ENERGY CONSERVATION IN THE AREA OF INDUSTRIAL POWER PLANTS

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I. INTRODUCTION

It is a frequently observed attitude of production people to regard energy as an unlimited resource. The power plant manager, on the other hand, is faced with limited plant capacities and the constant demand to supply energy production not only reliably but at minimum costs to the company. After all, he is handling a share of some 20 - 35 percent of the production costs and a saving of a fraction of one percent of the energy costs can mean a sizable amount saved for the good of the company.

This paper intends to look at energy conservation in its widest sense by presenting current trends in new power plant installations, as well as by commenting on in-house energy conservation measures in existing plants.

When pointing out general trends one has to keep in mind, though, that for various reasons conditions in the Indian pulp & and paper industry are quite different from those in highly developed nations. This is clearly and comprehensively outlined in the Report on Utilization and Conservation of Energy prepared by the National Productivity Council.

II. PRESENT TRENDS IN ENERGY CONVERSION PLANTS

1 FUEL

As a consequence of the increased costs for fossil fuels there has been a marked tendency towards energy self-sufficiency through the use of bark, residual wood, sludges and indigenous low grade fuels such as peat. At the same time dry solids content of waste liquor has been increased to 60 - 65 % to improve heat output.

Fig. 1 shows the general development in the Finnish pulp & paper industry. For market pulp mills self-sufficiency degrees of 92 % have been attained, for linerboard mills the corresponding figure is about 75 %. Conditions in other Scandinavian countries are equally impressive, while the average US figure is around 57 - 58 %. Sweden for its part has a "no oil"-plant in operation, using wood residue also for firing of the lime kiln.

Lower heating value of some wood fuels is given in Fig. 2.

2 Live steam conditions

With the availibility of new heat resistant alloy steels proven in utility service and higher plant availibility percentages achieved through continuous development and increased operating experience, live steam conditions have gone up in the past decades. Scandinavian countries have been leading the way while in the US and in some central European countries live steam conditions tend to be slightly more on the conservative side. In the US this may have been influenced by the prevailing energy price situation.

