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MISSION REPORT

Expert in Productivity Improvement
through Cogeneration

DP/IND/84/020/11-14

DURATION : 2 months

DUTY STATION : New Delhi, India

Prepared for

United Nations Industrial Development Organization

by

ROBERT ERICKSON

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UNIDO PROJECT REPORT

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PROJECT DESCRIPTION

The project post was attached to the National Council for Cement and Building Materials (NCB) as part of an international team coordinated through the NCB Centre for Productivity Enhancement. The purpose of the project was the identification of areas for potential waste heat recovery and definition of appropriate cogeneration systems to produce electrical power from the waste heat. The project activities completed during this period included:

a) working with NCB staff to identify heat sources in cement plants and characterise potential heat recovery streams;

b) travel to the Hyderabad Unit of NCB from where plant visits were made to three cement plants to gather energy data for evaluation of the site as a prospective cogeneration application;

c) preparation of cogeneration scheme, system sizing and economic evaluation of a cogeneration system at the specific sites;

d) preparation and presentation of a lecture on technologies, applications and economics of cogeneration in the cement industry. Lectures presented in Hyderabad and New Delhi;

e) preparation of a report discussing the general application in cement plants in India.

COGENERATION IN CEMENT PLANTS

The activities of this project focused on providing a technological and economic feasibility assessment for cogeneration systems using waste heat recovery available in cement plants. The primary heat resources evaluated during this phase of the project have been the heat exhausted from the clinker cooler and the exit gases from the suspension preheater string. These two sources combine to provide the potential of approximately 43 kWh/tonne of clinker produced. Waste heat recovery boilers and steam turbines are available from suppliers in India.

An economic evaluation of the cogeneration system was conducted to determine the conditions under which the system would be cost effective. The results show that a waste heat recovery cogeneration system will be cost effective in cement plants with production capacities of 1500 tpd and above with electric rates of Rs. 0.8/kWh and higher. Currently there are 20 plants in India with production rates of 1500 tpd or more producing approximately 12 million tonnes per year. This could result in a potential capacity addition of about 80 MW to the Indian generation capacity that would be financed with private capital.

Introduction of the cogeneration system at the cement plants is also useful since it offers means to offset the negative impacts on production due to power interruptions and cutbacks as it frequently occurs in some states of India.

By the year 2000, it is expected that an additional 45 million tonnes per year of cement production capacity will be built. These systems would typically be 3000 tpd plants where cogeneration systems would be cost effective having pay back periods of less than 3 years. These plants represent an additional potential of 300 MW of generation capacity.

This cogeneration capacity could cost effectively be increased by burning additional coal either in the waste heat boiler or in the calcinator. However, several problems exist with coal availability. The cement plant may also optimize its operating parameters differently given a waste heat recovery boiler cogeneration system is included in the plant. A data base on various plant operating conditions needs to be defined before this more detailed analysis can be completed.

A report was prepared presenting the details of the current analysis and is attached as Appendix-A.

CASE STUDIES

Technical and economic evaluations of cogeneration systems were made for three cement plants located in the southern part of India. These plant visits were made from the Hyderabad Unit of NCB. The plant visits included:

Larsen & Toubro Limited
Awarpur Cement Works
3200 tpd

Kesoram Industries Limited
Vasavadatta Cement Works
1800 tpd

Raasi Cement Limited
Vishnupuram Cement Works
1400 tpd

Cogeneration applications are technically feasible at all the these plants. In the case of the Awarpur and Vasavadatta Works, the systems are clearly cost effective with pay back periods of less than two years. In the case of Vishnupuram Works, the combination of a relatively small plant and low electric costs resulted in a pay back period of over four years even including financing options. This would be judged to be marginally cost effective.

The case study reports prepared for each of these plants are attached as Appendix-B.

LECTURES

Two lectures were prepared and presented to members of the NCB staff and industry representatives. The first lecture was given in Hyderabad on February 10, 1987 and the second in New Delhi on February 20, 1987, Presentation material used for these lectures is attached as Appendix-C.

RECOMMENDATIONS REGARDING NCB

The following recommendations are based on impressions gained during the two month mission. Approximately one half of the time was spent at the NCB unit at Ballabzarh and the remainder at the unit at Hyderabad. Points of significant contact with NCB staff were limited to four persons during the mission. Therefore, it is difficult to be definitive in recommendations regarding NCB.

