ENERGY GENERATION AND USE IN THE KRAFT PULP INDUSTRY

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INTRODUCTION

The pulp and paper industry is one of the largest users of energy among the process industries, but most of its requirements, both steam and electrical power, can be produced from by-product and waste material produced within the process.

This paper will discuss energy utilisation and generation in kraft pulp mills, and briefly describe the basic kraft pulping process.

THE KRAFT PROCESS

The kraft process is the most widely used chemical pulping process for a number of reasons:

- it produces the strongest pulp;
- it can handle a wide range of furnish: softwood, hardwood, bagasse and bamboo;
- the cooking chemicals can be recovered economically;
- it is energy efficient.

Figure 1 shows a simplified schematic of a kraft mill.

The wood furnish supplied to the mill can be in the form of logs (roundwood) or by-product chips from sawmills. The source of the wood supply has a significant affect on the energy production. If roundwood is chipped the waste wood produced per ton of chips will be around 200 kg, but when sawmill by-product chips are used the waste wood produced in the sawmill will be in the range of 450 kg/ton chips, as most of the log goes to produce lumber. This waste wood may be available to the pulp mill at a low cost, or even negative cost, allowing the production of low cost steam and electrical power.

The chips are mixed with white liquor (NaOH and Na_2S) and cooked, using steam, in a large pressure vessel called a digester, either in a continuous or batch process. During cooking the binder holding the wood fibres together is dissolved. This binder called lignin, has a high calorific value, and ultimately provides most of the energy required to operate the mill.

The mixture of fibres, dissolved lignin and spent cooking chemicals is passed over screens where the fibres are separated. The fibre is then washed, bleached and passed to the dryer where it is formed into sheets and baled for shipping to the paper mills.

The lignin and spent chemicals, called black liquor, passes to a multiple effect evaporator plant where the concentration is increased from 14-18% up to 65-75% for firing in the recovery boiler.

Multiple effect evaporators use the vapour driven off one effect as the heat source for the next effect. In desalination and some other processes as many as twenty effects can be used, but, because of the high concentration required in the product liquor, the boiling point rise of the black liquor limits the usual maximum number of effects to eight, and most commonly four or five are used. A five effect system evaporates approximately 4.25 lbs of water for every pound of live steam.

The concentrated black liquor is processed in a recovery boiler where the lignin is burned, providing heat to reduce and smelt the spent cooking chemicals. These chemicals, now Na_2S and Na_2CO_3, are tapped from the bottom of the furnace, dissolved in water, and, as green liquor, go to the causticizing plant where the Na_2CO_3 is converted to Na_2S and the white liquor recovered for reuse in the digester, closing the chemical recovery loop.

Energy consumption

Kraft mills use energy in various forms, heat, chemical and electrical:

- heat energy is usually in the form of steam;
- chemical as biomass or fossil fuel;
- electrical as self-generated or purchased electrical power.

Steam is used in most areas of the mill, the large consumers being the digester, the pulp dryer and the evaporator plant. It is used mainly at two pressure levels, 1,200 kPa (175 psig) and 400 kPa (60 psig).

Chemical energy is provided by the lignin in the black liquor, by waste wood, and by oil, coal or gas. These fuels are used in the boilers, and oil and gas in the lime kiln.

Electrical energy is used throughout the mill.

Kraft mills exist in a wide range of sizes, but most modern mills are between 500 and 1800 air dry tons of pulp per day (ADtpd), with new mills being in the range of 1200 to 1800 ADtpd.

While there are some energy economies of scale, the specific use is fairly constant over the size range and we can compare mills based on their consumption per ADt. Ambient conditions, summer and winter differences for example, have a very significant affect on energy consumption, particularly water temperature, and this must be considered in any comparison.

Tables 1 and 2 show typical specific steam and electrical power consumption figures for a modern kraft mill.

Modern mills are much more efficient in the use of steam, 25 years ago specific steam consumptions of 10 to 12 t/ADt were common, compared to 6 to 8 t/ADt for efficient plants today.

Table 1 Specific Steam Consumption, Softwood-Summer

Area	**Units**	**MP**	**LP**	**Total**
Cooking	t/ADt	1.15	0.05	1.20
Bleaching	t/ADt	0.35	0.47	0.82
Chemical Preparation	t/ADt	0.01	0.21	0.22
Pulp Dryer	t/ADt	1.45	0.17	1.62
Evaporator	t/ADt	0.04	2.05	2.09
Recovery Boiler	t/ADt	0.26	0.29	0.55
Miscellaneous	t/ADt	0.02	0.08	0.10
Total	**t/ADt**	**3.28**	**3.32**	**6.60**

Electrical power specific consumption has remained fairly constant over the years, despite real economies in many areas. This is due to the addition of environmental control equipment, and the integration of bleaching chemical plants into many of the mills.

Table 2 Specific Power Consumption

Area	Units	Amount
Woodroom	kWh/ADt	65.0
Pulp Mill	kWh/ADt	95.8
Pulp Dryer	kWh/ADt	109.5
Recovery Boiler / TG	kWh/ADt	73.5
Water Treatment / C. Tower	kWh/ADt	42.2
Effluent Treatment	kWh/ADt	40.0
Pulp Cleaning / Chem. Prep.	kWh/ADt	136.9
Bleach Plant	kWh/ADt	13.7
Power Boiler	kWh/ADt	41.1
Demineralizers / Evaporators	kWh/ADt	78.8
Recausticizing	kWh/ADt	13.7
Misc. Services	kWh/ADt	13.7
Total	**kWh/ADt**	**723.9**

STEAM GENERATION

Recovery boiler

Black liquor has a HHV of around 14,000 kJ/kg (6,000 Btu/lb) of dry solids, is fired with 25 to 35% water, and approximately 50% of the dry solids is inorganic material with an ash fusion temperature of around 1450°F. It is a difficult fuel and a very special boiler design is required.

Figure 2 shows a typical modern recovery boiler.

