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HOW PROCESS AND POWER PLANT CHANGES CAN INCREASE INDUSTRIAL COGENERATION: THE CASE OF KRAFT PULP MILLS

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Abstract—Industrial cogeneration can be substantially increased in energy intensive process industries, such as pulp and paper, by making process and operating changes such as reducing water use, minimizing effluent discharge, generating chemicals on-site and drying biomass fuels. The economic benefits of cogeneration are demonstrated by comparing three cases. The first is the no generation case in which steam is generated for process use and electric power is purchased from the utility. The second is the thermal match case in which steam is generated at a pressure substantially higher than needed for process and passed through a turbine to generate electric power before being used to meet the plant's thermal demands. In the third case, the maximum cogeneration case, more steam is produced than required by the plant. The additional steam is expanded through the turbine-generator to a condenser and generates additional electricity which can be sold. The study is based upon the conceptual design of a hypothetical 1000 tons/day bleached kraft pulp mill scheduled to begin operation in the United States in 1985, but the general approach and conclusions are applicable to a wide variety of industries with high energy demands.

Industrial cogeneration   Dual energy use systems   Industrial energy surveys   Bleached kraft pulp mills

INTRODUCTION

Cogeneration is the practice of using process steam or heat to generate electricity. Combining energy systems is more efficient and economical than producing steam and electricity separately. The most common method of cogeneration is the topping cycle. The topping cycle first generates electricity from high pressure steam and then uses the steam for process heat.

To maximize cogeneration when installing new equipment in an existing industrial plant or designing a completely new plant, it is important to know how much steam and electric power each area uses in a well-run, relatively efficient plant. This provides a data base from which one can begin to look for ways to save energy and generate more electricity. If a plant generates more electricity, it will have to buy less from a utility or will be able to sell power for extra income. In the United States, utilities must now buy electricity from industrial cogenerators and pay them a fair and reasonable price. The price is based upon the rate which utilities would have to charge their customers if they had to construct expensive new power plants. The pulp and paper industry is used in this paper as an example of ways in which industry can use energy more efficiently and maximize power output. The general approach and conclusions apply to a wide variety of industries with high energy demands.

THE BASIC ENERGY SURVEY

To establish a data base, energy surveys were conducted at two existing pulp mills in different parts of the United States. One began operating in 1967. The other began operating in 1978.

The energy survey teams working in the two mills confirmed observations made on visits to other industrial facilities.

Many mills and industrial facilities do not have adequate instrumentation to trace energy use. Some pulp mills, for instance, do not know where the energy goes within the mill or how efficiently it is used.

In large industrial complexes, each department or area may prepare reports or take control room readings pertaining to steam and electrical use. Yet the strip charts, log sheets, meter readings and other data together may provide only a partial historical record of energy use. In one mill, 134 reports about energy use were prepared each month, but there were inconsistencies and gaps. For example, readings often were taken at different times and at irregular intervals. Even if the historical record is complete, it cannot by itself tell an owner how to improve his operation. The data must be put on a common base and then analyzed.

In most industrial facilities, because of inadequate instrumentation and incomplete records, it is easier to prepare a mass balance than to prepare a heat or energy balance. A heat or energy balance is more informative. A mass balance deals only with quantity. It tells how many pounds of steam are used. A heat balance deals with quality and quantity. It multiplies the heat value of the steam (quality) by the mass (quantity).

Even a well-run industrial facility using energy efficiently may find many ways to improve its operation after analyzing current energy use via an energy balance.

THE 1985 DESIGN

After the surveys were completed, a conceptual design was developed for a hypothetical 1000 tons/day bleached kraft pulp mill scheduled to begin operation in 1985. The design incorporates new technologies which will be commercially available by 1985 and draws upon conclusions reached during the mill surveys.

The search for ways to conserve energy and maximize cogeneration requires the following tools:

A common data base, perhaps programmed into a microprocessor-based computer system.

A basic one-line diagram of the electrical system.

An up-to-date process flow schematic.

These are used to prepare a block diagram as shown in Fig. 1.

The kraft pulp industry is partially energy self-sufficient because one of its by-products is black liquor. Black liquor consists of water, cooking chemicals left from the pulping process and a dissolved natural wood adhesive called lignin which binds wood fibers together in trees. As the black liquor burns in a recovery boiler, steam is produced and 95% of the chemicals are recovered as smelt. In one of the mills surveyed, about 65% of the gross energy used per month comes from black liquor; 18–20% comes from forest residue and bark. This is called hog fuel. The remaining energy comes from fuel oil.

Because of the high cost of energy, mills have a dual energy use system to provide some of their electricity. One of the two mills surveyed cogenerates 21 MW, all that it needs to operate. The other mill, a large facility, cogenerates 32 MW. It needs 26 MW to operate and sells 6 MW to the local utility company. The energy survey revealed that by making process changes and burning more of the wood waste available from the logs brought to the mill, the mill can generate 26 MW for its own use and 18 MW for sale. Forty-four MW is the upper limit of the turbine-generator.

