever feasible, out of date or unnecessarily extended distribution systems should be eliminated or at least isolated effectively.

2.3 The amount of waste or reprocessing should be recorded and reduced.

2.4 Overprocessing must be avoided. Materials should be removed immediately they reach the desired temperature and condition.

2.5 The optimum steam pressure, process temperature and time for each item of steam-heated plant should be determined to reduce steam requirements. Then, control these factors automatically.

2.6 Particular attention should be paid to condendate and feedwater tank insulation.

2.7 Everyone concerned should be encouraged to appreciate the purpose of steam traps and ensure that they are correctly selected, fitted, protected, cleaned, maintained and cared for.

2.8 Improvement of steam-heated equipment should be made whenever possible.

Detailed Analysis for Some Selected ECOs*

In this section, attemps were given to analyses of ECOs observed in the steam production and utilization systems.

1. Reduction of blowdown loss.
2. Reduction of heat loss between extraction towers and dryers by insulating the four wet chip storage bins.
3. Reduction of heat loss between extraction towers and the wash-water collection tank by some piping modification and insulation.
4. Reduction of steam requirement by replacing steam ejectors with vacuum pumps.

ECO 1. Reduction of Blowdown Loss

The purpose of blowing down a boiler is to maintain a low concentration of dissolved and suspended solids in the boiler water and to remove sludge in the boiler in order to avoid priming and carryover.

Table 7.4 provides the total dissolved solids (TDS) for the boiler between January 1985 and February 1986. A plot of these values is given in Figure 7.4.

For the boiler with pressure below 300 psi, the allowable TDS in parts per million (ppm) is 3500. The blow volume, generally, should not greater than 10% of make-up water (22).

Consider the operation of November 1985, the average blow quantity was nearly 24% of the make-up water (see Table 7.1) and the corresponding TDS was 1620 ppm (see Table 7.4) With these information together with the distribution pattern exhibited in Figure 7.4, more attention should be paid to this boiler blow-down control.

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*Using purchasing price of 1.56 baht/kWh for electricity and 0.37 baht/kg for fuel oil for the calculation throughout this section.

Table 7.4 The TDS of the Boiler Measured Between January 1985 and February 1986

Month	Measured TDS, ppm			
	1	2	3	4
1985:				
January	3900	3962	3718	4401
February	5116	5326	5158	4253
March	3022	6603	3589	3540
April	4338	4217	3010	3734
May	-	5098	-	1065
June	2268	2356	2458	1899
July	2097	1934	4091	1873
August	1811	3041	1835	1885
September	4507	2049	2107	2115
October	1824	-	1222	-
November	1673	-	1567	-
December	1311	-	2470	-
1986:				
January	5129	4480	3423	-
February	2483	1690	-	-

