Improvement of Pulp Mill Energy Efficiency in an Integrated Pulp and Paper Mill

Leena Kilponen, Helsinki University of Technology
Pekka Ahtila, Helsinki University of Technology
Juha Parpala, Stora Enso Oyj
Matti Pihko, Stora Enso Oyj

ABSTRACT

Finland is among the most advanced countries in the world in the development and use of energy efficient technology. Minimizing the specific energy demand of industrial processes is one of the main objectives. This paper examines a case focusing on the improvement of pulp mill energy efficiency by saving steam with process modifications. A method of simple rules based on thermodynamic principles and process integration is applied.

In this particular study, the pulp mill heat demand would decrease by 7.6 %. The specific heat demand of pulp would reduce from the current 9.2 GJ/ADt of bleached pulp to the value 8.5 GJ/ADt, which, according to literature, exceeds the potential of the existing mills in the late 1990s. The results imply that similar savings can be found in other existing mills provided with a corresponding comprehensive analysis.

Introduction

Energy costs form a significant part of the operating costs of the pulp and paper industry. In different evaporation and dewatering processes primary energy is transferred into low-grade secondary energy usually in the form of warm or hot water, which in turn can be utilized under certain conditions. If the temperature level of the secondary energy is high enough, it can replace the use of steam for heating purposes.

This study presents a case of a typical modern pulp mill. When designing an improved heat distribution system, examination of the use of energy as a whole in the mill is necessary. In an integrated pulp and paper mill a number of separate business units occupy different subsections of the site and operate independently. This may leave hidden defects to the processes causing unnecessary energy use.

According to Franck et al. (1999), the potential for steam reduction has typically been 5 to 10 % in traditional process integration studies where new process equipment is accepted. Earlier studies on energy conservation indicate even more potential in the pulp and paper industry. In Finland it has been estimated that reduction rates of 16 % in process heat and 8 % in power consumption could be achieved by using the available technology (Jaakko Pöyry Oy 1990).

Today energy efficiency auditing procedures are yet under construction. Companies have just started implementing energy auditing and follow-up studies are not available. Due to the lack of evidence, there is still great prejudice against the profitability of energy conservation. Positive examples would encourage companies to proceed with their energy conservation investments and include energy efficiency auditing as part of their standard operations.

Methodology

In this study energy conservation calculations are based on the general rules of thermodynamics and process integration. To avoid complexity and large investment costs, the studies were made according to the following principles:

- Utilize the whole temperature potential of streams; don't mix streams at different temperatures.
- Avoid heating with primary energy at temperatures below the hottest available secondary energy.
- Study the availability of secondary energy, secure the operation of processes at all times.
- Calculate the profits and investment costs for each design. In the case of different alternatives, choose the best design according to its net present value.
- Study the effects of energy conservation on the whole process.

At the beginning of the studies the intention was to use pinch analysis in the calculations. During the background studies, however, it was found that the pinch analysis would have been too time-consuming. The advantage of pinch analysis is that it also reveals utilities where heat is transferred across the pinch, against the rules of the minimum use of energy. In an existing process following the pinch rules requires extensive work in the optimization of investment costs. In addition, the availability of secondary energy is rarely a restriction in pulp mills.

Price of Saved Steam

In this research the pricing method for saved steam is based on a publication of the Finnish Forest Industries Federation (1976), and has later been modified by Pihko (2000). The first step in the calculations is to define the price of saved high pressure steam according to the price of purchased fuels and their combustion efficiencies.

Saving steam should be based on the most expensive fuel used within the mill. A ratio term is needed if there are more than one fuel that is cut back. For example, oil usually serves only as backup fuel for peat and cannot be reduced without the other. The price of high pressure steam is the following:

$$P_{\mathrm{SHP}} = \sum_{i=1}^{n} \frac{3.6 X_i P_{\mathrm{EUR/t},i}}{\eta_i H_i} = \sum_{i=1}^{n} \frac{X_i P_{\mathrm{EUR/MWh},i}}{\eta_i}, \tag{1}$$

where P_{SHP} is the price of high pressure steam, X_i the ratio of the fuel i, $P_{\mathrm{EUR/t},i}$ the price of fuel i, $P_{\mathrm{EUR/MWh},i}$ the price of fuel i, η_i the combustion efficiency of the fuel i, and H_i the lower heating value of the fuel i. The equation has two forms according to the unit conversion of the fuel price.