Liquor from the evaporator plant, at 65 to 75% solids, is sprayed into the furnace through multiple nozzles, designed to provide uniform, relatively large, droplets. The liquor partially dries in suspension and accumulates on the furnace floor. In order to convert the sodium sulphate to sodium sulphide, a reducing atmosphere is maintained in the bed area by introducing less than stoichiometric air requirements, but enough material is burned to generate heat to smelt the chemicals and drive off volatiles which are burned above the bed. The hot gas rising from the bed is cooled in a large furnace section, before entering the superheater and saturated convection surface.

Slagging and fouling are major problems which have to be overcome with low temperatures, low velocities and numerous sootblowers. In addition to these problems if water is accidentally introduced into the bed, due to a tube leak, a disastrous explosion can occur. Not the most comfortable units to operate, but the kraft process would not be practical without the recovery boiler as the cost of cooking chemicals and alternate disposal of the spent liquor would be prohibitive.

The normal upper economic limit for steam pressure and temperature is around 6,200 to 10,000 kPa (900 to 1,450 psig) and 450 to 500°C (850 to 925°F) depending on the area and the local cost of electrical power. Although units have been built for slightly higher conditions the higher capital and maintenance costs can not usually be justified.

In the larger size range these boilers fire 2,000 to 3,500 tons black liquor solids per day and produce 300 to 550 tons steam per hour.

Power boiler

Most mills have a power boiler using waste wood (hog fuel) as the primary fuel, backed by oil or natural gas. These units are usually in the size range of 100 to 300 tons steam per hour and many are very similar in design to stoker fired coal units, although bubbling fluid bed units are becoming more common.

Dry wood has a calorific value of around 18,500 to 20,000 kJ/kg (8,000 to 8,800 Btu/lb) depending on specie, and is fired at 45 to 60% moisture, depending on location. It is a clean fuel, low sulphur and low ash, and the main problem in firing is the non-homogeneous nature, particularly as regards to size. It is usually a mixture of bark, planer shavings, sawdust, and chip fines, each of which have different handling and firing characteristics. In western coastal mills varying moisture and sodium chloride, from salt water, is also a concern.

A typical stoker/vibrating grate unit is shown in Figure 3.

COGENERATION

Although 'cogeneration' is a term which was coined during the Carter administration the concept has been known and used since the industrial revolution.

Figure 4 illustrates the efficiency advantage of cogeneration.

If a process or plant requires heat as steam, this may be generated in a boiler at the pressure required for the process, in which case, for the example shown with 100 t/h steam to process, 368.8 GJ/hr of fuel input is required.

If steam is generated at a higher pressure in the boiler and passed through a steam turbine exhausting at the process pressure, for the same amount of process steam, 425.3 GJ/h is required from the fuel and 12.5 MW electrical power can be generated.

As the process steam is the same in both cases the heat rate for the power generated is simply the difference in fuel input and for the example shown is 4,518 kJ/kWh (4,282 Btu/kWh).

This compares to 12,000 kJ/kWh for a straight condensing steam station or 7,700 kJ/kWh for a combined cycle gas turbine station, all are HHV.

DESIGN CONSIDERATIONS

The objective for the designer of a mill energy system is to meet the owner's needs for a flexible, reliable system, which results in the lowest energy cost per ton of pulp allowing his mill to be competitive in the world market.

A process plant owner's primary interest is uninterrupted production, and the cogeneration plant designer must recognise this and provide a plant with high reliability. This reliability can not be provided through high redundancy, as high capital cost could make the process plant non-competitive, so the challenge is to use simple, rugged equipment, and only provide spare capacity where it is absolutely necessary.

Every pulp mill is different. They vary in size, wood specie, product, ambient conditions, water quality, local regulations, energy costs, labour costs, transportation costs, and many other factors including owner / operators preferences and wish-lists.

All of these factors affect the steam and power plant design to varying degrees:

- Size is an obvious factor, especially as it affects economy of scale.
- The wood specie being pulped affects the quantity and the calorific value of the black liquor and the amount of bark available as fuel.
- The product can be market pulp, linerboard or dissolving grade, all of which have different implications for the steam and power plant.
- Power cost, availability and reliability determines whether the plant should purchase some power or be completely self-sufficient.

- Fuel cost and availability, especially hog fuel which could have a negative cost for disposal, sets much of the plant economics, and a surplus of hog fuel may make power sales attractive.
- Eco-labelling and CO_2 reduction may be a consideration, to minimise fossil fuel use.
- The acceptable IRR for incremental investment affects decisions in many areas: steam conditions, low grade heat recovery, and selection of process equipment,

All of the above factors must be considered, and in many cases the plant has to be designed with sufficient flexibility to handle varying conditions and different operating modes.

When looking at steam utilisation the objective is to use the lowest steam pressure possible in each process area, consistent with economics. Steam expanding in a turbine from 8,000 kPa to 400 kPa generates about 50% more power than if it was extracted at 1,200 kPa.

An example is the selection of steam conditions for the pulp dryer. Where fuel and power costs are high 400 kPa steam is normally used, but a large dryer using 400 kPa steam may cost $2-3 million more than one using 1,200 kPa steam. For this reason in North America where energy costs are relatively low most dryers use 1,200 kPa steam, although more low pressure machines are now being installed as energy costs increase.

ENVIRONMENTAL CONSIDERATIONS

The main environmental concerns to be considered in the design of a steam and power plant for a kraft mill are particulate and gaseous emissions into the air from the boilers, and odorous tank vents.

Particulate emissions from the boilers, and lime kiln, are controlled using high efficiency, multi-chamber electrostatic precipitators. Collected material from the recovery boiler and lime kiln precipitators is returned to the process, reducing the need for make-up chemicals.

CO, SO_2, TRS and H_2S emissions from the boilers are minimised through optimised operation. Recovery boiler operation has been improved very significantly over the last twenty years through the elimination of direct contact of the black liquor with flue gas, high solids firing, improved combustion air systems, and improved instrumentation and control.