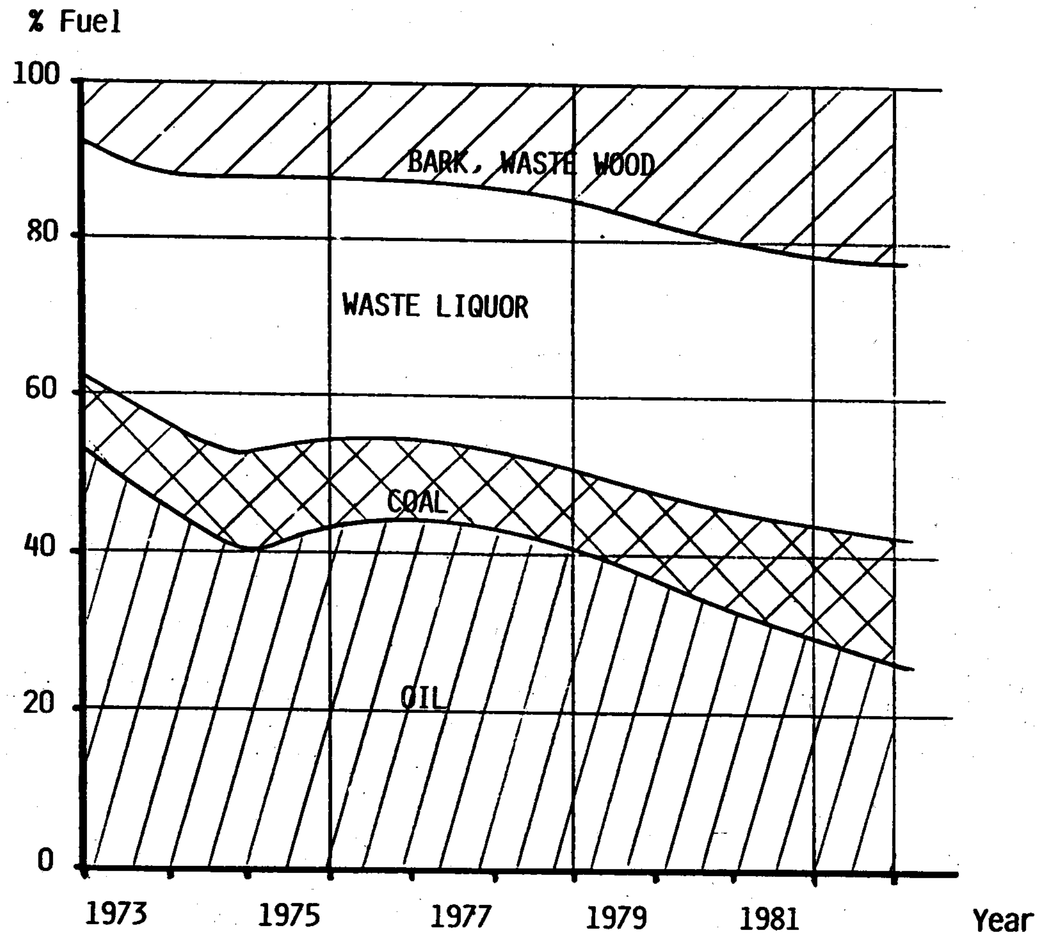


Fig. 1 FUELS USED IN FINNISH PULP & PAPER INDUSTRY

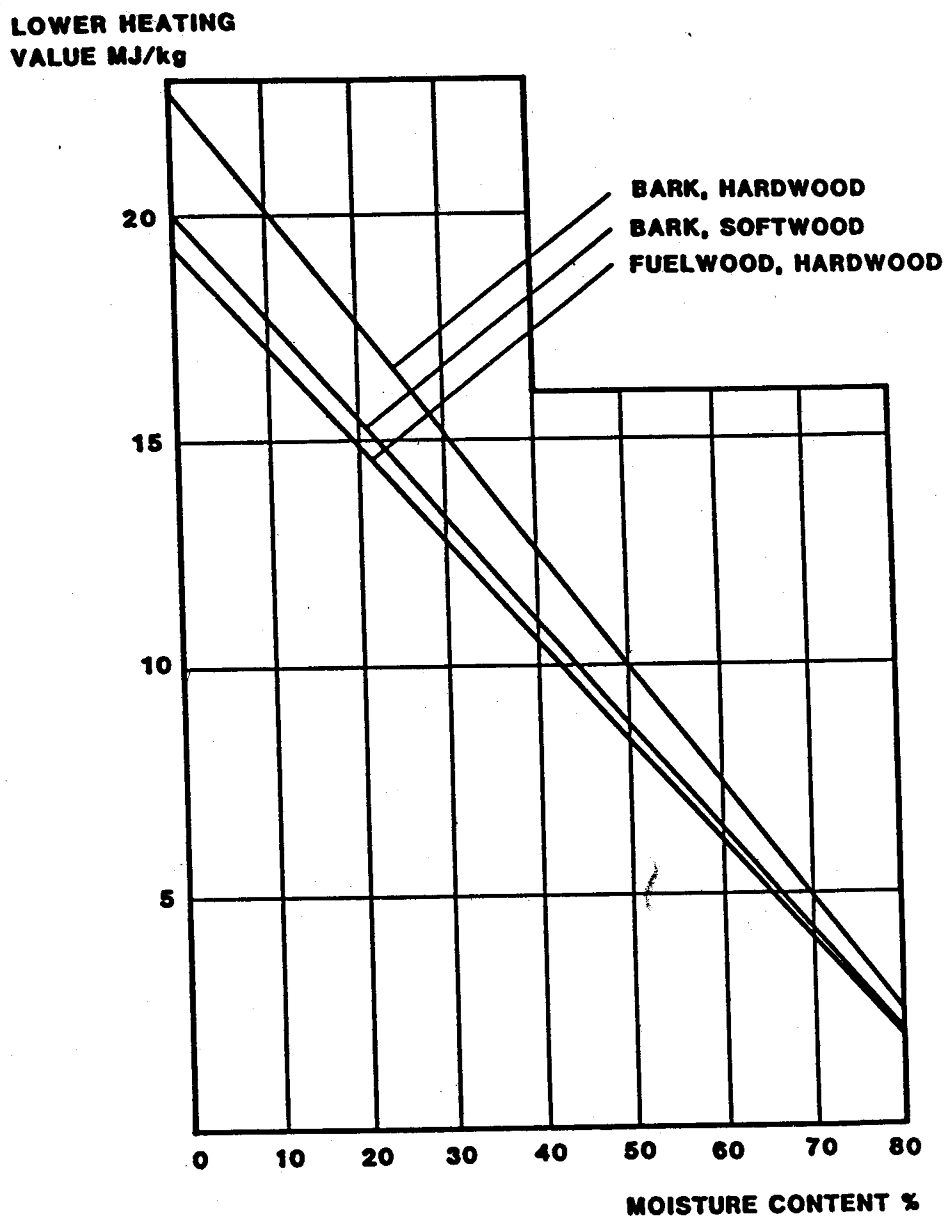


Fig. 2 Lower heating value of various wood fuels

Some typical data are given in figures 3 and 4, the latter referring to finnish installations.

Higher turbine entry pressures and temperatures allow improved adjustment of energy conversion to suit the required heat to power ratio of a particular plant. For example an increase from 35 bar / 440°C to 86 bar / 520°C will increase the available isentropic heat drop by approximately one third at a common back pressure level of 3 bar.

The attainable power/heat flow ratios for different livesteam and backpressure conditions are shown in Fig. 5.

Besides allowing higher power generation rates for a given amount of required production heat the higher live steam conditions result in an improved overall thermodynamic heat cycle efficiency as a result of the higher maximum cycle temperature attained.

The Carnot cycle efficiency is further improved by the addition of a regenerative boiler feedwater heat exchanger (h.p. heater) needed for the required higher final feed-water temperatures. This heat exchanger is normally supplied from a turbine extraction. Its use also allows to adjust flue gas exit temperatures to compensate for boiler fouling, thus avoiding corrosion problems at the boiler's cold end.

One of the consequences of increased live steam conditions is the necessity for improved feedwater quality, requiring full desalination and improved oxygen removal as well as installation of condensate polishing plants for the return condensates. In Europe feedwater desalination is done almost exclusively by means of ion exchange filters after mechanical prefiltering.

	old units	new units
SCANDINAVIA		
integrated mills	35 - 40 bar/350°C	80 - 110 bar/480 - 520°C
non integrated mills	35 - 40 bar/350°C	60 - 80 - (110) bar/480 - 520°C
CENTRAL EUROPE		
integrated mills	35 - 40 bar/350°C	(40) - 60 - 110 bar/420 - 520°C
non integrated mills	10 - 16 - 40 bar/sat. - 400°C	16 - 120 bar/sat. - 520°C
U S A	comparable to Scandinavian conditions in general	