The prices of saved middle and low pressure steams depend on the price of saved high pressure steam, power generation, and the price of purchased electricity. The steam consumption of a back pressure turbine depends almost linearly on the relative load of the turbine. The most important characteristic in back pressure power generation is the power to process heat ratio:

$$\alpha = P_g / Q_t, \tag{2}$$

where P_g is the power generation at the alternator terminals and Q_t the process heat demand.

The power to heat ratios of steams in different pressures must be calculated separately. The quantity of energy extracted in the turbine is proportional to the difference in the energy of the steam passing through the turbine. The power generation of the turbine at the alternator terminals is the following:

$$P_g = \dot{m}_b(h_b - h_2) - Q_{tl}, \tag{3}$$

where Q_{tl} is the turboalternator mechanical and electrical losses, $\dot{m}_b$ the boiler steam flow, h_b the boiler steam enthalpy, and h_2 the steam enthalpy after the turbine.

The definition of process heat is the following:

$$Q_t = \dot{m}_t h_t - \dot{m}_c h_c, \tag{4}$$

where Q_t is the process heat demand, $\dot{m}_t$ the steam to process, h_t the process steam enthalpy, $\dot{m}_c$ the process condensate return, and h_c the process condensate enthalpy.

The price of middle pressure or extraction steam is the following:

$$P_{SMP} = P_{SHP} + \frac{\alpha_{SMP} P_{SHP}}{\eta_g} - \alpha_{SMP} P_e, \tag{5}$$

where P_{SMP} is the price of middle pressure steam, α_{SMP} the power to heat ratio of middle pressure steam, η_g the efficiency of the turbine and turbogenerator, and P_e the price of purchased electricity.

The price of low pressure or back pressure steam is the following:

$$P_{SLP} = P_{SHP} + \frac{\alpha_{SLP} P_{SHP}}{\eta_g} - \alpha_{SLP} P_e, \tag{6}$$

where P_{SLP} is the price of low pressure steam and α_{SLP} the power to heat ratio of low pressure steam. If the turbine has several extraction stages, the price of each steam can be calculated similar to the Equations (5) and (6).

Investment Calculation Methods

The economic evaluation of a project's desirability requires a stipulation of a decision rule for accepting or rejecting investment projects. The next sections present the financial decision rules for wealth maximization: the net present value, payback period, and the internal rate of return.

Net present value. An investment proposal's net present value is derived by discounting the net cash receipts at a rate which reflects the value of the alternative use of the funds, summing them over the life of the proposal and deducting the initial outlay (Levy & Sarnat 1990). In this study, the net present value (NPV) can be defined as follows (Uusi-Rauva et al. 1993):

$$a_{n/i} = \frac{(1+i)^n - 1}{i(1+i)^n}, \tag{7}$$

$$V_0 = a_{n/i} \cdot S \text{, and} \tag{8}$$

$$NPV = V_0 - I_0, \tag{9}$$

where NPV is the net present value, I_0 the initial investment outlay, V_0 the net profit present value, S the net cash receipt at the end of year n, n the operation time, i the discount rate i. e. the required minimum rate of return on new investment, and $a_{n/i}$ the present value coefficient.

If the outcome of the net present value is positive, the investment is acceptable. Net present value is the most reliable feasibility indicator since it reflects the absolute magnitude of the project (Levy & Sarnat 1990). The larger the value is the better the profits.

Payback period. The payback period gives the number of years required to recover the initial investment outlay from a project's future cash flows. The payback can be calculated using the formula (Levy & Sarnat 1990):

$$\text{Payback period} = \frac{\text{Initial investment outlay}}{\text{Annual cash receipts}}. \tag{10}$$

The method has rather obvious defects. It concentrates solely on the receipts within the payback period; receipts in later years are ignored.

The payback period is often falsely used as an argument for rejecting profitable energy conservation investments. For example, Diesen (1998) suggests that the payback time should be less than 3-4 years to accept an investment. The reason for this is that a higher output provided by the implementation cannot be achieved due to limitations, complications, and bottlenecks that the implemented investment reveals elsewhere in the production line. In other words, Diesen's recommendation includes a certain margin for an unknown risk.