Other sources of air emissions are tank and other vents, and these are now collected, any water condensed, and the non condensable gases (NCG's) burned in the lime kiln, a separate incinerator or one of the boilers.

In modern mills liquid spills are collected and treated, either by being returned to the liquor cycle or treated in the main mill effluent treatment system.

Cogeneration is desirable from an environmental viewpoint, as more efficient use of fuel results in lower emissions, and burning biomass under controlled conditions results in much less air pollution than disposal in incinerators or landfill.

Modern control methods and equipment have made the kraft mill an acceptable neighbour.

POWER PRODUCTION

Cogeneration of electrical power and process steam is normally accomplished using high pressure steam generated in the recovery and power boilers to drive steam turbine generators, with steam extractions at the process pressures.

Gas turbine generators are also used, depending on site/mill specific criteria.

System configurations can vary widely, but the following comments generally hold true:

- If an extraction / back pressure steam turbine fits the cycle, it will generally prove to be the most economical.

  Flexibility to handle varying conditions can be provided by venting steam to atmosphere or a dump condenser, by-passing steam around the turbine and by purchasing, or selling, electrical power. Compared to the other options, this option produces a small amount of electrical energy relative to heat energy.

- Adding a condensing turbine, or a condensing end to a back pressure turbine, improves operating flexibility and allows additional power to be generated independent of process steam demand.
  Power generated in the condensing end of the turbine suffers an efficiency loss due to rejection of heat to the condenser cooling water, so the use of a condensing end is often determined by the incremental fuel and purchased power costs.

- A gas turbine produces a large amount of electrical energy relative to heat energy, so is useful when more power than steam is required. This may be the case where a large electro-chemical plant is located on site. It can take the place of a condensing turbine in a system, with better efficiency, but at present is limited to the use of high quality fuel, natural gas or distillate oil.

Figures 5-7 illustrate how the three systems outlined can be used in a mill.

Figure 5 shows a simple non-condensing steam plant. High pressure steam from the boilers is passed to the turbine, a portion extracted for the medium pressure process, and the balance exhausted at the low pressure process level.

The example shown is a large single line mill pulping aspen, a northern hardwood. This mill can, and does, operate isolated from the utility tie. The system balances the steam and power demand by by-passing steam around the turbine when the steam demand is high, and dumping low pressure steam when the electrical power demand is high. This mill can also pulp softwood, with somewhat different steam and power demands, and sufficient flexibility is built into the system to achieve an efficient balance.

The addition of a condensing end is shown in Figure 6. This example is a tropical mill pulping eucalyptus, a hardwood, and has only a small utility tie for black start or emergency service. Being isolated it produces many of its own chemicals, requiring 14 MW over the normal mill load, so a condensing section was required to be able to achieve a balance.

Figure 7 Shows how a gas turbine generator and waste heat recovery boiler (HRSG) can be integrated into the system. The balance shown is for a coastal mill pulping softwood, and the object was to maximise production of power for sale to a utility, hence the use of a condensing end on the steam turbine. To improve the efficiency a three pressure level HRSG was used, HP at turbine throttle conditions, IP at low pressure process pressure and LP at deaerator pressure.

The examples shown are typical, but the necessity to balance the site specific variables means that only rarely are two plants alike.

SUMMARY

In order to satisfy the many variables, cogeneration plants for kraft mills have to take many forms and be designed with the flexibility to handle rapidly changing conditions. Experience has proved that plants can be built to handle these conditions with a high degree of reliability.

Cogeneration has been used in the pulp and paper industry for many years, although in some areas of North America, with cheap electrical power, many mills were built without the ability to cogenerate. These mills are now less competitive in the market than those with cogeneration.

All of the new mills being built in South-East-Asia, South America and other areas include cogeneration plants, and, combined with their generally lower wood and labour costs, their lower energy costs gives them a competitive edge. We in North America are going to have to be have to be innovative in our use of technology, and co-operative with each other: industry; utilities; and governments, to maintain and improve our position in the world.