Fig. 3 Average live steam parameters in pulp & paper industry

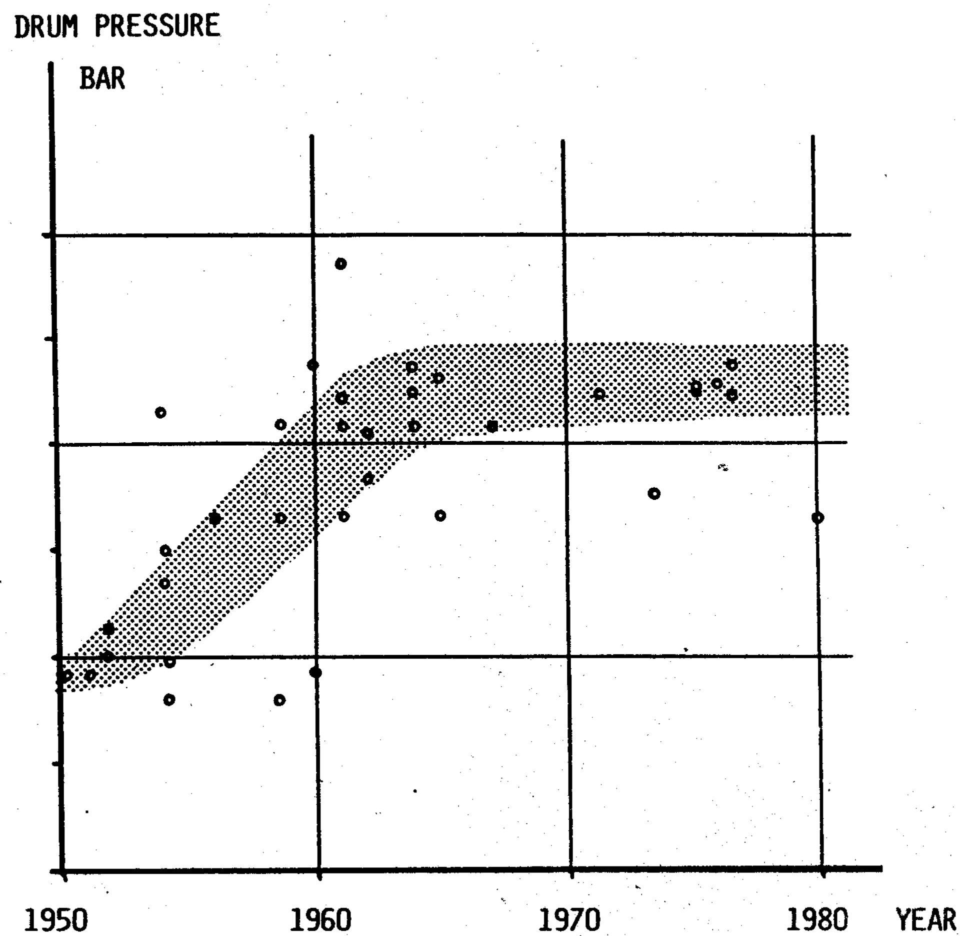
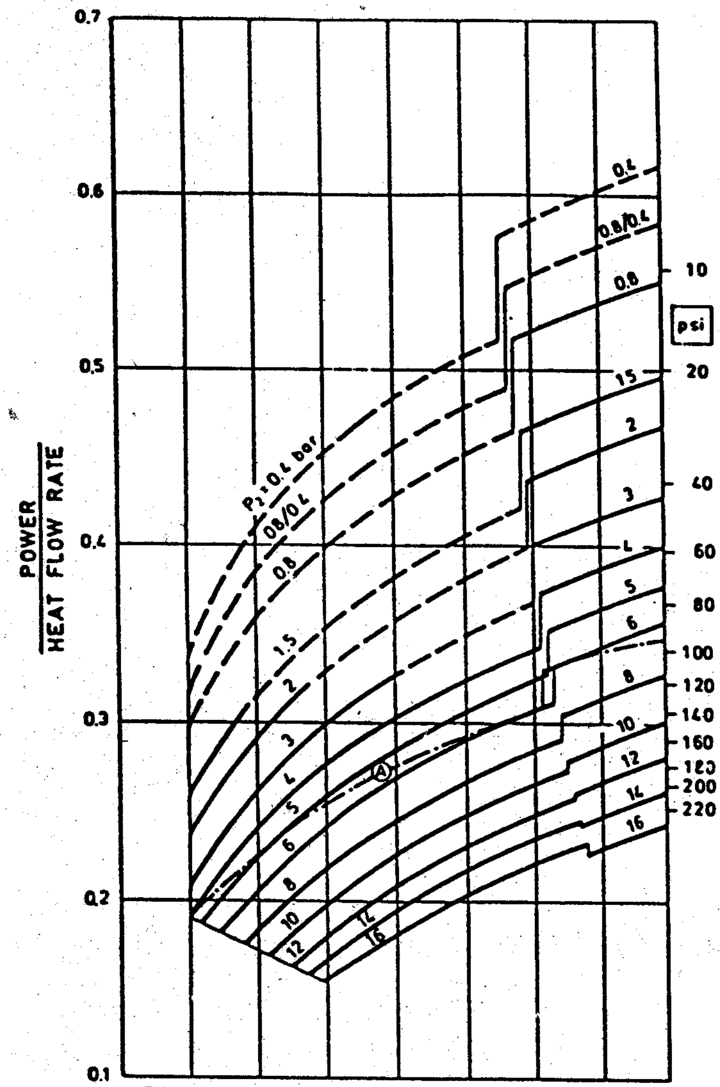