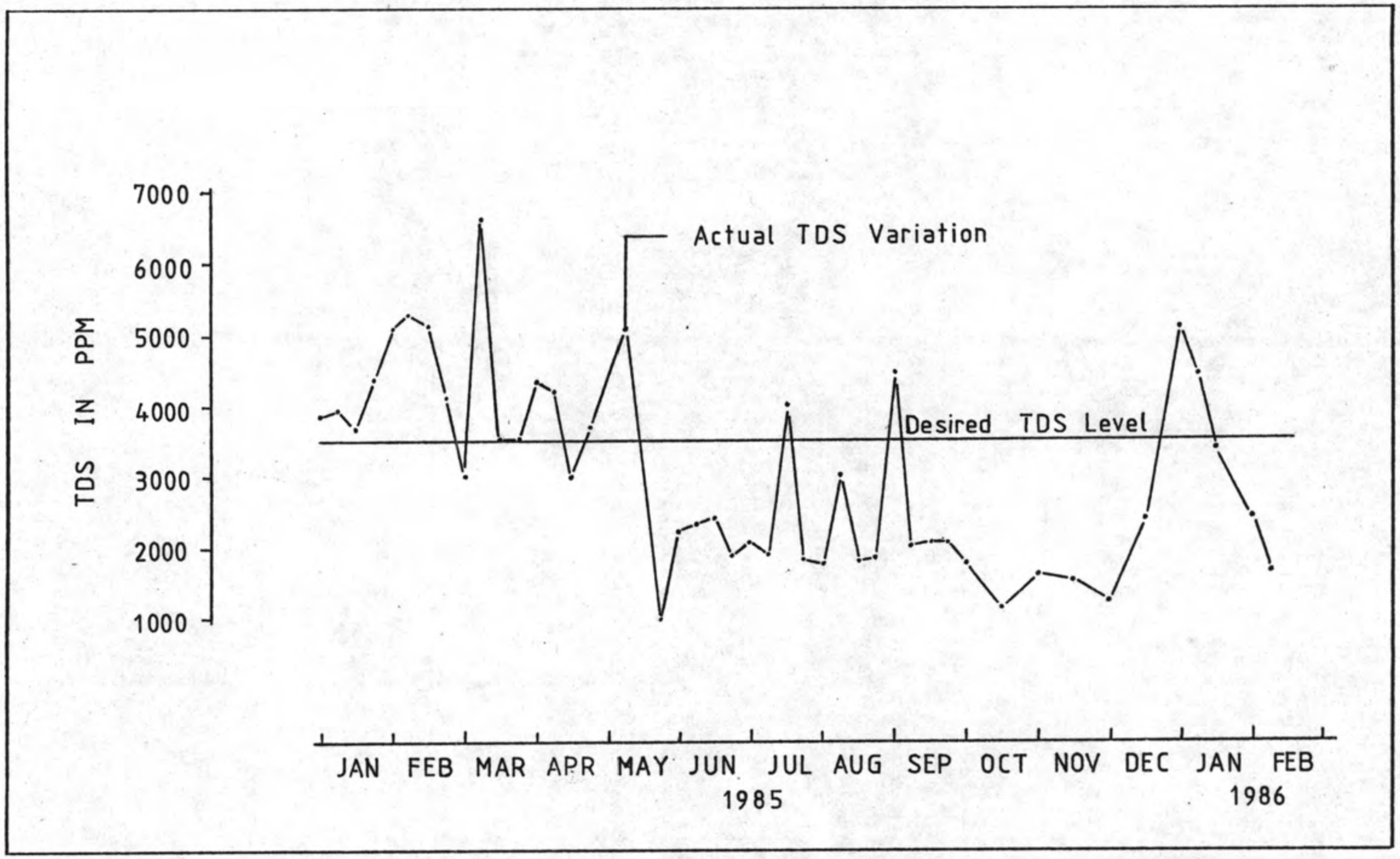

Figure 7.4 Plot of TDS for the boiler as measured between January 1985 and February 1986

Economic Analysis:

The following analysis is made using the data available in November, 1985.

Make-up water is .... 42512.00 liters/day.
Blowdown is .... 10164.00 liters/day.
10% of make-up water* is .... 4251.20 liters/day.
Possible blowdown reduction is..... 5912.80 liters/day.

Since the enthalpy of saturated water, from steam table
(at 9 kg/cm^2 g) is .... 181.25 kcal/kg,
the amount of energy saved is 1,071,695.00 kcal/day.

Specifications of heavy fuel oil used, from ESSO laboratory
of November, 1985 are as follows:
Low heating value is .... 9900.00 kcal/kg.
Specific gravity is .... 0.97 kg/liter.
Purchasing price (new rate) is 3.80 baht/liter.

With this fuel oil specifications, the above energy saving of 1,071,695 kcal/day is equivalent to fuel oil of 112 liters/day which costs 426 baht.

For the annual operation of 365 days, a saving of approximately 155,344 baht/year or 12,945 baht/month can be expected with a 'no-cost' investment.

ECO 2 Insulation of the Four Wet-Chip Storage Bins

The polymer chip after each extraction tower will be centrifuged and, then, transfered to two wet chip storage bins waiting for the next processing, i.e. the drying process. Data available at this stage will be analyzed to estimate heat loss from this portion.

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*Generally, the blowdown is 1-10 percent of the make-up water (22).

Using $Q = 4\,(\dot{m}_c)(C_c)(\Delta T)$, where $\dot{m}_c$ = mass flow rate of the wet chip, kg/hr; C_c = specific heat of the wet chip, kcal/kg°C; = ΔT temperature difference of the wet chip entering and leaving the bins, °C; the amount of heat loss from these four bins is 327,761 kcal/day.

In the drying process, after the storage bins, steam of 9 kg/cm^{2}g is required. To reduce the amount of steam requirement at this stage, heat loss from the storage bins must be prevented.