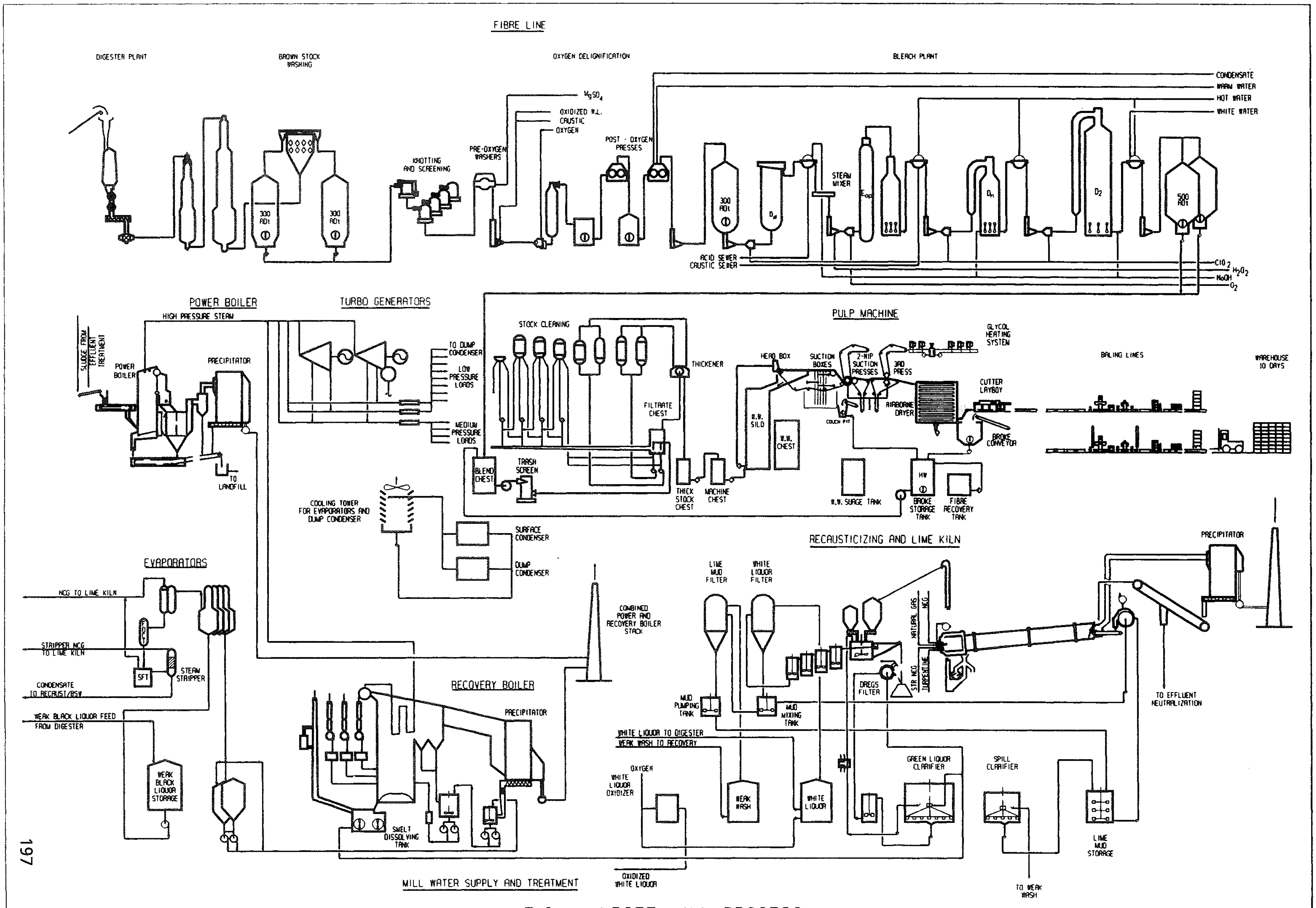


FIG. 1 - KRAFT MILL PROCESS

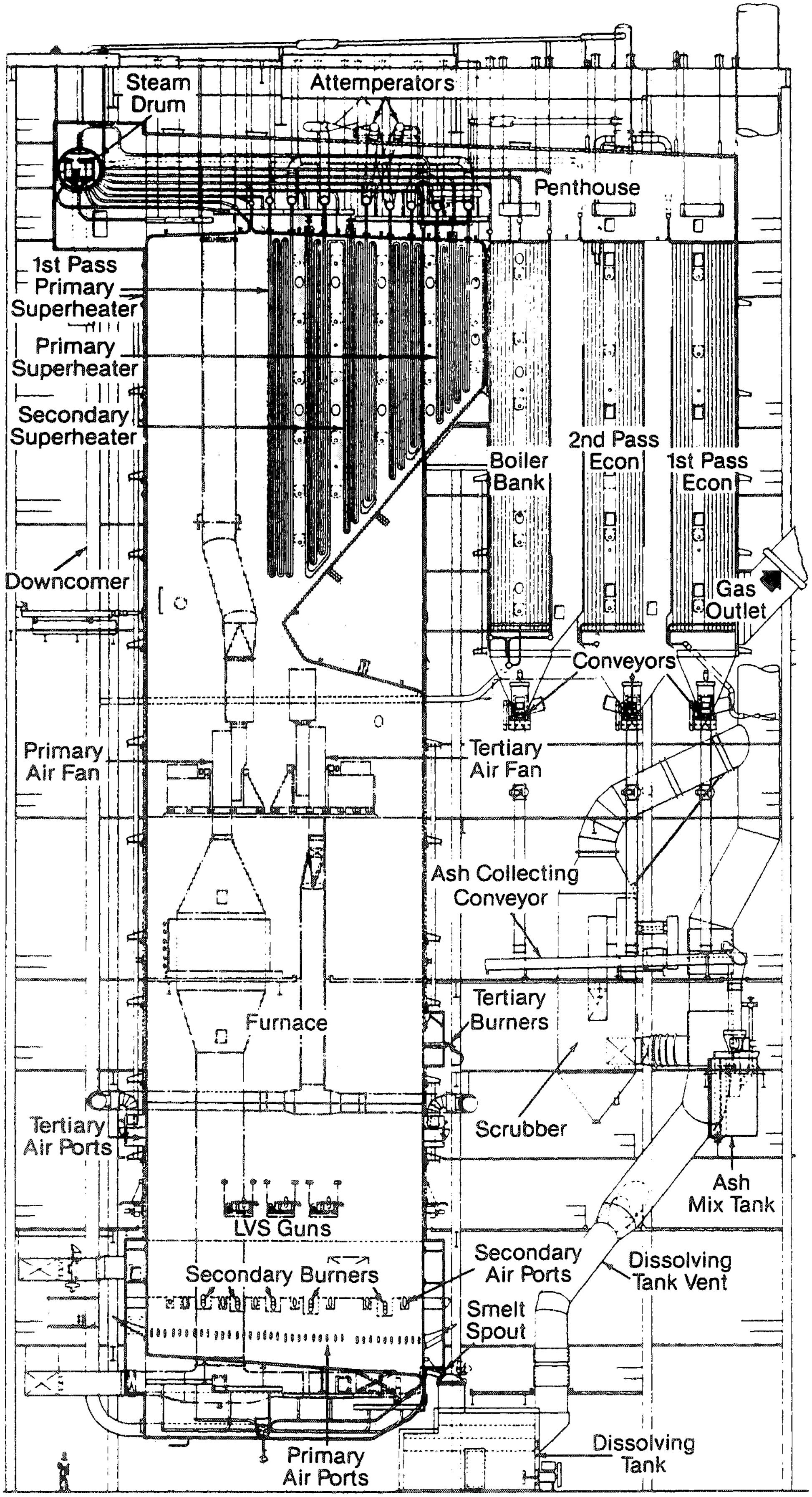