Fig. 4 BOILER DRUM PRESSURE VS. YEAR OF INSTALLATION
(Finland)



P_1	40	60	80	100	120	140/40	bar	180/60
t_1	450	480	500	520	530	535/535	°C	535/535
t_s	140	180	200	210	225	230/250	°C	270
P	10	20	30	35	40	40/60	MW	100
P_1	580	870	1160	1450	1740	2030/580	psi	2600/870
t_1	840	900	930	970	985	995/995	°F	995/995
t_s	285	355	390	410	435	445/480	°F	520
P	10	20	30	35	40	40/60	MW	100

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Fig. 5 Attainable Power / heat output ratio in back pressure power generation

P_1 = inlet steam pressure/reheat pressure
t_1 = inlet steam temperature/reheat temperature
P_2 = back pressure
t_s = feedwater temperature
P = generator output (normal output range with above steam conditions)
A = 4 bar back pressure with no feedwater preheating with extraction steam

A typical example of the required values for boiler feed-water and boiler water is given in Fig. 6.

3 Combustion technology

Development

The dramatically increased energy costs after the first "oil crisis" and the continuous lowering of the admissible emission levels has led to very intensive research efforts in the last ten years with the aim to use very low grade indigenous fuels or waste fuels resulting from the production of pulp and paper.

This has, on the one hand, led to the development of low-NO_x burners providing "soft" combustion and on the other hand, to fluidized bed combustion and as an off-spring, to the introduction of gasifier designs.

Fluidized bed combustion

The principle of fluidized combustion has been known and commercially used for some decades already, mostly in the form of reactors for chemical industries and for the gasification of coal to generate so-called producer gas.

Only in the last 7-8 years has fluidized bed combustion, however, been developed for use in steam generators. Although there are still comparatively few installations in commercial operation this type of boiler has sufficiently demonstrated its advantages and the achievable reliability to make it a very attractive alternative to conventional designs.

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FEEDWATER TREATMENT REQUIREMENTS FOR STEAM BOILER PLANTS

Recommended guidelines for the water-vapor cycle according to DENA (Dansk Kedelforening + Ekono + Norsk Dampkjelforening + Angpanneforeningen)

Boiler water for boilers of standard construction and with highly efficient water separation of steam used for turbines.

Drum pressure	gage pressure		bar		24	35	67	90	125	160
Superheated steam	gage pressure		bar		22	32	62	84	110	140
pH_{25} upper limit				<	9.1 + lg $\varkappa$*					
pH_{25} lower limit				>	9.5	9.5	9.0	9.0	8.5	8.5
p-value		I	meq/kg	<	8	6	2	0.75	0.20	0.05
		II	meq/kg		1 ... 8	1 ... 6	1 ... 2			
Conductivity	$\varkappa$*		mS/m	<	400	350	80	40	15	4
Sodium + Potassium	NA		mg/kg	<	800	650	150	80	30	8
Phosphate	PO_4	II	mg/kg		10 ... 20	<15	<15	2 ... 6	2 ... 6	2 ... 6
Silica	SiO_2		mg/kg	<	60 + 6 p	35 + 3.5 p	7	3.0	1.0	0.35
$KMnO_4$-consumption			mg/kg	<	300	200	80	40	15	5

The efficiency of water separation varies considerably for different boilers. The purity of the steam supplied to a steam turbine should be checked and based on the results the maximum allowable salt concentration in the boiler water can be determined. This salt concentration may be much lower than the values given in the table above.

When the heat flowrate, even locally, exceeds ~230 kW/m² (72900 Btu/h sqft) the target values for drumpressure 160 bar (except for SiO_2) should be used for all boiler pressures. For feedwater the recommended values for >67 bar should be used.

I The maximum p-value is independent of feedwater treatment

II When using phosphates to reduce residual hardness. Control of pH using coordinated phosphate method in the pressure range 35 ... 90 bar PO_4 between 10 ... 20 mg/kg and in the range 67 ... 125 bar between 7 ... 15 mg/kg

*) $\varkappa$ = conductivity of boiler water from a neutralized sample at 25 °C

Water-steam cycle

Analysis Data				Treated water	Make-up water after MB	Feedwater and Condensate: Drum Pressure Gage pressure, ≤ 67	Feedwater and Condensate: Drum Pressure Gage pressure, >67	Feedwater and Condensate: Once Through	Sat. steam to superheater: Supplying a Turbine Drum pressude, bar ≤ 40	Sat. steam to superheater: Supplying a Turbine Drum pressude, bar >40	Sat. steam to superheater: Without Turbine
pH_{25}					>6	8.5 ... 9.2*)		7.0 ... 9.2**)			
Oxygen	O_2	mg/kg	<		0.01	0.01	0.01	***)			
Hardness		meq/kg	<		0.001	0.003	0.001	0.001			
Total iron	Fe	mg/kg	<	0.05		0.05	0.02	0.02	0.02	0.02	
Total aluminium	Al	mg/kg	<	0.10							
Copper	Cu	mg/kg	<			0.01	0.003	0.003	0.01	0.003	
$KMnO_4$-consumption		mg/kg	<	10	5	The quality requirements					
Silica	SiO_2	mg/kg	<		0.02	for boiler water		0.02	0.02	0.02**)	
Sodium + Potassium	Na	mg/kg	<		0.02	should be determined for		0.01	0.02	0.01	0.1
Conductivity	$\varkappa_{25}$	mS/m	<		0.05	each case		0.02****)			
Oil + sludge + foaming materials					Not detectable						

*) Unless the FW pump manufacturer requires a higher pH. Alkalization for drum pressures above 67 bar is preferably – in once through boilers always – to be done using volatile alkaline substances.