1. NCB staff needs to interact with the consultants as a training activity rather than only to provide support to the consultant as he completes the task of the mission. In this case, the task was to evaluate cogeneration potential in cement plants.

2. NCB's function is to provide support services and technology transfer to the cement industry. To accomplish this objective they need to prepare and publish reports and probably a monthly journal. They do not have the facilities to prepare and publish any significant volume of reports. The management does not expect the staff to publish reports and therefore the information tends to stay only within NCB as transferred in various meetings. NCB should expand its word processing and reproduction support facilities and evaluate publishing a monthly technical journal.

3. NCB staff needs broader contact with the cement manufacturers and with process equipment manufacturers. The knowledge that NCB has needs to result in a more specific impact that can only be attained by working directly with systems hardware and product manufacture.

4. In the cogeneration area the NCB staff needs to work closely with Bharat Heavy Electricals, Ltd., a manufacturer of boilers and turbines. NCB can supply cement process related information while BHEL has the power systems background. Presentations from both organizations need to visit cement plants with operating cogeneration systems. The most likely location for these plants is in Japan.

5. NCB needs to develop a data base of plant performance data at various operating parameters that will allow the optimum integration of the cogeneration system into the total process. The current process is optimized to minimize thermal energy consumption. Operating parameters need to be developed that will minimize total energy consumption.

6. One option to develop the above data base is to use the planned control process simulator. The simulator currently proposed by F.h. Smidth is only a control station training simulator to train operators in the use of the FLS DDC cement plant process control system. NCB staff needs to prepare specifications for the development of a full process simulation that will include algorithms that specifically represent various system components of the clinker manufacturing process. It may be possible to obtain data for these algorithms by working with the Larsen and Tuobro plant and the Madras plant where FLS is enstalling the fully computerized process control systems.

7. In certain unique areas such as cogeneration, NCB should consider identifying a project manager who will be responsible for contracting with equipment manufacturers for the design and development of a cogeneration system. Cement plants operate at the same performance parameters relatively independent of plant size. One characteristic cogeneration plant could be developed scaled only by size to accommodate various cement plants. NCB should not develop on independent staff to design cogeneration systems.

APPENDIX A

COGENERATION FEASIBILITY USING WASTE HEAT RECOVERY IN CEMENT PLANTS IN INDIA

COGENERATION FEASIBILITY USING WASTE HEAT RECOVERY IN CEMENT PLANTS IN INDIA

INTRODUCTION AND SUMMARY

In the past decade energy costs have been increasing rapidly with electrical energy costs generally increasing faster than fuel costs. During the past year world price for primary energy has declined. However, electrical energy costs have not. The cement industry, being an energy intensive industry, has made steady progress in improving the fuel efficiency of kilns but has experienced increased electrical energy consumption per tonne of cement. One answer to rising electrical power costs in cement plants is the utilization of waste heat recovery cogeneration systems.

Cogeneration is the sequential production of two forms of useful energy, usually heat and electricity, from the same input fuel source. In the case of the cement plant, heat is first used in the process of producing clinker with waste heat being recovered for the production of electrical energy using a boiler, steam turbine system. Improvements in kiln energy efficiency have reduced the heat available for recovery in a waste heat boiler. However, sufficient energy is available in the exit gases from the preheater and the clinker cooler of dry process kilns to provide the potential for a cost effective electrical power generation system.

Several gas flow options are available for use in heat recovery systems. Use of heat from the exit gases of the suspension preheater stream and the clinker cooler stream have the least impact on clinker production process. These two waste heat streams were utilised as energy sources for evaluation of cogeneration systems at plants with 1400 tpd, 1800 tpd and 3000 tpd. The exhaust streams will provide the potential generation capacity of approximately 44 kWh per tonne of clinker production. Economic cost-effectiveness is dependent on system capacity and value of the electrical energy produced. In general, cogeneration systems will be cost effective for plants producing over 1500 tpd with electric rates of Rs. 0.8/kWh or above.

HEAT RECOVERY OPTIONS

Heat is available for use in a heat recovery boiler from several sources associated with the kiln operation. Figure-1 and Table-1 (Reference-1) summarise the location and characteristics of the mass flow rates and temperatures of available gas streams. The highest temperature gas is available at the kiln exit. It is desirable to use the highest temperature heat source available because of the increased steam cycle efficiency available at higher steam temperatures. Three cement plants in the United States operate cogeneration systems using kiln exit gas and are able to produce as much as 50 kWh/tonne from this source (Reference 2, 3, 4). Use of this heat source has a major impact on the kiln design and operation of the kiln. All dry kilns in use in India are of the suspension preheater type (some with precalcinator) that do not allow the recovery of kiln exhaust heat.