In a new industrial facility without the limitations imposed by existing equipment, can cogeneration be increased even more? Based upon both technical considerations and dollar considerations, the answer is yes. A new mill can incorporate the same process changes as existing mills, plus promising new technologies. The conceptual design of a 1985 mill began with a basic block diagram. The final concept was developed step by step after a 3-month literature survey. Because opinions in the technical literature differ over the best new technologies, each option was carefully evaluated and its effect on the central design and overall energy use was assessed. The final conceptual design includes both proven technologies and promising developing technologies which, in the judgment of the engineering team, will be commercially available by 1985. The design preserves flexibility and operating options. For example, the mill includes a new developing pulp bleaching sequence, but the mill can also operate using an existing pulp bleaching sequence. The new mill can cogenerate between 97 and 105 MW. The new mill, however, also requires more electrical power to operate. There is, however, an impressive net gain in cogeneration even after mill requirements are deducted from the total amount of electricity produced.

Many of the features of the conceptual design are applicable to industries in addition to pulp and paper.

Chemicals are generated on site. This increases energy use at the site. Overall, however, it saves both energy and dollars. By producing its own chemicals, the mill saves the energy which would have been used to manufacture the chemicals off site, convert them to a form suitable for shipment, transport them to the site, and then convert them to a form suitable for the process. An example in the pulp and paper industry is caustic soda. If the mill buys it off-site, energy must be spent to concentrate it through evaporation for shipping. It must be diluted again at the mill. Increased energy costs and shipping costs also mean that industry must pay more to purchase chemicals. One of the most energy efficient and cost effective solutions may be for industry to lease rather than purchase small on-site chemical production facilities from their traditional chemical suppliers.

Water use is reduced. One of the areas of greatest energy loss is the water system in most industries. Reducing the flow of water reduces heat losses. Reducing the flow of water also reduces the electrical energy required to run pumps. In the pulp washing, screening and bleaching area, reducing the amount of water can drop energy consumption from 18.6% of the total in an existing mill to 5.4% of the total in new mills.

Liquid waste discharged from the process is eliminated by closing the process loop. Large waste treatment and aeration ponds are not needed. This reduces heat losses and electrical energy use for pumps and aerators.

The modern mill site is more compact. This cuts down on the length of pipes. Shorter steam piping runs mean lower thermal energy or line losses.

High efficiency electric motor drives replace steam turbine drives. Electrical energy use goes up, but steam use drops. There is a net gain in efficiency.

Wood waste with an assumed 55% moisture content is dried to 30% moisture before being burned in a power boiler. Three methods of drying were evaluated. The first was flue gas drying. The second was a direct-fired fuel dryer. The third was steam drying. The third option was selected. Its advantages include no latent heat losses from water evaporation, no temperature limit on exit flue gas from the boiler, and high heat transfer rates. The steam dryer returns