Internal rate of return. The internal rate of return (IRR) is defined as the rate of discount, which equates the net present value of the cash flow to zero (Levy & Sarnat 1990). If the internal rate of return is greater than the required rate of return of the investment, the investment is acceptable. The internal rate of return can be compared with the cost of funds to yield a 'margin of profit'. Mutually exclusive decisions should be dictated by differences between the alternative proposals' net present values and not by their internal rates of return.

Subject Analysis

In this study the subject of investigation is the Stora Enso Fine Papers Oy Oulu Mills (Figure 1). The mills include a sulfate pulp mill, a paper mill with two paper machines PM6 and PM7, and a sheeting plant. The capacity of the pulp mill is 370 000 t/a of elementary chlorine free (ECF) pulp. The paper mill produces coated art paper, using as its raw material fully bleached softwood and hardwood pulps from the pulp mill. The capacity of PM6 is 420 000 t/a and PM7 382 000 t/a. The capacity of the sheeting plant is 300 000 t/a.

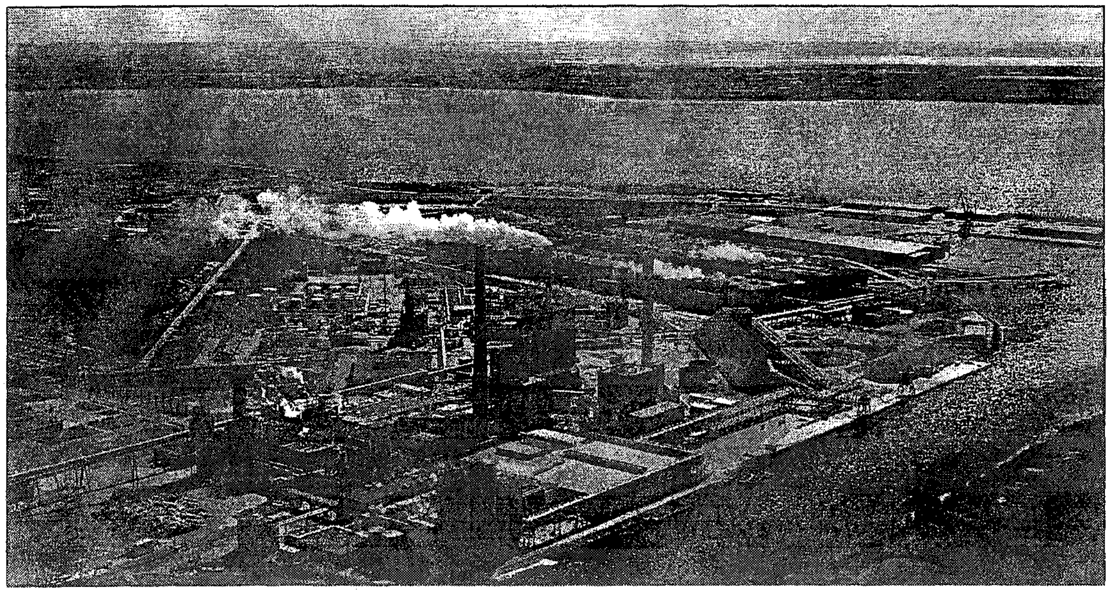

Figure 1. Stora Enso Fine Papers Oy Oulu Mills

The pulp mill excess heat and power are utilized in the paper mill and chemical industry located nearby. The incineration of heavy black liquor takes place in the chemical recovery boiler SK7. The rest of the heat energy for the process is produced in the fluidized bed boiler K3 fuelled by bio-fuels and peat. Back pressure turbines T5 and T6 convert a part of the steam energy into electrical energy. The rest of the power demand is covered by purchased electricity.

In the Oulu Mills the savings in energy were found by analyzing and looking for alternative process options from the process streams. Separate flow sheets were drafted for the mills' primary heat system and the pulp mill warm water system (see Appendices 1-3). The purpose was to define the temperature levels, flow rates, and the distribution of the main heat streams in the process. The flow sheet of the pulp mill warm water system was especially important because it revealed the availability of secondary energy for any alternative use.

According to Gullichsen and Fogelholm (2000), the heat demand of the existing pulp mills is on average 11-12 GJ/ADt of bleached pulp. The average heat demand of the Oulu pulp mill is only 9.2 GJ/ADt, which is very close to the 8.5-9 GJ/ADt potential of the existing mills in the late 1990s. In this sense, the Oulu pulp mill is already energy efficient.