**) In case silica problems occur in the turbine, it is recommended to reduce the silica concentration in the boiler water and in the steam to one-half of the concentrations given above

***) According to the pH-value

****) After cation exchange

Fig. 6 Feedwater Treatment Requirements for Steam Boiler Plants

The principle of FBC consists in burning fuel particles in a hot sand bed that is kept in a floating, fluidized state by a stream of heated air, evenly distributed over the furnace bottom. Combustion occurs in two stages, first the fuel is burned under reducing conditions followed by the addition of secondary air in the oxidative burning zone. The resulting soft combustion at maximum temperatures of around 850°C and the intensive mixing of fuel particles and sand lead to very good burn-out rates, low NO_x development and partial binding of sulphur and other fuel contaminants in the ash. The low maximum combustion temperature allows the use of fuels with particularly low ash melting points.

Two different types of fluidized bed boilers are in use, the stationary and the circulating FBB. In the latter the whole fluidized bed material circulates from the furnace via centrifugal separators back to the furnace. This allows especially good combustion with larger fuel particles repeatedly passing the combustion zone until complete combustion is reached.

Figures 7 and 8 show schematics of typical installations.

Fuels commonly used are coal, particularly low grade and sulphur rich coal, bark, sawdust, wood chips, centricleaner rejects, deinking and effluent treatment sludges, biogas from anaerobic effluent treatment etc. Petroleum coke and pelletized municipal wastes as well as waste oil and tyre rubber have also been tested as potential fuels.

Emission control of sulphur dioxide is carried out by adding finely ground limestone in the furnace. The resulting calcium sulphate is removed together with the ash and can be sold to the building materials industry or dumped without environmental risks.

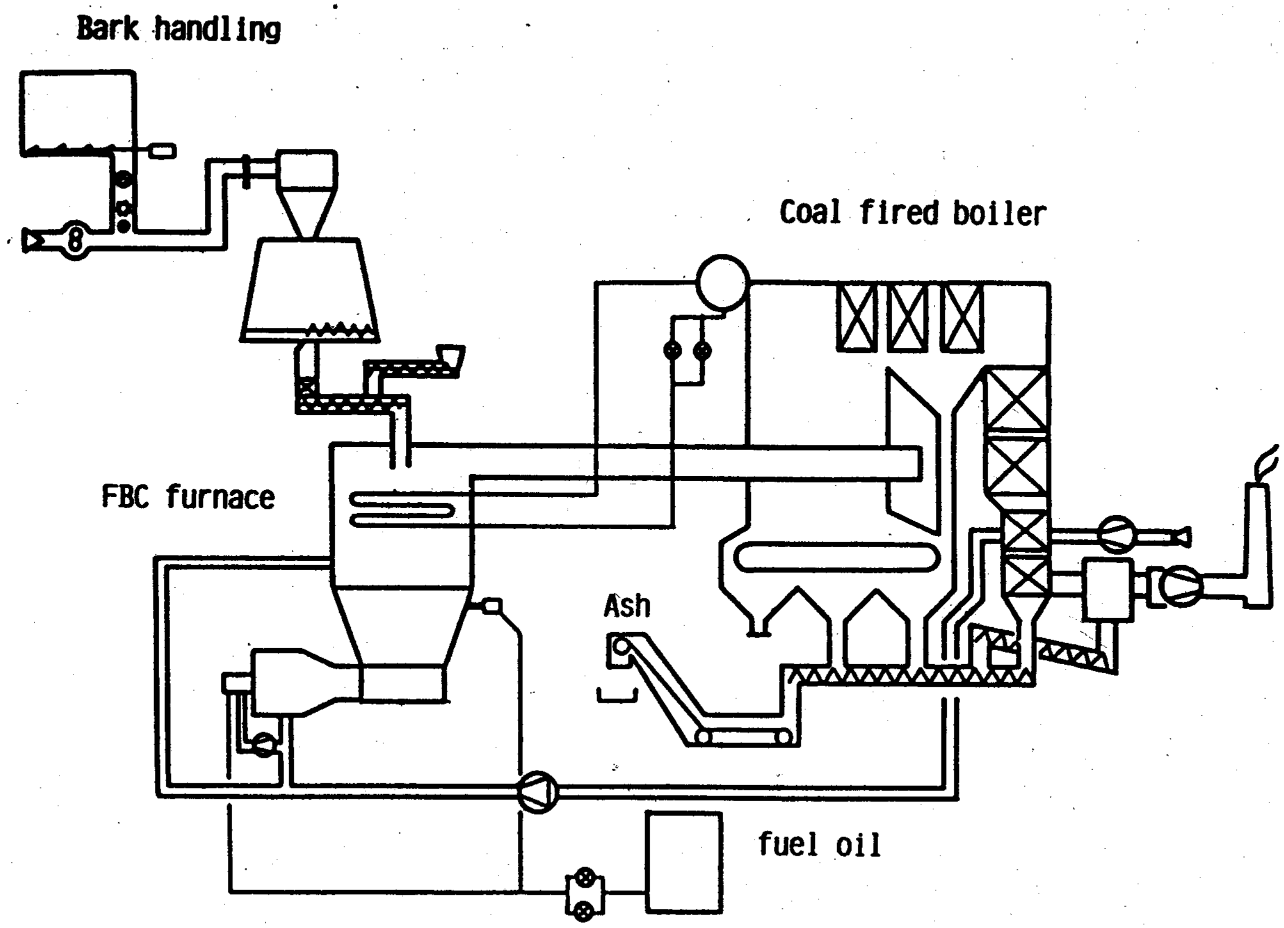


Fig. 7 Retrofit FBC furnace for bark firing (15 MW, Tampella)