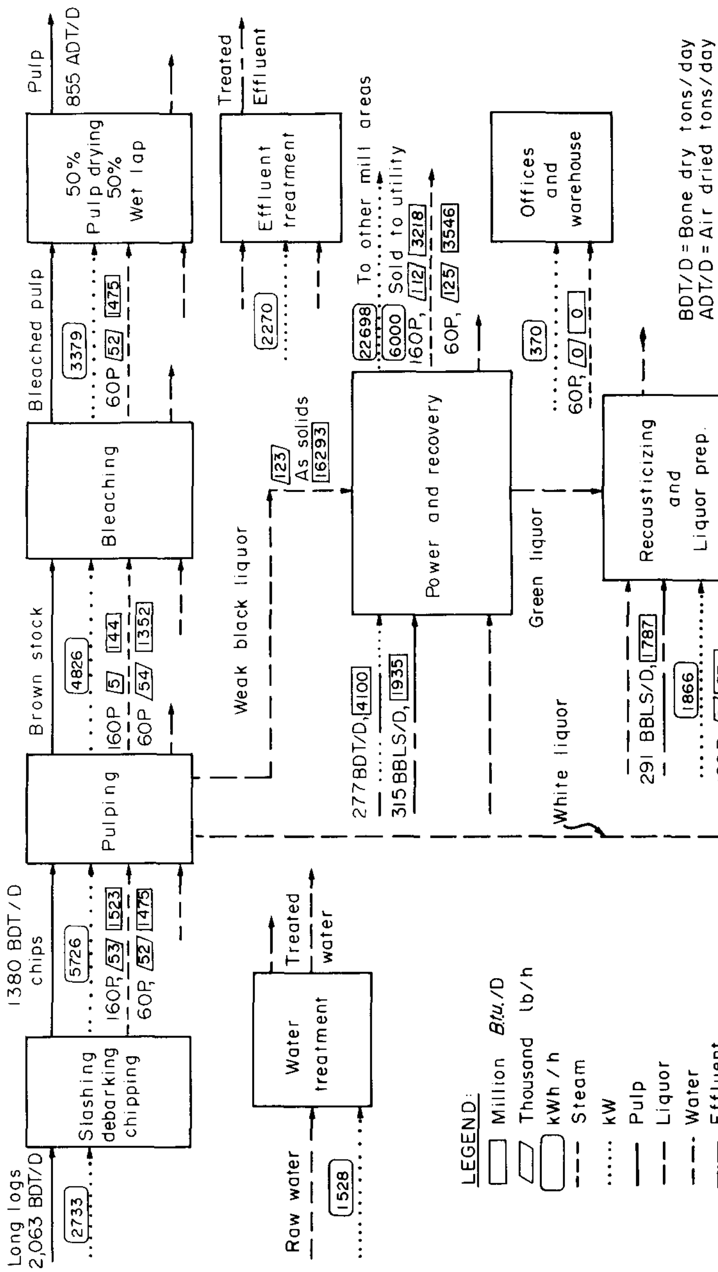

Fig. 1. General flow and block diagram of a typical average production, 850 tons/day, bleached kraft pulp mill, Northeast, U.S.A.

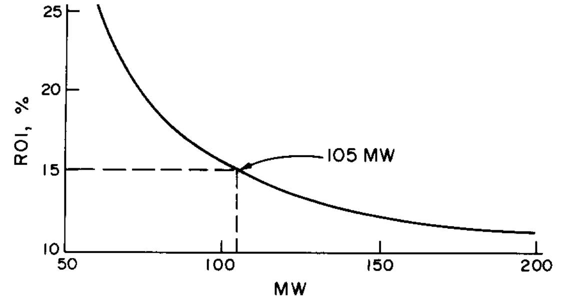

Fig. 2. Projected return on investment vs megawatt size 1985 pulverized coal-fired industrial power plant.

evaporated water to process, takes the least amount of space, and has the lowest capital cost. Thermal energy (steam) is used to dry the fuel, but steam output from a boiler increases when it burns drier fuel.

Two types of power plants were designed for the 1985 facility. The first is a wood waste-fired power plant. If wood waste is available to burn, the maximum cogeneration capacity is 97 MW for the 1000 ton/day mill studied. The upper limit is set by the amount of wood waste available. Maximizing cogeneration requires a larger capital investment for larger fuel handling facilities, larger boilers and in the maximum cogeneration case, more steam is generated than is needed to run the industrial facility. The extra steam is used to generate additional electricity which can be sold. Despite the larger initial investment, it is a particularly attractive design option when fuel costs are low. When a facility has surplus wood waste to burn, for example, this additional fuel is virtually free.

The same mill with a pulverized coal- instead of a wood waste-fired power plant cogenerates 105 MW. In this instance, when fuel costs are higher, the best return on investment is the thermal match case because it requires a smaller capital investment. In the thermal match case, electric power generation is limited by the process steam load. No more steam is generated than the mill requires to operate. Figure 2 compares the 60 MW thermal match case for the 1985 coal-fired plant to larger power plants with condensing power capability, including a 105 MW plant.

This curve is based upon a computerized cost analysis. The 105 MW coal-fired plant was selected for the maximum cogenerated case, based on 15% as the minimum acceptable return on investment. All power generated will be sold. As a result of legislation passed in the United States in 1978, industrial facilities can sell electricity to a utility at one rate, then buy back whatever electricity they need to operate at a lower rate. Cogeneration becomes a source of revenue. The size of the coal-fired plant is based upon 8400 h of operation per year, a selling price of between 6.34 and 7.79 cents per kilowatt-hour, and a coal price of \$3.70/MBtu. If fuel costs drop to \$3.15/MBtu, the return on investment on a large plant improves. If coal prices drop from \$3.70 to \$3.15/MBtu, the return on a 130 MW plant increases from 13 to 15%, the acceptable minimum.

Table 1 shows the final results of the design of a new 1985 mill maximizing industrial cogeneration. Through process and operating changes and design of a larger, more efficient power plant, cogeneration capacity more than doubled.

Table 1. Summary of electrical energy generated and consumed existing survey mill vs 1985 conceptual design mill with wood waste-fired power plant

	Existing survey mill (MW)	Conceptual 1985 mill (MW)
Maximum power generation capacity	44	97
Power actually generated	32	97
Power consumed	26	39
Surplus power	6	58

SUMMARY

Technology is changing. The regulatory environment is in a state of flux. Energy prices are unpredictable. The extent to which industry and utilities will work together remains to be seen. The conceptual design of this 1985 pulp mill is not necessarily the definitive mill of the future. It does, however, contribute a new perspective to ways in which industry can improve its operation. Evaluating two existing mills gives a basis for comparing the past to the future.

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REFERENCE

[1] Based on Pulp Mill Design for Maximum Cogeneration, prepared for the Electric Power Research Institute, Palo Alto, CA (1982).