The largest overall gas volumes of exit gases are available from the preheater exit gas and exhaust air from the clinker cooler. Use of these two gas streams into an integrated preheater gas boiler, cooler gas boiler and multistage turbine is being utilised in more than 10 cement plants in Japan (Reference 5). This system approach is able to produce 30 to 45 kWh/tonne of clinker. Use of the preheater exit gas alone is being used in one plant in Switzerland (Reference 6) and has the potential of producing 10 to 25 kWh/tonne of clinker.

Consideration has also been given to the use of clinker cooler exhaust gas alone. Because of the low temperature of this source (230 - 260°C) the steam cycle systems have very low overall efficiency. It is possible to improve the system cycle efficiency with the use of organic fluids (i.e. freon, tolune, freon/water, etc) as the working fluid in a Rankine power system. The increase in efficiency could be about 30%. However, these systems have a higher initial cost, there is little experience in the use of this type of system and the equipment is not commercially available in India.

Because of the above considerations, the study of waste heat recovery cogeneration systems in India focussed on the utilization of the preheater exit gas and clinker cooler gas. All applications considered are based on steam power generation system where the equipment is available in India.

SYSTEM DESCRIPTION

A feasibility analysis for the generation of electrical power using waste heat is presented for a typical 1800 tpd plant with a dry process kiln. The plant is assumed to have a four-stage suspension preheater with precalinator. Heat is available from both the preheater and the cooler exit gas streams. The utilization of this heat is summarized in Table-2. Using both exhaust streams at the production rate of 75 tph a power generation capacity of 3304 kW (gross), 3040 kW (net) could be installed.

The typical power generation system evaluated in the plant studies uses steam as the working fluid with recovery of heat from the preheater exit gas and the cooler exhaust. These two heat sources would be integrated into a one multi-stage turbine-generator set as shown in Figure-2. The heat from the cooler exhaust stream is utilized as both a source of feed water preheat to the suspension preheater boiler and for direct steam production for injection into a lower pressure port of the multistage turbine. The split of energy usage from the cooler requires detailed information on various multi-stage turbine performance that will need detailed analysis in the preliminary system design phase. However, this technology is well proven with more than ten such systems operating in Japan (Reference-5).

Boiler feed water returns from the condenser and is preheated by the cooler exhaust and continues to the boiler located in the preheater exit gas stream where it is evaporated and super heated. The steam is then introduced into the turbine to generate electricity.

At the same time, part of the return feed water flow is utilized in the boiler located in the cooler exhaust stream where the feed water is preheated, evaporated and super heated but at a lower pressure than the preheater boiler. This lower pressure steam is introduced into a later stage of the turbine to increase the quantity of power produced. The cooling water utilized in the condenser is circulated between the cooling tower and the condenser. For this 3304 kW gross generation, approximately 250 litres per minute of condenser make-up water will be required.

Dust loading at the preheater exhaust stream does not pose a problem. Current waste heat recovery boilers are operating in the U.S. at higher dust loadings in systems using direct kiln exhaust or kiln by-pass gas with only one stage cyclone separation. To remove the more abrasive dust from the cooler exhaust, cooler ESP outlet gas is introduced into the boiler.

All of the kiln gas flow from the preheater passes through the heat recovery boiler where the temperature is reduced to 200°C. The gases will either by-pass the gas conditioning tower or pass through the tower without a requirement for use of the conditioning tower. There is sufficient energy remaining in the exhaust flow to provide drying of the raw material even at the 4% moisture experienced during the rainy season even if only half of the preheater exhaust gases are used for raw material drying. Where vertical shaft roller mills are used, the 200°C outlet temperature will be sufficient to provide drying even if an additional 1% moisture is added at the mill table to stabilise grinding. For vertical roller mills all of the preheater gas flow is assumed to be required for material transport.

The cogeneration system would be controlled automatically with its own microprocessor for start-up and shut down of the turbine-generator set. Data concerning the waste heat boiler and turbine-generator are transmitted back to the central control room. The turbine-generator can be automatically restarted from the control room after short duration shut-downs of the kiln (where the kiln is kept hot). No power can be generated during shut-downs of the kiln.

