Cogeneration Advances : A Case Study

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Abstract

Pulp and paper industry has been adopting the "Concept of Total Energy" for a longtime by producing power from process steam. Since 1980 onwards advancements have taken place in co-generation and consistent efforts have been made for burning poor grade coals efficiently. Fluidised bed boiler has been proved to be a boon for the Pulp and Paper sector. The present paper deals in the various advancement taken place in the fluidised bed technology and how the Central Pulp Mill of J K Paper Ltd. has brought down the steam and Power consumption by efficient co-generation. 2 case studies have also been given for small and large paper mills with various alternatives of co-generation.

INTRODUCTION

Cogeneration may be defined as simultaneous or sequential production of two or more forms of useful energy from a single primary fuel source. Generally it refers to production of electrical power from the process steam. Cogeneration is also known as combined heat and power (CHP) cycle. Modern cogeneration techniques can provide economical, efficient and environmentally acceptable power production. Pulp and Paper Mills and other process industries which are more self sufficient will have improved control over future production costs with improved cogeneration. Surplus power could be sold out to other industries or the state electricity boards wherever feasible (1).

In the Pulp and Paper Industry cogeneration is not a new concept, having been used for decades. Early Pulp and Paper Mills often located far from electrical transmission lines were obliged to generate their own electricity, often using cogeneration.

Forms of cogeneration

Any manufacturing plant requiring a large quantity of medium or low pressure process steam lends itself to cogeneration. Steam generated at higher pressure can be efficiently reduced to the process condition by converting some of the thermal energy into electrical energy.

Power/Steam ratio

For cogeneration the "concept of total energy" is used and various combinations depending upon the power and steam ratio are being used in the industries. In practical terms there are 2 common forms of cogeneration:

- Solid fuels, oil, natural gas or black liquor burning systems generating high pressure steam which is passed through back pressure or single/ double extraction cum condensing turbine with or without regenerative feed water heating system supplying steam to process and generate power.
- Gas turbine or Diesel cycles which provide electrical power and generate steam at low pressure with the exhaust heat which is used directly in the process.
- Combination of above two schemes i.e. a back pressure / extraction turbine and a DG set preferably on RFO being a cheaper fuel. It will

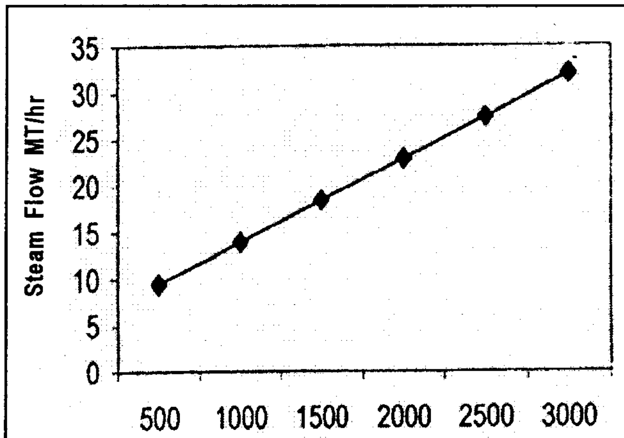


Fig. 1 Load in KW

Table-1 3 MW worthington back pressure set performance curve

KW	Steam tph	Steam kg/kwh	No load steam flow MT/hr	Useful steam tph	Useful steam kg/kwh
500	9.50	18.0	5.0	4.5	9.0
1000	14.00	13.5	5.0	9.0	9.0
1500	18.50	12.3	5.0	13.0	9.0
2000	23.00	11.5	5.0	18.0	9.0
2500	27.5	10.8	5.0	22.5	9.0
3000	32.0	10.7	5.0	27.0	9.0

help reduce the initial investment on condenser. One disadvantage will be that whenever the process demand falls there will be venting of LP steam.

Blowing off excess exhaust steam

When the turbine is an extraction/back pressure type the power gap could be bridged by blowing off a certain quantity of exhaust steam to atmosphere. This may appear at first sight to be very wasteful but actually it is not so wasteful as it appears to be. Look at the graph, the no load steam flow of a 3 MW, 40 kg/cm^2, 400°C back pressure TG set is 5 TPH. The back pressure is at 4 kg/cm^2. Since it is a straight line curve the steam flow is directly proportional to the electrical load on the TG Set, so if the steam is vented out to atmosphere when the process steam demand is low then the cost of venting steam will be Rs. 4.0 kwh (@ 9kg/kwh- Table 1) with the steam cost of Rs. 443/- MT variable cost which is reasonable as compared to the cost of grid power which is 5.50/ kwh.