The current study focused on five potential energy saving opportunities found by investigating the pulp mill steam utilities. The preheating of chemically treated water with scrubber water would require adding a third heat exchanger between the two current heat exchangers in the drying department. The circulation water used in wood deicing could be heated indirectly with scrubber water. Scrubber water could also be used for the preheating of the recovery boiler combustion air. The whole temperature potential of the hot water from the turpentine condenser could be utilized by connecting the stream directly to displacement bleaching. The rest of the hot water could be used for preheating of the circulation water in the mill district heating system.

To evaluate the feasibility of the found opportunities, it was necessary to analyze the duration curves of all process variables affecting the designs. The investment costs of the proposed modifications were also determined.

Results

The results with three investment calculation methods are shown in Table 1. The discount rate of the net present value is 15 % and the operation times are 10 to 15 years. The price of purchased electricity is so decisive on the results that the calculations were made with two prices 25.2 and 33.6 €/MWh according to the estimated future minimum and maximum prices of electricity in the Nordic Power Exchange (Nord Pool). As seen in Table 1, the negative impact of loss of cogeneration power is the greater the higher the price of purchased electricity.

The designs with positive net present values are profitable. Only one design, the preheating of the recovery boiler combustion air, was found to be uneconomic due to its large investment costs. The costs would be considerably lower in a new mill. The total net present value of the profitable designs is 815 000 – 1 561 000 € depending on the price of electricity. The preheating of chemically treated water is the most profitable, hot water tank by-pass the next etc.

Table 2 presents the estimated potential for saving heat with the five proposed modifications. The annual savings in heat energy would be 70.9 GWh. This is equal to 7.6 % of the pulp mill heat demand. The pulp mill heat demand would drop to 8.5 GJ/ADt which exceeds the estimated potential of the existing mills in the late 1990s.

Electricity production decreases by 2.0 MW due to the loss of cogeneration power. This is equal to 3.1 % of the Oulu Mills total power production. There will also be a small increase (166 kW) in the pulp mill power demand in winter due to the increased pumping of the scrubber water.

Emissions reduction in the Oulu Mills is based on the use of peat. The use of peat decreases by 15.3 % which is equal to 26 600 t/a. Accordingly, the carbon dioxide emissions reduce by 25 100 t/a, the sulfur dioxide emissions by 53 t/a, and the nitrogen oxides by 740 t/a.

The reduction in the Oulu Mills' CO_2 balance is 5.1 %. The total CO_2 balance includes all fossil fuels in use at the mills: peat, oil, and liquefied petroleum gas (LPG). Oil is used in the lime kiln, and as backup fuel in the recovery and fluidized bed boilers. LPG is used in the IR dryers of the two paper machines. A flow sheet of the pulp mill warm water system after the changes is presented in Appendix 4.

Table 1. Results of Investment Calculations

Case I: Electricity 33.6 EUR/MWh	Net present value [EUR]	Payback period [a]	Internal rate of return [%]
Preheating of chemically treated water	547 300	1.0	101
Hot water tank by-pass	173 600	0.5	216
Wood deicing	56 300	4.7	20
Mill district heating	37 300	3.8	26
Preheating of SK7 combustion air*)	-487 900	12.1	3
	Max. 814 600		

Case II: Electricity 25.2 EUR/MWh	Net present value [EUR]	Payback period [a]	Internal rate of return [%]
Preheating of chemically treated water	939 200	0.6	159
Hot water tank by-pass	283 700	0.3	340
Wood deicing	240 700	2.9	35
Mill district heating	97 500	2.4	42
Preheating of SK7 combustion air*)	-251 600	8.0	9
	Max. 1 561 200		

*) uneconomic, not included in the max. values

Table 2. Estimated Heat Energy Savings per Year

Process modification	MWh/a
Preheating of chemically treated water	39 000
Preheating of SK7 combustion air*)	24 400
Wood deicing	15 800
Hot water tank by-pass	11 000
Mill district heating	5 100
Max.	70 900

*) uneconomic, not included in the max. value

Comments and Conclusions

This study confirms that process integration still has a substantial profit potiential in the pulp and paper industry. In this particular case, applying a method of simple rules resulted a heat saving potential of 7.6 % in a pulp mill performing well according to the current standards.