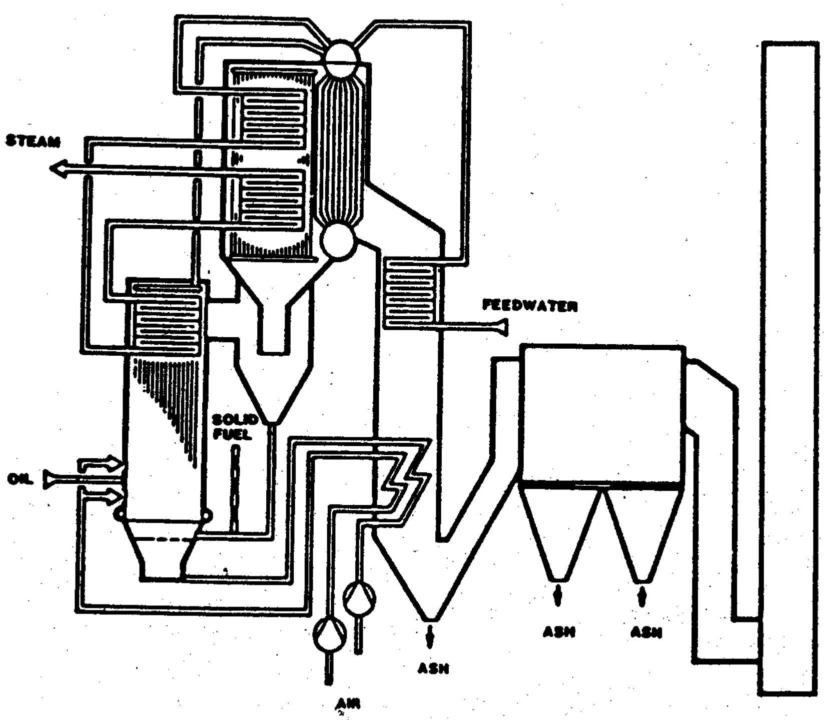


Fig. 8 Principle of circulating fluidized bed combustion (FBC)

This is often a superimposed control loop additional to the usual combustion air control and permits to minimize excess air and thereby reduces boiler losses.

- use of microcomputers or mill-wide computer systems with software for carrying out optimization calculations. These systems are run off-line in the majority of cases and provide information on the most economic combination and loading of boilers and turbines, within given constraints, to achieve minimum overall fuel costs under all demand situations.

- use of computer based supervision programmes that continuously monitor all important mass flows, temperatures, pressures and other characteristic values and perform calculation of efficiences, specific consumption figures, cost of operation etc. and also supply reports of all kinds, trend curves and alarm protocols on screen and in form of printouts.

- use of the aforementioned computers is now being extended to include also the task of energy cost distribution within the company, i.e. the debiting of energy costs to individual production departments or cost centers, taking into account credits for energy inputs in the form of waste fuels, spent liquor and return condensate.

- control systems to smooth out sudden load swings and heat/power demand imbalances such as those caused by web breaks in paper machines or steam surges resulting from batch digester operations. These systems are particularly important in plants that do not operate condensing turbines. Load variations are kept within specified limits, acceptable to reliable and safe boiler operation and at the same time back pressure fluctuations are minimized withour necessity for blowing off excess steam to the atmosphere. The storage capacity of boiler feedwater tanks and make-up water reservoirs as well as additional steam accumulators and emergency condensers are woven into a comprehensive control circuit.

- micro computers or integrated controllers for monitoring the external grid connections in order to keep power intake within the contract restrictions. These systems sound warnings and/or operate load rejects on basis of actual readings or prognosis calculations f.i. in case of limited 15 minute average load contracts.

- use of voltage stabilized electronic frequency relays to operate load shedding in case of sudden grid loss thus avoiding total blackouts.

- tie-line control operating directly on the turbine speed governor to keep power intake from grid on predetermined levels.

5 Prime Movers

With regard to efficient utilization of steam power generation the proper sizing of a new machine still is the most important aspect, requiring intensive study and planning work to avoid capacity bottlenecks or extended operation beyond the design optimum of the blading.

Improved instrumentation for monitoring the turboset and increased reliability of the sets have led to recommended intervals for complete overhaul in the range of five to seven years.Instrumentation such as shaft vibration monitoring, originally used only on large utility turbosets have found entry into industry size turbines. In addition to the conventional fully hydraulic or mixed hydraulic/ electric control systems even fully electric systems are now being offered on the market. In these designs also safety features such as turbine overspeed trip are implemented electrically.

Due to the level of fuel prices versus price for purchased power the use of condensing turbines is still decreasing and new installations are now the exception to the rule. Old existing condensing turbines are frequently only kept running at minimum steam flow to condenser to serve as a balancing unit or as a safety measure in case of sudden loss of grid power. The inadequate compensation for saleable overproduction power has contributed strongly to the phasing out of condensing turbines in Europe. In the Federal Republic of Germany for example the share of extraction condensing turbines of the total in-house generated power has gone down from 70 % in 1962 to 60 % in 1975 and now is probably in the range of not more than 30 - 40 %.