Till late seventies we had only chain grate and spreader stoker coal fired boilers in the Pulp and Paper industry running with efficiency in the range of 60 to 65% having lot of problems in burning of poor grade coal as the availability of good quality grade 'B' and 'C' coal came down drastically for the process industry. The boilers used to be low pressure boilers generally at 18.0 kg/cm^2 and a few industries had boilers of 40 kg/cm^2 having spreader stokers. Introduction of fluidized bed boilers proved to be a boon for burning poor grade coal having ash content as high as 40% or more which was an impossible task of burning on a chain grate stoker. It also became possible to burn both conventional and nonconventional fuels in FBC boilers like rice husk, wood dust and pith etc. Gradually industries started replacing or converting the chain grate boilers with fluidized bed ones whose efficiency used to be in the range of 78-80% with most of the Indian coals, even some manufacturers were able to produce boilers with 83 to 85% efficiency.

Fluidized bed technology

Basically the fluidized bed technology may be classified in to following two categories:

1) AFBC - Atmospheric Fluidized Bed Boiler

2) PFBC - Pressurized Fluidized Bed Boiler

Atmospheric fluidized bed boiler (AFBC)

The application of atmospheric fluidized bed combustion technology for industrial use and power generation had become commercially accepted as it can burn poor grade fuels and offers less complex solution to meeting stringent emission limits than pulverized fuel fired boilers. The inherently lower emissions result from the ability to operate the boiler at a relatively constant combustion temperature of 815 to 925°C. With combustion in this range for coals having high sulphur content, a sorbent such as raw lime stone or dolomite can be added to the bed along with coal to capture over 95% of the sulphur through the formation of gypsum which is very much useful particularly in cement industries. The low temperature along with the stage combustion air also reduces NOx emissions to less than 150 ppm (308 mg/Nm^3).

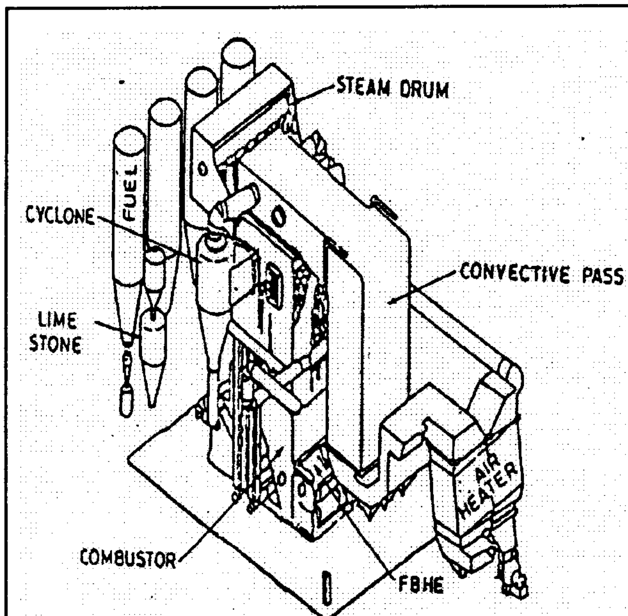


Fig. 2 CFBC Boiler

AFBC Boilers are being manufactured in two general designs-

- **Bubbling fluidized bed system (BFB)**

  Fluidized bed boilers under operation in India in most of the process and pulp/paper industries fall in this category. The superficial air velocity through the combustion is in the range of 3 to 8 ft/sec (0.91 to 2.44 mtr/sec). With this arrangement we are able to burn poor grade coals. The thermal efficiency of these boilers vary in the range of 80 to 85%.

- **Circulating fluidized bed system (CFB)**

  Technological advancement and competition continue to lead the way to production of affordable energy. Circulating fluidized bed (CFB) combustion technology is most suitable for the low grade and waste fuels, it has become the technology of the choice because of its ability to cost effectively meet stringent emissions requirements.