A thorough evaluation of the whole mill is a prerequisite to any process integration study. The effects of the proposed modifications have to be carefully analyzed to avoid bottlenecks which would ultimately restrict the operation time of the investments. After determining the best opportunities, alternative proposals should be evaluated against their costs, risks, and profits by using the net present value as the primary criterion.

When companies are striving for better competitiveness, the improvement of energy efficiency is often mentioned as one of the tools. In practice, few companies are active in utilizing their full potential. In conclusion, energy conservation is an area which will require increasing resources in the future – an aspect that has yet to be widely recognized.

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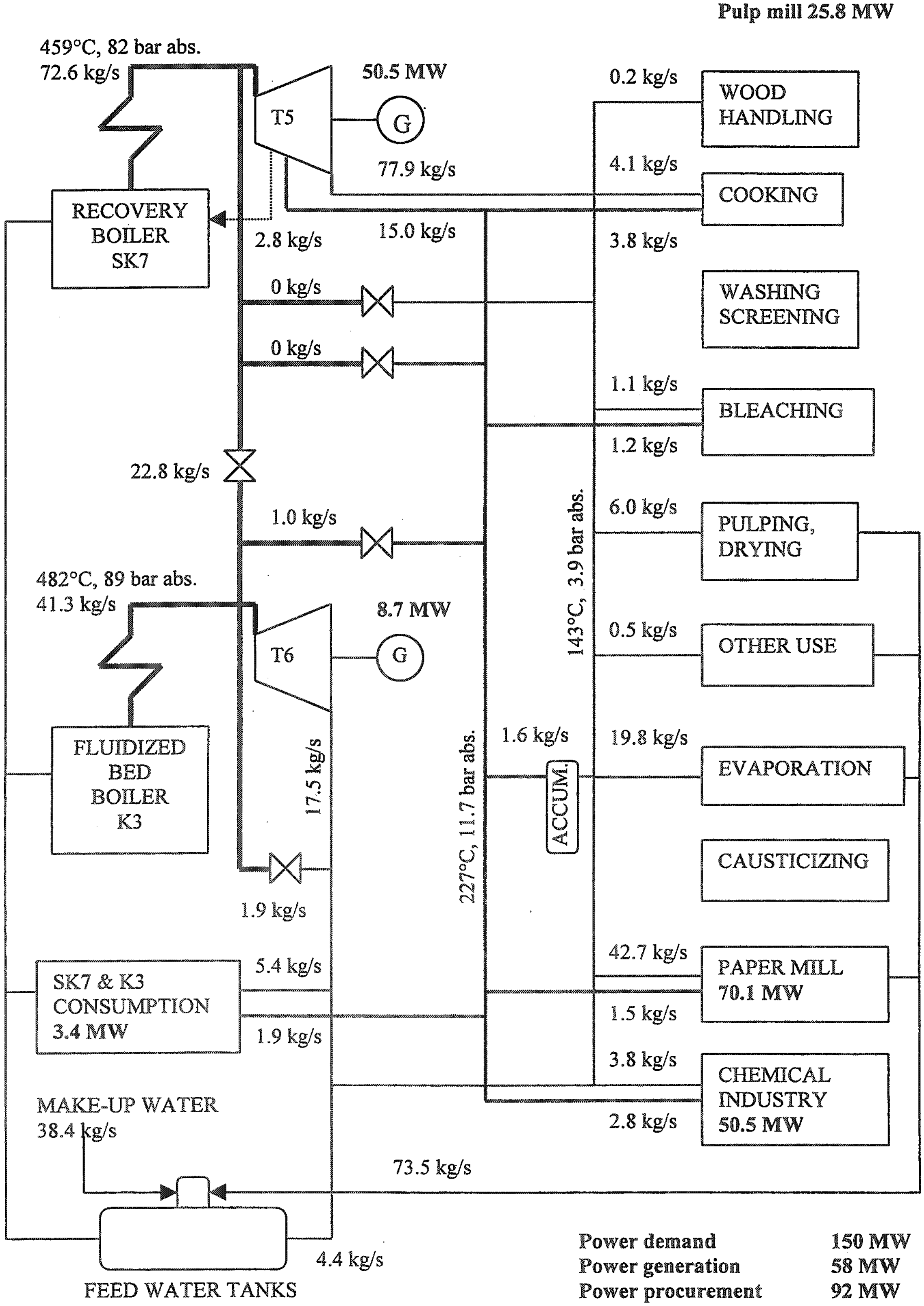
APPENDIX 1: Flow Chart of Primary Heat, Summer 1 Jul – 30 Nov 1999