Economic Analysis:

Specific enthalpy of steam (9 kg/cm^{2}g) is ...638.8 kcal/kg

Steam production cost (fuel oil cost plus 30% more for labor and other operating expenses) is ...0.37 baht/kg.

Boiler efficiency, Table 7.2, is ......89.6%.

Hence, the amount of heat loss calculated above is

$$\frac{(327{,}761 \text{ kcal/day}}{(638.8 \text{ kcal/kg})\ (89.6\%)} \times (0.37 \text{ baht/kg})(365 \text{ day/yr})$$

which equals 77,380 baht/year or 6448 baht/month.

Investment:

Fiberglass (32 kg/m^3, 50 mm. thick., 16 rolls)...58,400 baht.*

Labor (3 technicians, 4 days) ....1,200 baht.

Alumium sheets and others ....35,000 baht.

Hence, total investment is ....94,600 baht.

With the information described above, the simple payback period is 447 days or 1 year 3 months.

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[*] Based on the selling price for the "HT Microfiber Blanket" issued by the Microfiber Industries Ltd. on February 7, 1985.

ECO 3 Piping Modification and Insulation for the Region Between the Extraction Tower and the Wash-Water Collection Tank

Heat loss occurs when the washing water flows from the upper portion of the extraction tower to the wash-water collection tank. The temperature of the flowing solution drops during this stage by about 15°C.

To calculate heat loss, we use the equation

$$Q = (\dot{m}_{ww} C_{ww} + \dot{m}_{m} C_{m}) \Delta T$$

where $\dot{m}_{ww}$ = mass flow rate of washing water, kg/hr;

$\dot{m}_{mm}$ = mass flow rate of monomer, kg/hr;

C_{ww} = specific heat of washing water, kcal/kg°C;

C_{m} = Specific heat of monomer, kcal/kg °C;

and ΔT = temperature drop at this region, °C.

With the data gathered, the amount of heat loss from this region is approximately 21,249 kcal/hr.

The process after this collection tank is evaporation which requires steam of 2 $kg/cm^2 g$. The heat loss mentioned above must be prevented to reduce steam requirement in the evaporation process.

Economic Analysis:

Dry saturated enthalpy of steam (2 $kg/cm^2 g$) is 650.90 kcal/kg.

Steam production cost, see ECO 2, equals .... 0.37 baht/kg.

Boiler efficiency, Table 7.2, is .... 89.60 %

Hence, the energy cost for the loss of 21,249 kcal/hr, estimated above, is $\dfrac{(21{,}249 \text{ kcal/hr})}{(650.90 \text{ kcal/kg})(89.6\%)} \times (0.37 \text{ baht/kg}) =$

12.08 baht/hr

For the 365 days of continuous operation, this amount of energy cost equals 105,821 baht/year (or 8,818 baht/month).

Investment:

Fiberglass	30,000 baht
Piping modifications	25,000 baht
Labor (3 technicians, 5 days)	1,500 baht
Others (wraping sheets, rivets, etc.)	15,000 baht
Hence, total investment is	71,500 baht

With the information described above, the simple payback period is 9 months.

ECO 4 <u>Replacement of Steam Ejector with Vacuum Pumps</u>

For the twenty-four (24) hours of continuous running, each single-stage steam ejector for the finishing towers consumes 96 kg per hour of high pressure steam of 9 kg/cm^{2}g, see Appendix I.3 item 'The Finishing Tower steam Ejector' for more information. Energy cost for this quantity of steam can be estimated as follows:

Steam production cost, see ECO2, is	0.37 baht/kg.
Daily operation time of the ejector is	24 hours.
Annual operation time of the ejector is	365 days.

Hence, energy cost for the 96 kg/hr of steam is (96kg/hr)(24hr/day)(365days/yr)(0.37baht/kg) or 311,155 baht/year.

The duty of this ejector at the finishing towers is to pump out the dowterm vapor from the towers. An alternative method to do this is to employ a vacuum pump with designed rating of 1 HP (0.746 kW).

Economic Analysis:

Energy cost (per year) for the vacuum pump is (0.746 kW) (8760 hr/yr) (1.56 baht/kWh)................ 10.195 baht.

Energy cost for the ejector, as described above, is................................ 311,155 baht.

Therefore, energy cost reduced (per year) is 300,960 baht.

Investment:

Two vacuum pumps[*] .... 65,450 baht.