CFB technology is an advanced method of utilizing coal and other solid fuels in an environmentally acceptable manner. This technology is flexible enough to handle wide range of coals plus the petroleum coke which is a byproduct of refineries and is available in the market. CFB boilers are generally economical when the capacity of boiler is 100 tph or more, however industrial boilers in smaller capacities have also been installed. The auxiliary power consumption in CFB boilers is about 2% higher than the BFB boilers. Fuel is fed to the lower furnace where it is burned in an upward flow of combustion air. Fuel ash and unburned fuel carried out of the furnace are collected in a cyclone separator and returned to the lower furnace. When the coal/coke is having high sulphur content the lime stone is used as a sulphur sorbent. Furnace temperature is maintained in the range of 815-925°C by suitable heat absorbing surface. CFB uses superficial air velocity of 13 to 25 ft/sec (3.96 to 7.62 mtr/sec). This process offers the following advantages:

- **Fuel flexibility**

  The relatively low furnace temperatures are below the ash softening temperatures for nearly all fuels, as a result the furnace design is independent of ash characteristics which allows a given furnace to handle a wide range of fuels.

- **Low SO_2 emissions**

  Limestone is an effective sulphur sorbent in the temperature range of 815-925°C. SO_2 removal efficiency of 95% and higher has been demonstrated along with good sorbent utilisation.

- **Low NOx emissions**

  Low furnace temperature plus staging of air feed to the furnace produce very low NOx emissions.

- **High combustion efficiency**

  The long solids residence time in the furnace resulting from the collection/recirculation of solids via the cyclone separators plus the vigorous solids/. gas contact in the furnace caused by the fluidization air flow, results in high combustion efficiency in the range nearer to 90% even with difficult to burn coals.

Pressurized fluidized bed boilers (PFBC)

Pressurized fluidized bed combustion power plants have also progressed and may provide significant savings in both capital costs and cost of electricity over other coal based technologies. Present generation PFBC power plants are combined cycle systems that generate power from both a gas turbine and a conventional steam bottoming cycle. The boiler operates much in the same way as in AFBCs except that the combustion takes place at pressures of 11.00 to 15.00 bar. This is accomplished by placing the combustor or boiler inside a pressure vessel that allows the combustor to operate under pressure without having to act as a pressure barrier. The higher pressure is reported to increase the effectiveness of lime stone in capturing the SO_2, therefore requiring somewhat lesser amount of lime stone and significantly reduces the required bed area of the combustor and allows the flue gases to be exhausted through a gas turbine expander, a feature that increases the power production and plant efficiency by about 15% over that of a conventional system which has only a steam bottoming cycle. There are both bubbling and circulating versions of PFBCs. The description of PFBC boiler is given for the sake of knowledge as an advancement in FBC technology and does not have relevance to pulp and paper industry.

Switching over to HP boiler

With the rising prices of fuel energy conservation came in to being, industries started putting more efforts to economise fuel consumption and therefore emphasis was given to recover waste heat, utilize the heat efficiently and cost effectively and therefore industries strategy discarded the old low pressure boilers at 62 ata and 85 ata etc. Power was being generated utilizing the "Concept of Total Energy" i.e. power from process steam. With higher

CASE STUDY-A

50 TPD Pulp and Paper Mill (Writing+Printing : 16000 TPA)

Furnish: 50% bagasse pulp, 50% waste paper/imported pulp

Total steam requirement	:	12-13 tph
Total power requirement	:	2000 kw
Fuel & GCV	:	Rice Husk, 3300 Kcal/kg
Rate of Rice Husk	:	Rs. 1200/- PMT
Boiler efficiency	:	78%
Cost of grid power	:	Rs. 5/- per kwh
Cost of DG power	:	Rs. 3.50/- per kwh