Figure 2 - Modern B&W Recovery Boiler

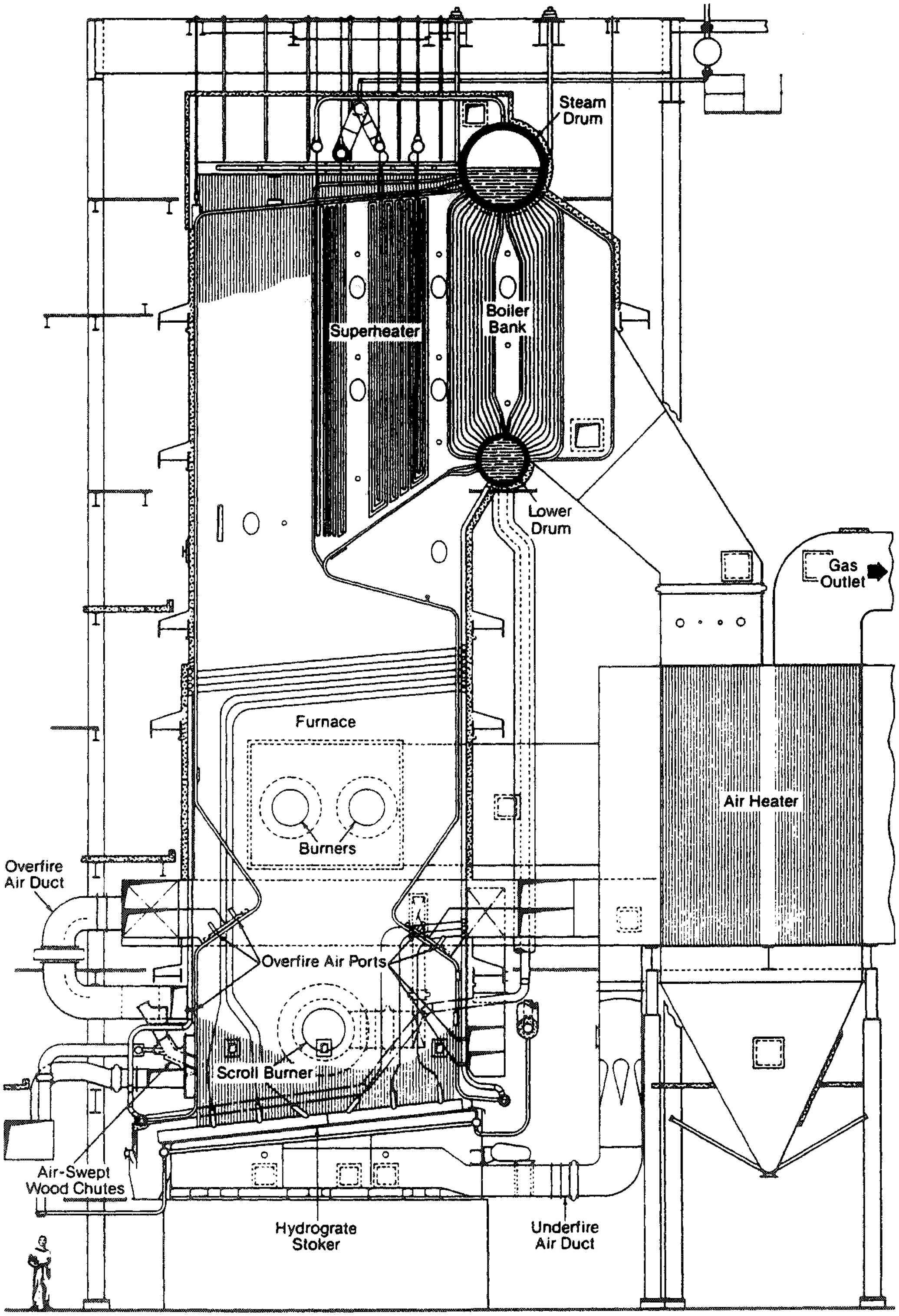