Operation of the cogeneration set is assumed to be a secondary function to the primary function of kiln operation. Experience in operating cogeneration systems is that they have more than 95% availability. The experience of a cogeneration system operating in Switzerland using preheater exit gas only is noted as follows (Reference 6). On no occasion has cement production been interrupted or decreased due to the waste heat recovery boiler or turbine generator set. Availability has been about 94% referred to kiln operating time which could be improved. Operations and maintenance of the cogeneration system has been conducted without any increase in the number of personnel at the plant.

Kiln operation may also be optimised at different operating parameters if a waste heat recovery cogeneration system is integrated into the cement plant. Table-3 presents data assuming that the preheater outlet temperature was increased to 410°C. This would require higher coal consumption that could be accomplished in the calcinator. The result is an increase of power production from 25.3 kWh/t to 36.6 kWh/t. At the fuel cost of Rs.540/tonne of coal and Re.1/kWh electrical energy rate, there is small decrease in the total energy cost to produce one tonne of cement. The cogeneration system will provide a means of stabilising total energy costs even if there are variations in kiln operations.

An additional data base will have to be developed to optimise both kiln and cogenerator operations. This may be accomplished using the NCB plant simulator when it is installed. Effects of different operating temperatures on quality of clinker will also have to be evaluated.

The availability of power and reliability of power in some States of India is not good. Captive power production offers a means to offset the negative impacts on production due to power interruptions and cutbacks. For the 1800 tpd cement plant the capacity of 3040 kW from the cogeneration is somewhat short of critical power requirements of about 3500 kW needed for kiln and coal grinding operations. However, with proper load management steady kiln operations can be maintained. Problems only would be encountered in start-up of large motors.

SYSTEM COST

A budgetory cost estimate has been made for the cogeneration system and is presented in Table-4. Cost of the system is estimated to be Rs. 664 lakhs and to be made up of components manufactured in India. The cost estimate is based, in part, on turbine-generator set data supplied by Bharat Heavy Electricals Ltd and cost break-down percentages experienced in construction of this type of an overall system. The resultant cost of cogeneration systems on a Rs./kW basis is summarised in Figure 3. This figure shows an increasing unit cost with decreasing size that makes it difficult for small systems to be cost effective.

For the purpose of calculating a payback period on this system, an operations and maintenance cost of Rs. 0.13 kWh was assumed. This cost included materials (i.e. chemicals for boiler feed water treatment), labour assigned for direct maintenance of the cogeneration system, and a sinking fund to allow major overhaul of the primary system components.

ECONOMIC EVALUATION

The cost-effectiveness of the 3300 kW (gross), 3040 kW (net) waste heat recovery cogeneration system was evaluated using the cash flow analysis presented in Table-5. The analysis is based on an 1800 tpd plant where electric rate is Rs. 0.9/kWh with a demand charge of Rs.30/kW/month as these appear to be average values in India. Revenues are based on being able to displace power that would otherwise have to be purchased. The total power production is based on operating the system at its net capacity of 3040 kW for 7200 hours per year (82.19% of 8760 hours). Electric rates are assumed to escalate at 10% per year. Operations and maintenance costs are calculated based on the gross power output of 3300 kW operating 7200 hours per year at a cost of Rs. 0.13/kWh. The demand is also based on gross capacity and an average demand charge of Rs. 360/kW/year. Insurance cost is based on a value of 0.8 percent of initial cost and escalates at 6% per year as does the operations and maintenance cost.

Depreciation, an incentive credit and taxes are also taken into account Depreciation is based on the WDB method. The incentive is calculated as the difference between the WDB and straight line method using the full economic life of the system. Taxes are calculated based on a 50% tax rate.

Results of this analysis show a payback period of 5.11 years and an internal rate of return on investment of percent based on 10 years of 17.4 percent. That is the discount rate that brings the 10 years of positive cash flow back against the initial cash outflow to provide a zero net present value. This table was calculated based on a 100% equity in the system, that is no financing.

The payback period is sensitive to initial cost and to electric rate. Figure 4 shows the sensitivity to initial cost of system size. This data was used along with electric rates of Rs. 0.7/kWh, 0.9/kWh and 1.1/kWh to evaluate the simple payback period. Assuming that a simple payback of 4 years or less is the decision criteria for making a choice to proceed with the project, system sizes of greater than 3000 kW with electric rates of Rs. 0.9/kWh or greater would be required.