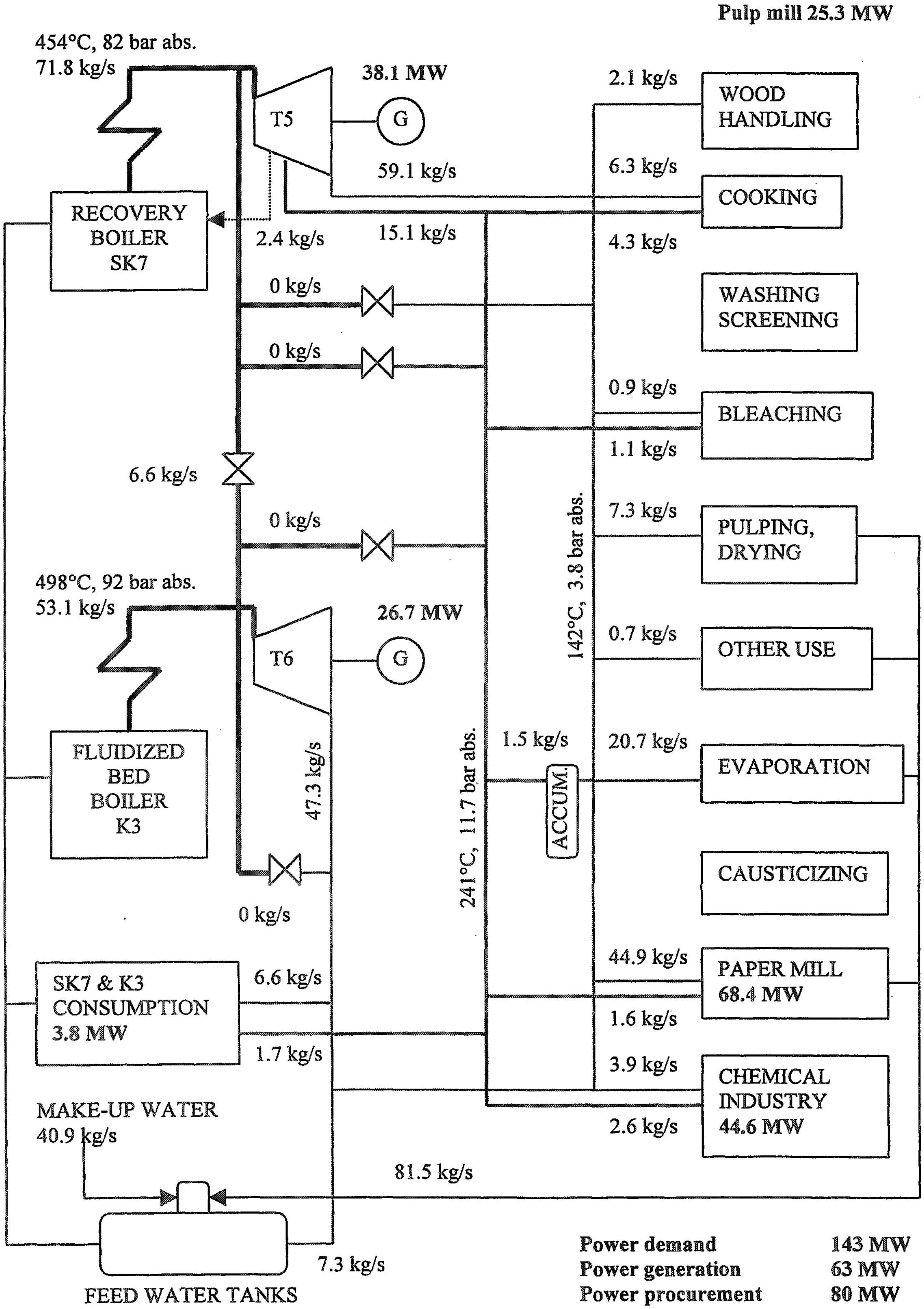
Production 1086 t/d 90 % bleached pulp
Average outside temperature 10°C