Figure 3 - B&W Wood Fired Boiler

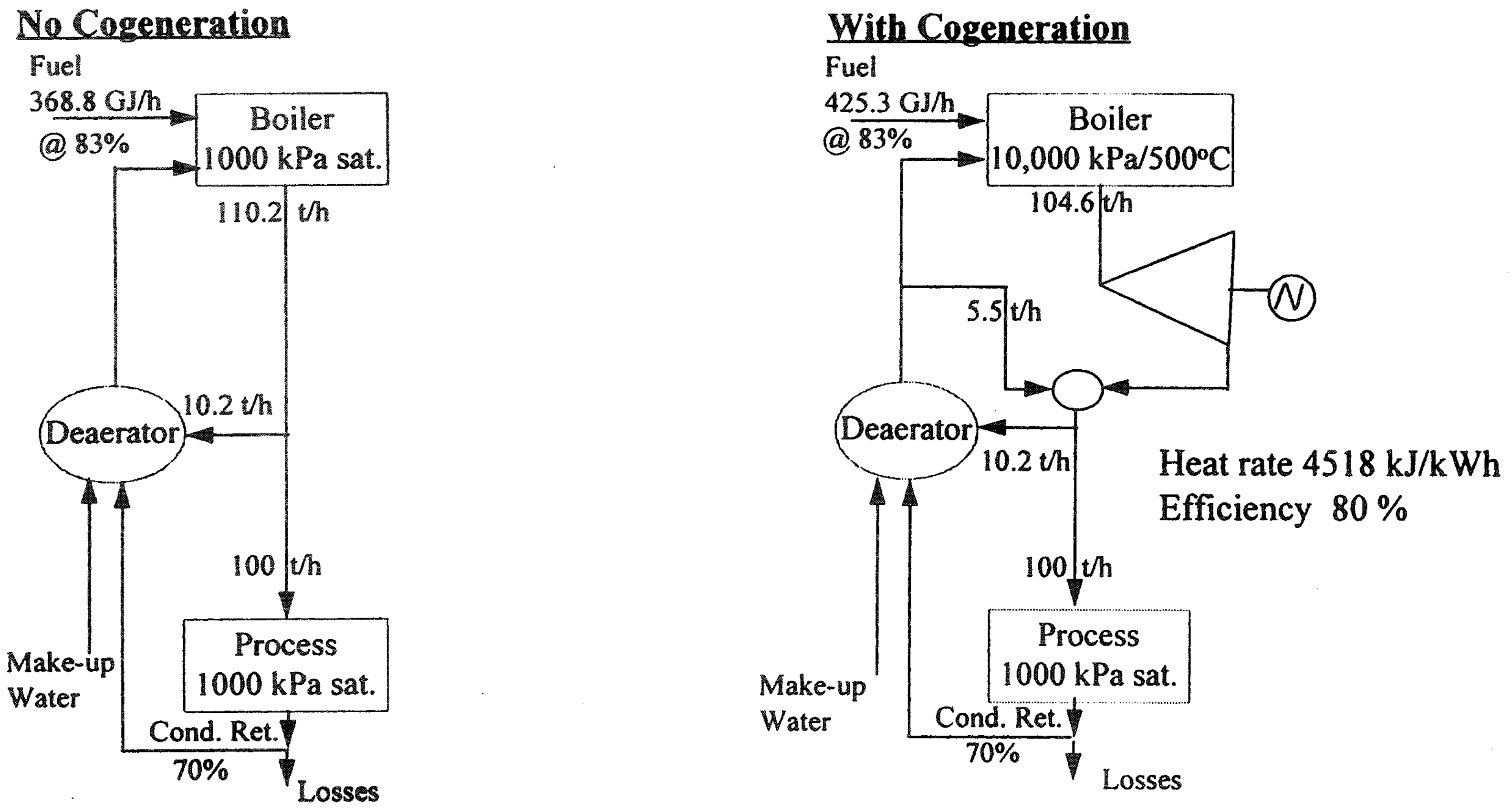
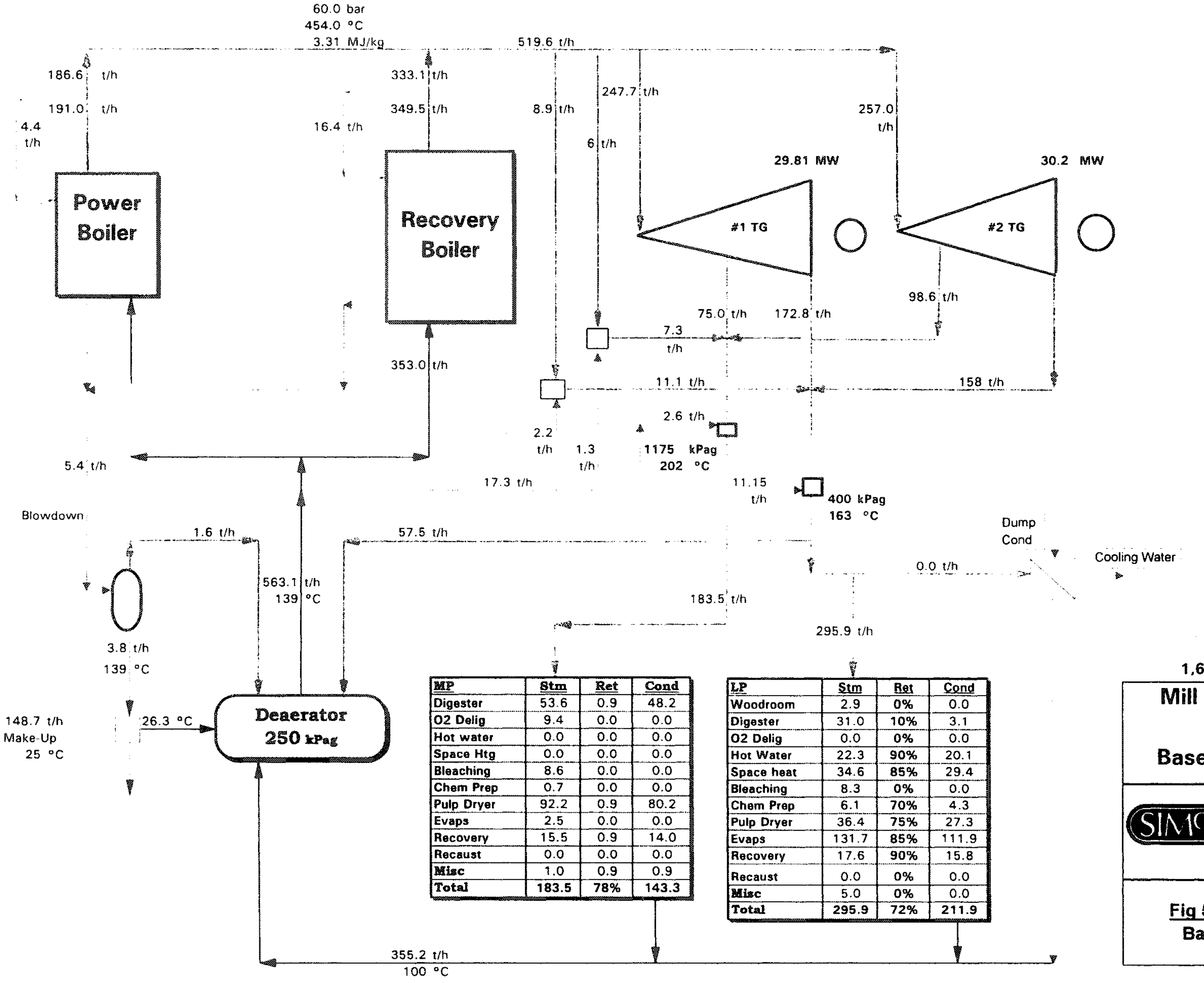