Scheme of Co-gen	Alter-native	Technical scheme	Details of equipment	Investment Rs. lacs	Operating cost Rs. lacs/annum	Savings wr to 1st scheme	Payback yrs	Remarks
Divided scheme	1	• Generate saturated steam from LP boiler and supply steam through PRD • Generate power from DG sets. • Keep grid power as back up.	• 15 tph, FBC, Multi fuel boiler at 10-12 kg/cm^2, saturated • DG sets each of 1250 KVA	120 100 ------- 220	Cost of fuel for 104000 MT of steam/annum : 273 Cost of DG power : 560 Cost of grid power (est) : 20 Int & Dep @ 16% : 35 ------- 888			
Combined scheme	2	• Generate HP super heated steam • Generate power from an extraction /back pressure TG set - 700 kwh • Generate 1300 kwh balance power from DG sets • Keep grid as back up power	• 15 tph, FBC, Multifuel boiler, 42 kg/cm^2, 410^{0}C • A back pressure cum extraction TG set, cap. 1MW Extraction at 8kg/cm^2 Qty. 2.5 MT avg. Exhaust at 4kg/cm^2 Qty. 9.0 MT avg.	150 150 100 ------- 400	Cost of fuel for 104000 MT of HP steam : 322 Cost of DG power 1300 kwh : 364 Cost of grid power : 20 Int & Dep @ 16%: 64 --------- 770	118	1.5	Additional investment boiler- 30 lacs TG - 150 lacs ----------- 180 lacs
Combined scheme	3	• Generate HP super heated steam • Generate power from an extraction /back pressure TG set - 700 kwh • Draw grid power to meet the short fall of 1300 kw • Keep DGs as standby for back up power	• 15 tph, FBC, Multifuel boiler, 42 kg/cm^2, 410^{0}C • A back pressure cum extraction TG set, cap. 1MW Extraction at 8kg/cm^2 Qty. 2.5 MT avg. Exhaust at 4kg/cm^2 Qty. 9.0 MT avg.	150 150 100 ------- 400	Cost of fuel : 322 Cost of grid power : 520 Cost of DG power (est) : 20 Int & Dep@16% : 64 --------- 926	-38		

Option no. 2 appears to be the most economical one Grid power cost keeps on varying from state to state and also depends upon the draw of power from Electricity Board.

CASE STUDY-B

160 TPD Integrated Pulp and Paper Mill (Writing+Printing : 50000 TPA)

Steam requirement	:	12.5 T/T of paper (9.5 T for process and 3.0 T for Power)
Power requirement	:	1400 kwh/T of paper
Electrical load	:	8000 kw (peak 8750 kw)
Electrical steam load	:	76 MT/hr
Avg steam from recovery boiler	:	20 MT/Hr, Balance from coal fired boiler
Avg steam requirement at 4 kg/cm²	:	44 MT/Hr, (Max 50 tph)
Avg steam requirement at 11 kg/cm²	:	11 MT/Hr, (Max 20 tph)
Avg steam requirement for power generation at condenser	:	15 tph (Max 20 tph)

Alternative	Technical scheme	Details of equipment	Investment Rs. lacs	Operating cost Rs. lacs/annum
1	• Generate steam in coal fired & SR boiler at 42 kg/cm², 410°C • Pass the entire quantity of steam through a 9 MW double extraction cum condensing TG set and extract steam at 11 kg/cm² : avg 11 tph (max 25-30 tph) 4 kg/cm² : avg 44 tph (Max 50 tph) To condenser : 15 tph (max 25 tph) • Generate 8 to 8.5 MW power from TG set • Power backup support : grid power	• 1 No. 9 MW, double extraction cum-condensing TG set with 80 tph inlet steam, 20 tph at 11 kg/cm², 50 tph at 4 kg/cm² condenser of 25-30 tph cap along with cooling power • 1 No. 60 tph coal fired FBC boiler operating at 42 kg/cm², 410°C • 1 No. SR boiler suitable for 275 MT BL solids operating at 42 kg/cm², 410°C	- Boiler 900 - TG set with allied equipment 1600 - Cost of rec. boiler 2500 ---------- 5000 ----------	- Cost of power generation : 1150 - Cost of backup grid power : 140 - int+dep@16% : 800 -------- 2090 --------
2	• Generate high pressure steam in Coal fired and SR boiler at 84 kg/cm², 450°C • Pass the entire quantity of steam through a 7 MW extraction cum-back pressure TG set operating at 82 kg/cm², 440°C Extract steam at 11 kg/cm² Avg. 11 tph (max20 tph) at Avg 44 tph (max 50 tph) • Generate power from TG set @ 6 to 6.5 MW • Generate balance power from an efficient DG set • Backup support grid power	• No. 9 MW, Single extraction cum-back pressure TG set with 55 tph inlet flow (max 65 tph) Extraction at 11 kg/cm² @11tph (max 20 tph) Back pressure at 4 kg/cm² with a flow of 44 tph avg (50 tph) • 1 No. 45 tph, 84 kg/cm² 450°C FBC, coal fired efficient boiler • 1 No. SR boiler, suitable for 275 MT BL solids operating at 84 kg/cm², 450°C • 1 No. 4 MW Wartsila make DG set on RFO	Boiler - 800 TG set - 700 SR boiler - 3000 Wartsila DG - 800 ---------- 5300 ---------	Cost of TG power : 250 Cost of DG power : 370 backup grid power : 140 int + dep@16% : 848 ------- 1608 -------