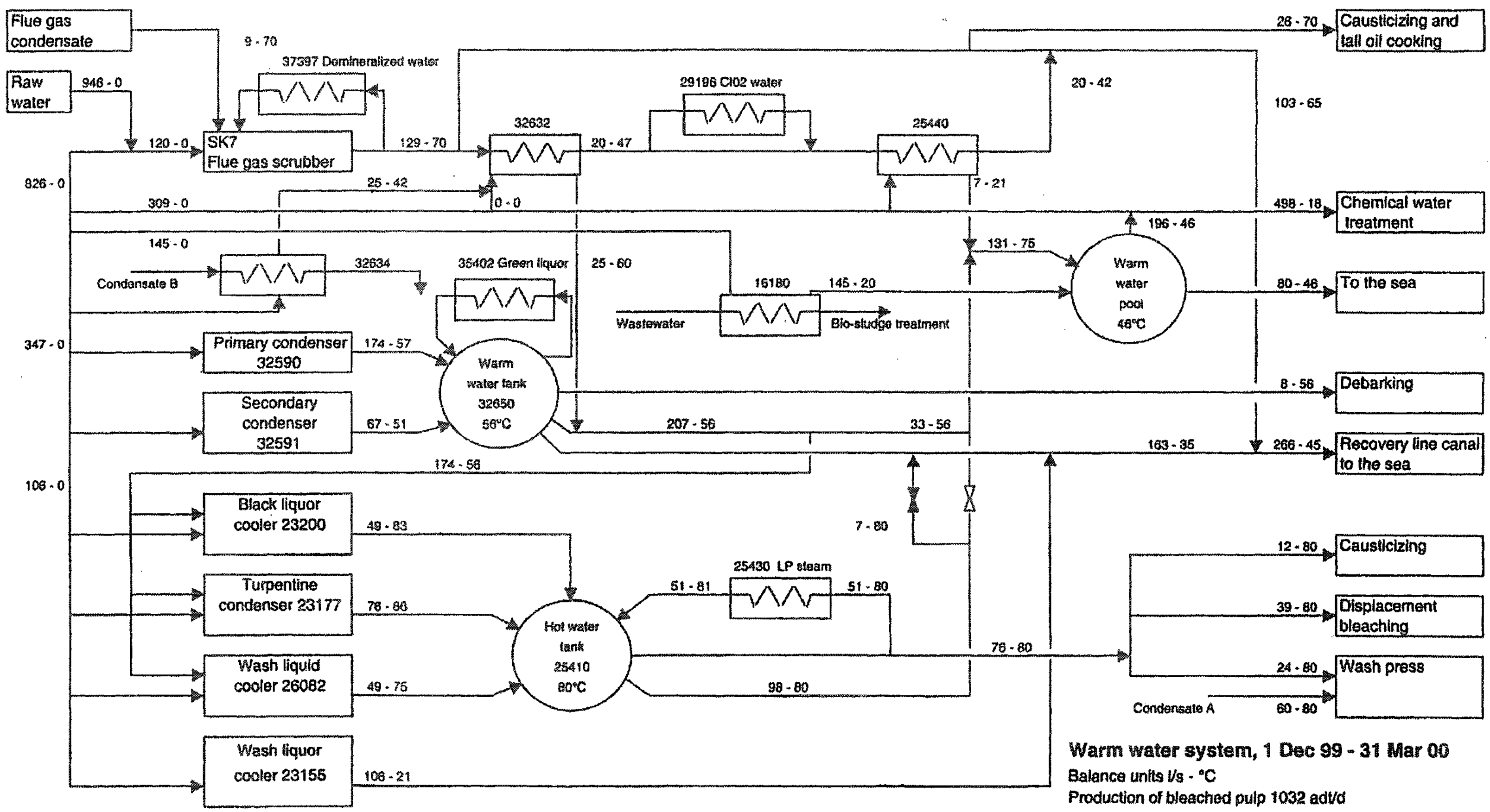
Power demand	**150 MW**
Power generation	**58 MW**
Power procurement	**92 MW**