Figure 4 - Cogeneration Example



MP	Stm	Ret	Cond
Digester	53.6	0.9	48.2
O2 Delig	9.4	0.0	0.0
Hot water	0.0	0.0	0.0
Space Htg	0.0	0.0	0.0
Bleaching	8.6	0.0	0.0
Chem Prep	0.7	0.0	0.0
Pulp Dryer	92.2	0.9	80.2
Evaps	2.5	0.0	0.0
Recovery	15.5	0.9	14.0
Recaust	0.0	0.0	0.0
Misc	1.0	0.9	0.9
Total	**183.5**	**78%**	**143.3**

LP	Stm	Ret	Cond
Woodroom	2.9	0%	0.0
Digester	31.0	10%	3.1
O2 Delig	0.0	0%	0.0
Hot Water	22.3	90%	20.1
Space heat	34.6	85%	29.4
Bleaching	8.3	0%	0.0
Chem Prep	6.1	70%	4.3
Pulp Dryer	36.4	75%	27.3
Evaps	131.7	85%	111.9
Recovery	17.6	90%	15.8
Recaust	0.0	0%	0.0
Misc	5.0	0%	0.0
Total	**295.9**	**72%**	**211.9**

Steam Produced	t/h	kg/s
Rec. Blr	349.5	97.1
Pwr Blr	191.0	53.0
Desup.	17.3	4.8
Total	**557.7**	**155**

Steam Used	t/h	kg/s
11 Barg	183.5	51.0
4 Barg	295.9	82.2
Deaer	57.5	16.0
Dump	0.0	0.0
S/blow	20.8	5.8
Total	**557.7**	**155**

Power Produced		
#1 TG	MW	29.8
#2 TG	MW	30.2
Total	**MW**	**60.0**

1,667 ADt/d 2,420 tBLS/d

Mill Steam & Power Balance Base Aspen - Winter

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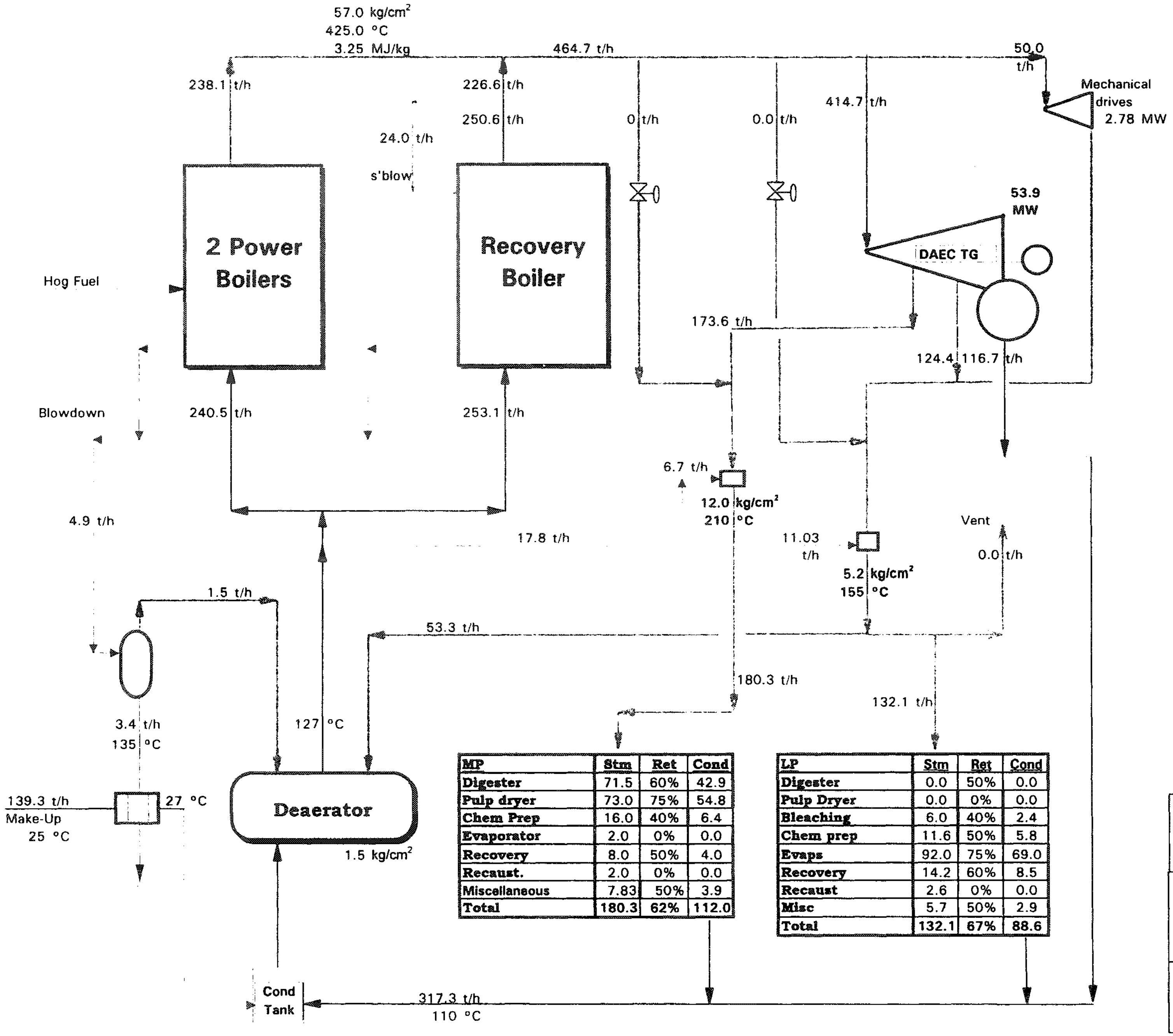
Fig 5-Single Extraction Back Pressure TG's



MP	**Stm**	**Ret**	**Cond**
Digester	71.5	60%	42.9
Pulp dryer	73.0	75%	54.8
Chem Prep	16.0	40%	6.4
Evaporator	2.0	0%	0.0
Recovery	8.0	50%	4.0
Recaust.	2.0	0%	0.0
Miscellaneous	7.83	50%	3.9
Total	180.3	62%	112.0