Looking to above alternative the latter one is attractive from the point of view of operating cost. However, the above schemes could be thought of at the initial stages of plant set up as it becomes difficult to replace the equipment with high pressure at a later stage.

pressures, although the initial investments are comparatively high the pay backs are quite atracttive. Where immediate replacement of the old system is not possible Topping TG sets are also quite popular.

Most of the pulp and paper industries used to pass certain quantity of process steam through the pressure reducing and desuperheating station thereby losing power. Steam should never be permitted to expand from one pressure to a lower pressure without getting some value added results form the expansion. A reducing valve, from the thermodynamic point of view, is an invention of devil. It sets out to degrade good heat and to dissipate the good high potential. In the modern concept the pressure reducing and desuperheating stations are either kept shut or they are being replaced by small single stage back pressure turbo-alternator set so as to generate some power and turbine used to work as a pressure reducing station.

Two case studies of the following capacities of pulp and paper mills are given here using the various schemes of co-generation system. As is evident from the illustrations it is very clear that for small paper mills who use the divided scheme i.e. supplying steam from low pressure saturated steam boilers and using power from grid or DG sets, the combined scheme i.e. power from process steam is economical.

Case study- A : a 16000 TPA pulp and paper mills based on bagasse pulp and waste paper/ imported pulp (WPP).

Case study- B : An integrated pulp and paper mill of 50000 TPA (WPP).

A case study of JK Paper Ltd.,

(Unit Central Pulp Mills)

The unit - Central Pulp Mills came into existence in 1966 with one 35 TPH oil fired boiler, one recovery boiler for 207 tpd solids at 42 kg/cm^2, 410°C, one 3.0 MW back pressure TG set and one 3.0 MW extraction/condensing TG set. Since the steam generation cost with oil was high so 2Nos 20 tph each WIL make pulsating grate coal fired boilers were installed and commissioned in 1978 which did not work well and so converted to spreader stoker type after a short span of about 6 months. The JK Group took over this unit in 1992 and with the development of fluidized bed technology one of the Coal Fired Boilers was converted to FBC in 1993 and capacity of this boiler was also enhanced to 30 tph. Since running of inefficient spreader stoker boiler was a costly affair so one 50 tph, 42 kg/cm^2, 410°C TBW make AFBC boiler was installed and commissioned in 1994. With the installation of this boiler both the above WIL boilers became standby equipment which resulted in large coal savings as the boiler has been running since then at an average efficiency of 83% with a load factor of 95%. Unlike the FBC boilers provision of secondary air is made for creating turbulence and arresting the unburnt fine particles going along with the flue gases. The boiler has provision of cinders refiring system to reburn the unburnt coal particles of the fly as collected in the boiler bank and economizer/ air heater ash hoppers which has helped achieving the high efficiency.

Considering the same price and GCV of coal before and after commissioning of this boiler the coal saving works out to about 10000 MT/annum or say Rs. 200 lacs/annum.