Labor force(4 technicians, 1 week)......... 2,800 baht.

Additional accessories (pipes, joints, etc.).. 10,000 baht.

Repairing and maintenance, per year[**] ...... 2,400 baht.

The useful life of the pumps (approx.)..... 10 years.

The firm's cost of capital (assumed)........ 12 %.

Salvage value of the pumps after 10 years, assumed to be 5 % of their initial prices .... 3,273 baht.

Applying the payback period technique, we obtain

$$0 = -P + CF\,(P/A,\ i\%, n) + SV\,(P/F,\ i\%, t)$$

where P = the initial investment of the project = 65,450 + 2,800 + 10,000 = 78,250 baht;

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[*] The two pumps (one standby) is manufactured by the Dresser Industries, Inc. of the U.S.A. with suction pressure of 6 psi., capacity of 8 CFM, pipe size of $3/_4$ in., speed of 1580 RPM, and nameplate rating of 1 HP. This information is provided by the Foo John Trading Co. on August 23, 1986.

[**] Assume that the pumps are rewired four (4) times and four sets of their ball-bearings are replaced.

CF = cash flow during the ten (10) years considered = 300,960 - 2,400 = 298,560 baht/year (or 24,880 baht/month);

SV = the salvage value of the two pumps after ten years = 3,273 baht;

i = the effective interest rate per year, assumed to be equal to the firm's cost of capital of 12 %;

n = the payback period being sought, month;

t = the useful life of the pumps = 10 years;

$(P/A, i\%, n)$ = the uniform payment series present worth factor;

$(P/F, i\%, t)$ = the single payment present worth factor.

By substituting these values in the above equation, we have

$$0 = -78{,}250 + 24{,}880\,(P/A, 1\%, n)^{*} + 3{,}273\,(P/F, 12\%, 10).$$

When n = 3, see Table I.2 and I.3 (Interest Tables), the above equation becomes

$$0 = -4024.014$$

and when n = 4, the equation becomes

$$0 = 19{,}885.666$$

The results, attained above, indicate that the payback period is somewhere between n = 3 and n = 4.

ECO 5 Elimination of an Excessive Ejector for the Finishing Towers

An experiment conducted in December 1985 by the production department revealed that one of the two ejectors for the finishing

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[*] The i-value must be devided by 12 to obtain monthly rate.

towers can be stopped without any effect to the towers' operations.

The energy cost saving by this ejector is 311,155 baht/year, see ECO 4, with a "no-cost" investment.

Summary

In this chapter we investigated the thermal system concentrating on steam generation and utilization of the plant. For the steam generation sub-system, general operating conditions of both water side and fuel oil side were described. The boiler heat balance was determined to identify the system performance. The steam utilization sub-system, on the other hand, was analyzed to disclose the quantity of steam flowing to each piece of equipment concerned. Upon completion of these two basic computations, energy conservation opportunities (ECOs) were identified. Then, detailed analysis was made for some selected ECOs.

Data collected during November 1985 were used in the calculation process and the result indicated that the boiler efficiency is 89.6 percent. We recommended that the calculation be reviewed when more reliable data is available.

In estimating steam consumption for each piece of equipment, the first law of thermodynamics was employed. The specific data from the real manufacturing processes were all omitted, rather, they were substituted by some appropriate symbols. The results, however, were derived from the actual data obtained.

A ranking of steam consuming equipment was given in Table 7.3 and Figure 7.4 in order to highlight the thermal energy distribution in this plant.

Economic analysis was made for the prominent ECOs revealed attractive investment in many cases. These results are summarized in Table 7.5.

Table 7.5 A Summary of the Results from Detailed Analysis

	Item	Expected Annual Saving,฿	Investment ฿	Payback Period
ECO 1	Reset blowdown rate	155,344	none	immediately
ECO 2	Construct insulation for the wet chip storage bins	77,380	94,600	lyr,3 mo.
ECO 3	Modify and insulate the piping system for the region between the extraction tower and the wash-water collection tank	105,821	71,500	9 mo.
ECO 4	Replace steam ejector with vacuum pump for the finishing towers*	298,560	78,250	4 mo.
ECO 5	Stop excessive ejector of the finishing towers	311,155	none	immediately
	Total saving	948,260	244,350	Less than 1 yr 3 mo.

*See ECO 4 for more details.