LP	**Stm**	**Ret**	**Cond**
Digester	0.0	50%	0.0
Pulp Dryer	0.0	0%	0.0
Bleaching	6.0	40%	2.4
Chem prep	11.6	50%	5.8
Evaps	92.0	75%	69.0
Recovery	14.2	60%	8.5
Recaust	2.6	0%	0.0
Misc	5.7	50%	2.9
Total	132.1	67%	88.6

Net Steam Produced		
Rec. Blr	250.6	t/h
Pwr Blrs	238.1	t/h
Bark Blr	0.0	t/h
Desup.	17.8	t/h
Total	**506.5**	t/h

Steam Used		
11 Barg	180.3	t/h
4 Barg	132.1	t/h
Cond.	116.7	t/h
Deaer	53.3	t/h
Vent	0.0	t/h
S/blow	24.0	t/h
Total	**506.5**	t/h

Power Produced		
DAEC TG	MW	53.9
Diesel	MW	0.0
Total	**MW**	**53.9**

Power Required	**MW**
Woodroom	3.0
Digester	11.5
Stock Prep	6.8
Power Boiler / TG	2.5
Rec & Precip	2.3
EVaps, Caust & Kiln	2.5
Chem Plant	14.0
Water & Effluent	3.5
Offices & Misc.	1.0
Pulp Dryer	4.8
Townsite	2.0
Total	53.9
Generated	53.9
Purchased	0.0

1250 ADt/d 1,700 tBLS/d

Mill Steam & Power Balance

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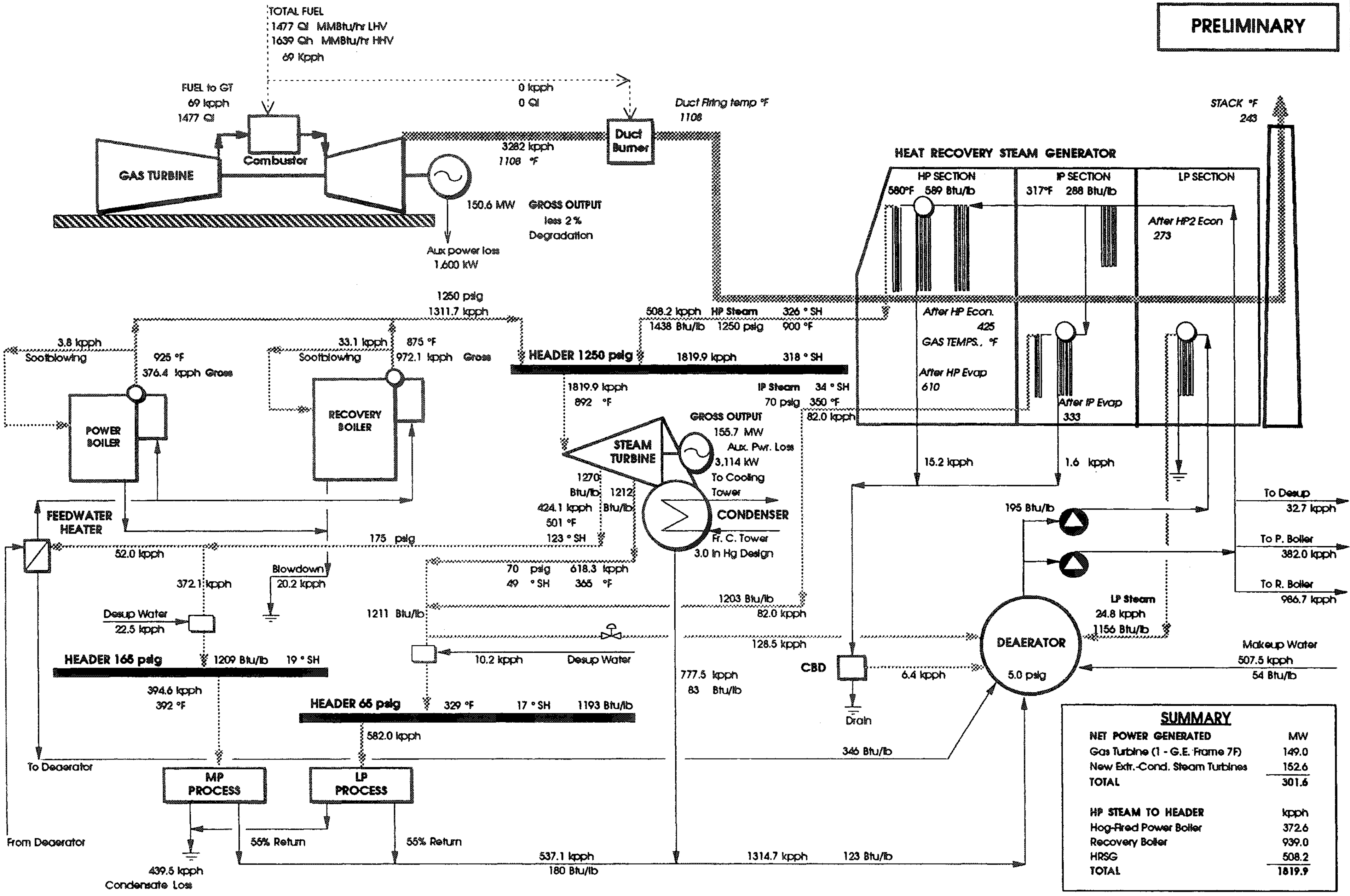
Vancouver
Canada

Fig. 6 - Double Extraction Condensing TG

Eucalypt



SUMMARY

NET POWER GENERATED	MW
Gas Turbine (1 - G.E. Frame 7F)	149.0
New Extr.-Cond. Steam Turbines	152.6
TOTAL	301.6
HP STEAM TO HEADER	kpph
Hog-Fired Power Boiler	372.6
Recovery Boiler	939.0
HRSG	508.2
TOTAL	1819.9

FIG. 7 - COMBINED CYCLE COGENERATION PLANT

OVERALL STEAM AND POWER BALANCE

SIMONS

17-Sep-93

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