Use of bamboo dust in FBC boilers

JK Paper has been consuming bamboo dust by under feed system in FBC retrofitted boiler and over feed in the 50 tph TBW boiler. The experience has been as following :-

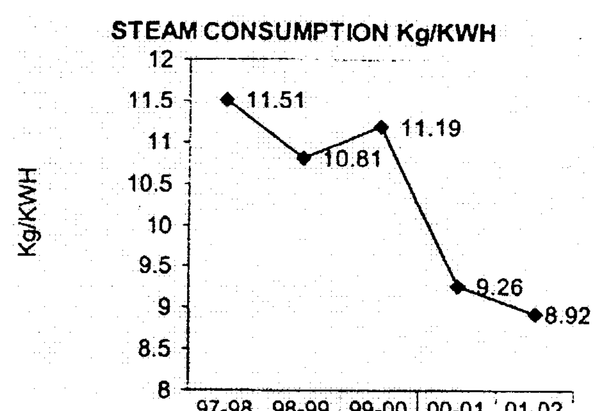
Underfeed system

The bamboo dust used to be mixed with coal and fed to the furnace through the underfeed system. The draw back was that only limited quantity of the dust could be consumed say @ 3 to 5% of the coal quantity. The following problems used to be faced:

- Jamming of inlet chute of coal feeders.
- Jamming of mixing nozzles with bamboo chips.
- Variation in boiler pressure due to above jamming.

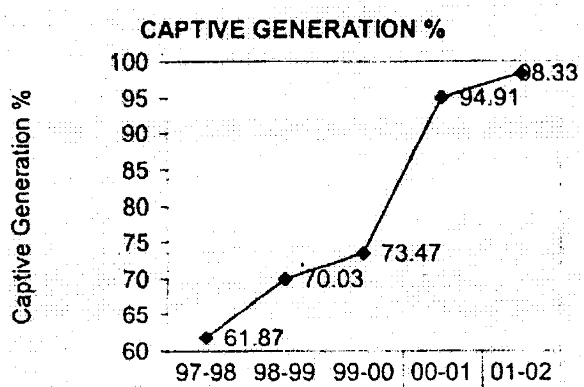
Over feed system

Bamboo dust is consumed in 50 tph TBW boiler through over feed system. A separate bunker is provided by the side of coal bunker for storage of



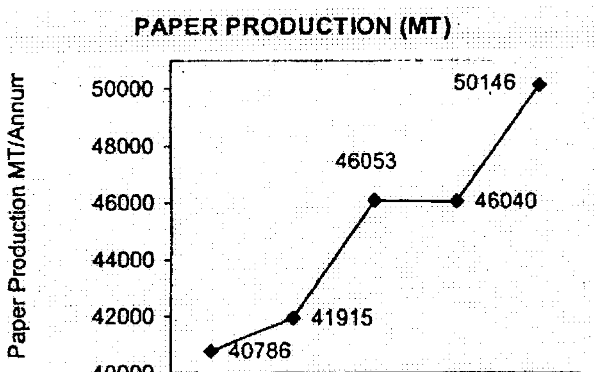
	97-98	98-99	99-00	00-01	01-02
Steam Kg/KWH	11.51	10.81	11.19	9.26	8.92

Fig. 3 Specific steam consumption in kg/KWH



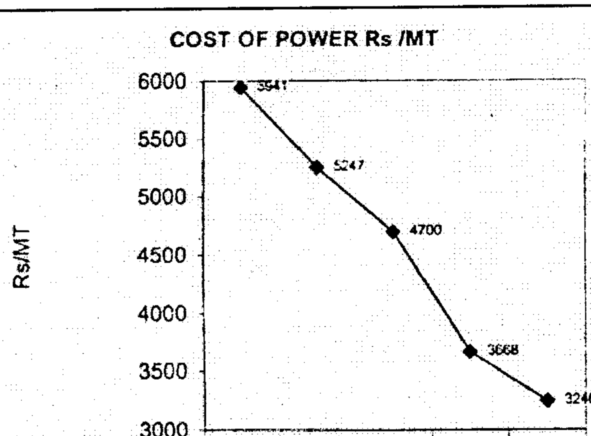
	97-98	98-99	99-00	00-01	01-02
Captive Generation %	61.87	70.03	73.47	94.91	98.33

Fig. 4 Yearwise enhancement in co-generation



	97-98	98-99	99-00	00-01	01-02
Production MT	40786	41915	46053	46040	50146

Fig. 5 Yearwise Paper Production



	97-98	98-99	99-00	00-01	01-02
Cost of Power/MT	5941	5247	4700	3668	3246

Fig. 6 Cost of Power / MT of Paper

the bamboo dust and feeding arrangement is also through a variable speed rotary feeder. With this arrangement although it is possible to consume more quantity of dust to the extent of 6 to 8% but the problems faced are as follows:

- Sudden increase in furnace pressure.
- Variation in steam temperature (400-440°C)
- Increase in bed temperature of 1st compartment to 950°C as against normal temperature of 915°C.