APPENDIX 2: Flow Chart of Primary Heat, Winter 1 Dec 1999 – 31 Mar 2000

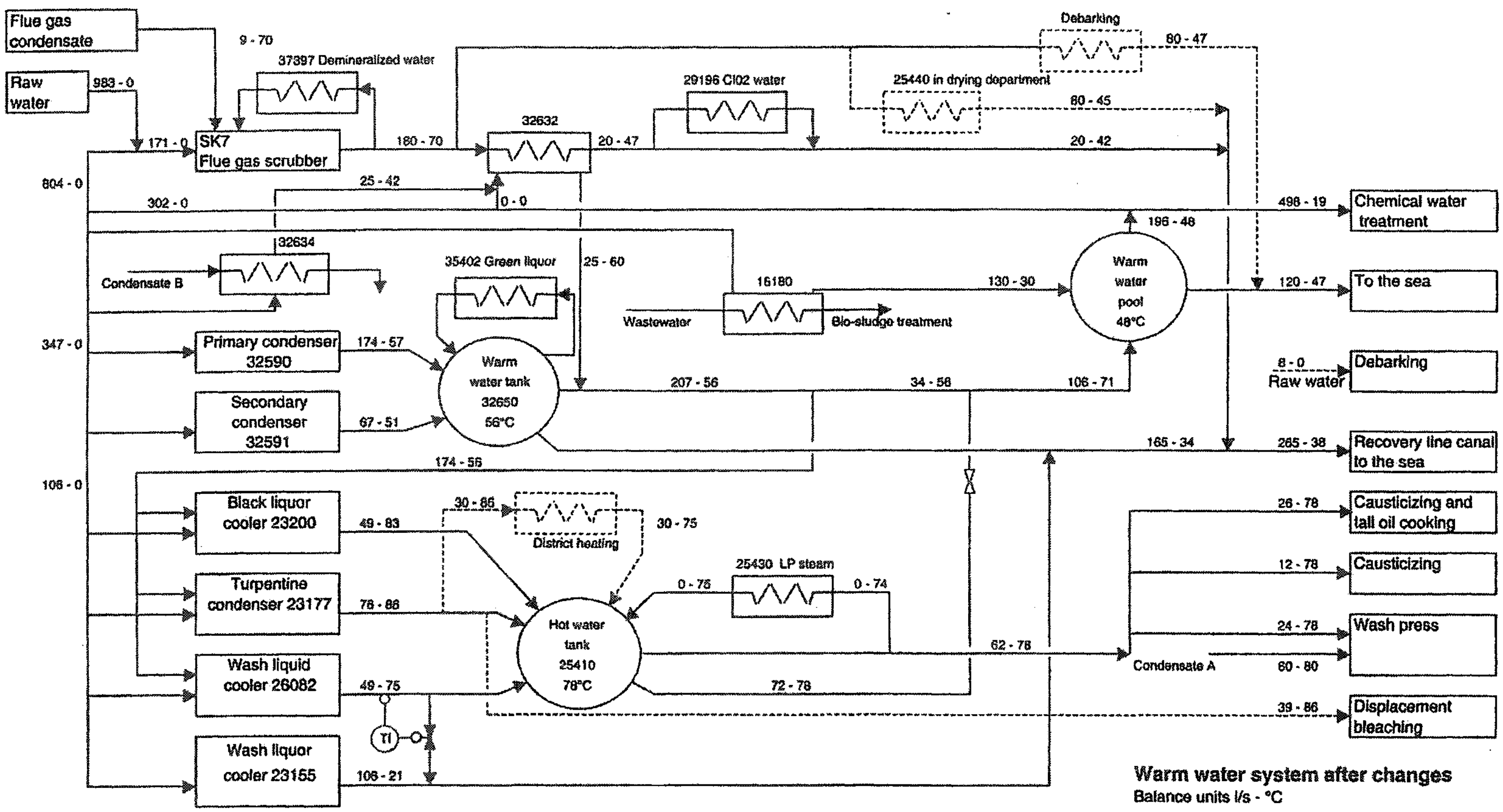
Production 1032 t/d 90 % bleached pulp
Average outside temperature –6°C



Power demand	**143 MW**
Power generation	**63 MW**
Power procurement	**80 MW**



Warm water system, 1 Dec 99 - 31 Mar 00
Balance units l/s - °C
Production of bleached pulp 1032 adt/d



Warm water system after changes
Balance units l/s - °C