Floating extraction backpressure turbines are an economic alternative frequently used for supplying extraction steam to the hp-heater and for the second stage heating of digesters.

In these designs some three to four different turbine pass-out points are being used, depending on the actual turbine loading. As a consequence unnecessary throttling losses are avoided.

Some mills lying close to natural gas supply networks have found gas turbine plus waste heat boiler installations a commercially attractive alternative to back-pressure generation plus purchased power in case of high power / heat ratios.

Still higher power output levels can be attained for equal production steam demands in combined gas turbine / steam turbine installations ("combi-cycle") at generating efficiencies of up to 47 %. In these installations steam is raised in a waste heat boiler using the gas turbine exhaust gases as combustion air for supplementary firing. The steam is fed to a conventional steam turbo-generator.

The principal power yield and fuel consumption characteristics are given in figures 9 and 10.

As for large driving motors for boiler fans, feedwater pumps etc. speed controlled electric motors and in some instances also variable speed hydraulic couplings, are now standard equipment.

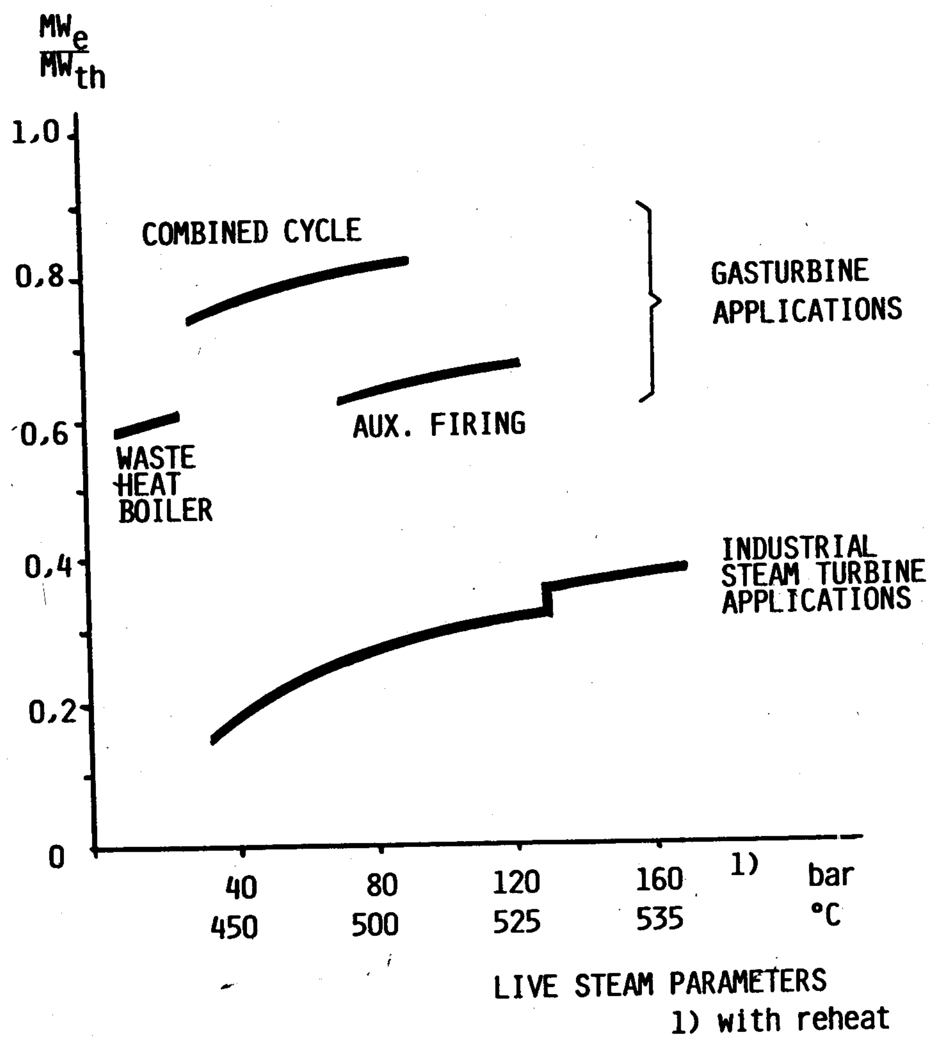
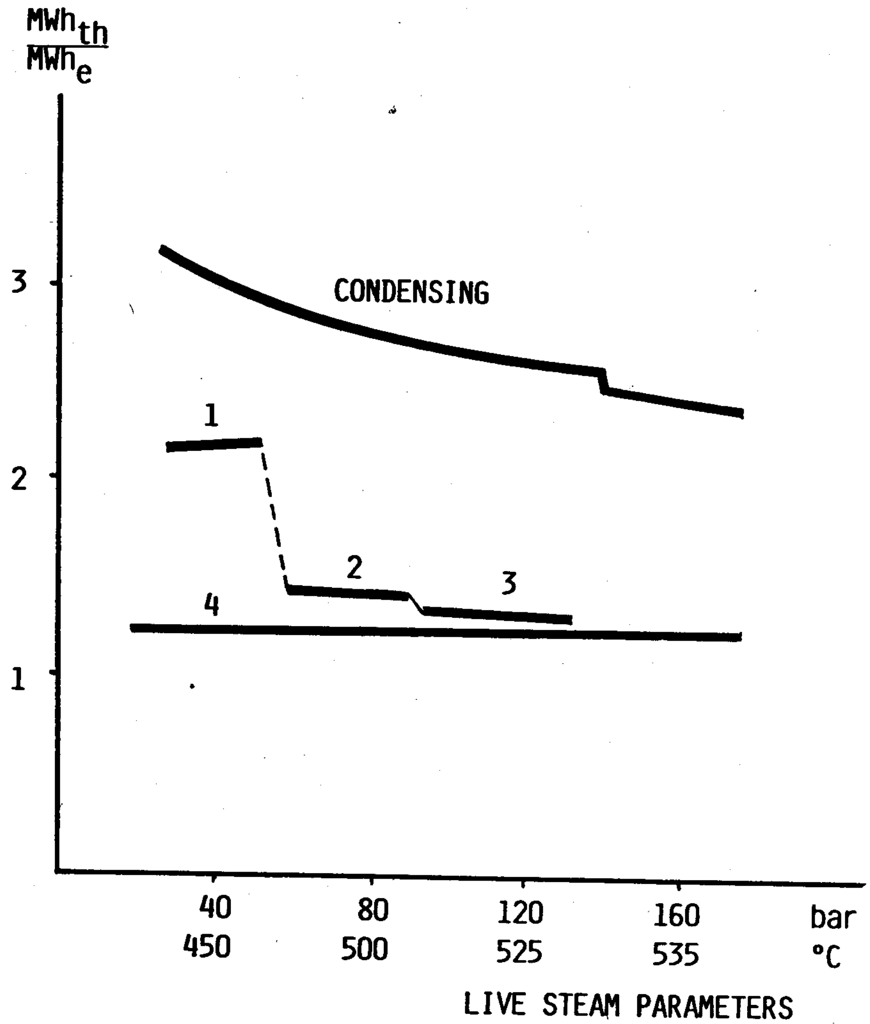