Captive generation

With a view to have efficient cogeneration 1 no. 12 MW, double extraction cum condensing turbo alternator of EME, Russia (Energomach Export) make was installed and commissioned during April 2000. Both the extractions are controlled with a DCS system. The two extractions are at 11.0 and 4.0 kg/cm^2. The trubine has no load steam flow of about 2 tph which is around 2.5% of the maximum HP inlet flow of 80 tph. It has the advantage that maximum steam could be extracted and the flow to condenser shall be minimum thereby power generation cost will be minimum. Since both the extractions are controlled it is possible to maintain fairly constant steam pressure in the LP and MP steam headers which ultimately helps in smooth process plants operation and economical cogeneration.

Regenerative system

Apart from the two extractions the turbine has a regenerative feed water heating system. Steam is bled off from the low pressure zone after second extraction and fed to a low pressure heater to utilize partly the heat of steam for heating boiler feed water which otherwise would have been wasted as the condenser cooling water.

Parameters

Inlet feed water temp.	- 63.5°C
Outlet feed water temp.	- 80°C
Qty of feed water	- 75.0 m^3/hr
Pressure of steam	- Rs. 0.37 kg/cm^2
Savings	- Rs. 50 lacs/annum

With the installation of this TG set the other 2 TG sets (Back pressure and condensing type) have become standby units and JK Paper Ltd have 100% self-sufficiency on captive cogeneration. The graphs depict the company's growth with respect to production of paper (Fig. 3) and how the cpative generation has gone up over a span of 8 years and cost of power generation has come down as a result of reduction in specific steam consumption. With a view to enhance cogenration JK Paper have carried out certain changes in the process for increasing the use of low pressure steam at 4 kg/cm^2 in place of medium pressure steam at 11 kg/cm^2.

Pulp mill

Earlier medium pressure steam was being used in Pulp Mill for cooking purposes. With a view to enhance cogeneration use of LP steam has been introduced to the extent of 50%. Although it was anticipated that the cycle time shall increase, in actual practice the change in cycle time is practically negligible.

Earlier MP steam qty for cooking and blowing = 17.2 MT/dig.

Now, MP steam qty has been reduced to = 8.93 MT

LP steam addition = 7.87 MT

Additional power generation with the above change = 150 kWh

Recovery boiler primary air heater

With the introduction of LP steam in the primary air heater the additional power generation is around 38 kWh.

Trial of petcoke in 50 tph FBC boiler

With a view to reduce cost of captive generation JK Paper is proposing to carry out trials for burning petcoke along with Indian coals in the ratio of 20:80. The cinder refiring system provided in the boiler shall help control the unburnt in fly ash and also the SOx emissions.

Use of fly ash from the AFBC boilers

The fly ash, from the boilers, is conveyed to an ash silo through dense phase ash conveying system and from there it passes through ash conditioning arrangement and then transported through trucks. About 10-15% of the fly ash is being used for brick making and the remaining is dumped in low lying land acquired for the purpose. It is felt that after using the petcoke gypsum shall be formed by the addition of lime stone in the bed which will improve the quality of fly ash and in turn improve quality of fly ash bricks. For lack of demand we are not able to utilize the fly ash for brick making by more than 15% although the fly ash bricks have more strength, good finish etc. Perhaps it requires more publicity to bring up the level of confidence of a common man on the use of the fly ash bricks.

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CONCLUSION

J K. Paper Ltd, Unit : Central Pulp Mill has been able to reduce the specific energy cost by running a single big boiler and single double axtraction TG Set. Pet Coke is available in the market in substantial quantity. The boiler manufacturers are required to do more R&D for the effective and efficient utilization of this GCV cheaper fuel containing high sulphur content. There is ample scope for Co-generation in small paper mills using bagasse pulp and waste paper. It is always economical to go for high pressure system.

REFERENCE

1. 13th International ASME flid bed conference Orlando, Florida, May 95.

(Paper presented during the Zonal Seminar on Cogeneration and Developments in the Utility areas of Pulp and Paper Industry 5-6th July, 2002 at Bhubaneshwar).