Fig. 9 POWER YIELD VS. PROCESS HEAT FOR COMBINED HEAT & POWER GENERATION (CPH)



1 ... Gas turbine + waste heat boiler
2 ... Gas turbine, combined cycle
3 ... as 2, with auxiliary firing
4 ... conventional steam turbine

Fig. 10 FUEL CONSUMPTION PER NET MWh_e IN CPH - GENERATION

III. ENERGY CONSERVATION

1 GENERAL REMARKS

Energy conservation, in order to be effectively executed, cannot be simply imposed from the top because it requires understanding of the measures being taken and the cooperation of people on all organizational levels. Without their positive engagement most energy conservation measures, if at all successful, will at best be short-lived. This is more a question of man's natural resistance to change rather than one of wanton disregard.

It is because of this human factor that energy conservation can be compared to quality control and it is not surprising, therefore, that reports are found in literature about the successful use of energy conservation "circles" under the guidance of an appointed energy coordinator. Use of creative methods such as brainstorming sessions have also been reported in this connection.

For proper results energy conservation should

- be a permanent effort provided with follow-up routines to verify the expected results of a certain measure and in case of positive results to ensure its survival until becoming routine

- be led by and coordinated by a qualified person who, as Mr. Judt pointed out in his paper, should report directly to top management and receive full backing from it. At least in the initial phase it should be organized as a group effort.

- always concentrate on the general energy supply and cost situation to avoid creating bottlenecks or cost increases in other areas by pursuing an isolated conservation project

- establish a number of key values and cost factors to provide a common yardstick against which progress is to be measured and to visualize the impact on overall costs a certain conservation measure is expected to have. These cost factors should include capital recovery and interest over a reasonable period of time

- already in its early stages lead to recommendations for the minimum extent of instrumentation required

- make extensive use of graphic representations. Sankey-type flow diagrams are most instructive in this respect.

2 SOME SPECIFIC POINTS

Every power station engineer obviously knows the areas where energy conservation work should attack but, nevertheless, some particular points may be worth mentioning

- elimination of air leaks in boiler casings
- monitoring of boiler excess air factor. Shown in graphic form this will give clues also to habitual differences between different shift crews
- checking of the temperature differences of boiler air heater and economizer, again in form of a graph

- modifying soot blower travel speed, pressure, nozzle size, blow frequency and duration to avoid unnecessary steam losses

- checking of boiler gas and air ducting for avoidable pressure losses resulting from inadequate installation and alignment

- checking of spray water supply for unnecessary high pressures

- occasional performance check-ups on major pumps on basis of head/flow characteristics. Permanent sampling points should be installed for this purpose on suction and pressure sides of the pumps

- periodic checking of pressure after turbine control stage for clues to blade fouling

- mechanically limiting the amount of cooling steam passing to the condensor under lp-turbine no-load conditions

- establishing the condensor fouling characteristic

- replacing steam traps by orific devices at less important drainage points

- flow measurement for return condensates. Sufficient cooling down of the condensate f.i. with makeup water

- return condensate monitoring with conductivity probe that automatically operates a dump valve in case of contamination

- tracking down waste of pressurized air. Considering that 10 m^3 of free air compressed to 7 bar require appr. 1 kWh we are talking about money. An air leak of 1 mm diameter in a 7 bar system results in a continuous loss of .4 kW. Checking by departments can be made during standstill periods.

- separation of pressurized air systems according to quality and pressure demands.

CONCLUSION

Energy conservation in all its forms, carried out as an earnest and continuous effort with full management support can bring about spectacular savings in an energy intensive industry such as the pulp & paper industry and should not be neglected, not even in the most modern plant.

Studies into energy savings potentials show again and again that many good ideas are known to operating personnel but lie fallow due to lack of time, resources, guidance and organizational support.

Workshops of this kind, hopefully, contribute towards tapping this hidden potential.