One way of decreasing the payback period and increasing the internal rate of return on investment is to finance the system. Table-6 presents the cash flow analysis for the same system but with financing at 12.5 percent interest with a 2:1 debt to equity ratio. The loan is for a period of 10 years with a 2 year moratorium. The system can be constructed in approximately 12 months from signing of construction contracts.

With the two year moratorium, there is one year of operation where revenues are realised but no principal or interest payment is required. The result is that the pay back period is reduced to 2.4 years and the 10 year IRR is 47 percent. It should be noted that the payback period is sensitive to construction time since a large portion of the equity is recovered in the second year of the loan moratorium. Payback period is also very sensitive to annual hours of operation. The above system, assuming that it is financed, was used as the base line system. Hours of operation were then varied to determine the impact on pay back period. The results of this analysis are presented in Table-7.

TABLE 7

Payback Period Sensitivity to Operating Hours

Operating Hours	Payback Period
4000	6.01
5000	4.72
6000	3.05
7000	2.45
8000	2.05

Even with financing of the system, it is necessary to operate more than 5500 hours annually to have a pay back period of less than four years.

CONCLUSION

Cogeneration systems designed to use waste heat recovery in cement plants are technically feasible. The energy available in the exit gas from the suspension preheaters and the clinker cooler exhaust will provide the potential to generate approximately 44 kWh/tonne of clinker produced. Systems of various types are in operation in several countries throughout the world.

Economic feasibility also is justified for systems where the plant production rate is greater than 1500 tpd and the electric rate is Rs. 0.9/kWh or greater. System performance is also sensitive to the quality of waste heat available. This analysis was based on the retrofit of a cogeneration system to a kiln optimised for minimum exit temperatures and minimum fuel consumption. Integration of the cogeneration system into the kiln operations will require optimisation of both net electrical energy consumption and fuel consumption that may result in different operating conditions. Additional kiln performance data would be required to make this assessment and the system optimisation would be sensitive to both fuel and electrical energy costs.

Several states in India have problems with the availability of power. Use of a cogeneration system to provide captive power at the cement plant can increase the ability of the plant to maintain its production rate and reduce its average fuel consumption per tonne of clinker. Steady operation of the kiln appears to require 32 kWh/tonne and coal grinding about 8 kWh/tonne of clinker. This would use the power available from the cogenerator. The only problem may be large starting current requirements when bringing large electric motors on-line. This problem may be accommodated with careful load management.

Use of a cogeneration system at cement plants also has benefits for the State operated electric utilities especially in States that have power shortages. The installation of capacity at the cement plant has to net result of increasing the capacity available to the utility. This is done with the use of private capital.

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3 Bush, C.W., "The decision for cogeneration at Riverside Cement", presented at the 15th International Cement Seminar, Chicago, Illinois, December, 1979

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5 Noguchi, K, Japan's Cement Industry Today, Rock Products, May, 1982

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TABLE 1

Characteristics of Extraction Gas Streams
Available for Heat Recovery

POINT OF GAS EXTRACTION	Designation	SPEC MASS FLOW 2) m^3/kg	Temperature ^oC	Underpressure m bar	Dust Content 1) g/m^3
1	Preheater Exit Gas	0,6 - 1,8	280-600	20-80	20-100
2	Preheater intermediate Gas	0,1 - 0,4	500-800	30-70	50-150
3	Kiln exit gas By pass gas	0,1 - 0,5	1000-1200	2-10	50-300
4	hot air from cooler (secondary air)	0,1 - 03	700-900	0,1-05	5-200
5	Exhaust air from cooler	0,4 - 1,8	150-400	0,1-0,5	5-20

1) AT STANDARD TEMP. AND PRESSURE (0°C, 1.013 bar)

2) REFERRED TO CLINKER

TABLE 2

Potential Cogeneration Capacity from Preheater and Cooler Exit Gas Streams

	Preheater Heat Recovery	Cooler Heat Recovery
Gas Flow Nm^3/h	1850	2400
Temperature °C	360	230
Boiler Exit Gas Temperature °C	200	110
Specific Heat $\frac{KJ}{Nm^3 \, ^\circ C}$	1.4	1.3
Available Heat (OOO)KJ	414	374
Cycle Efficiency Percent	22	18
Cogeneration Capacity Kw	25.3	18.7

TABLE 3

TOTAL SYSTEM ENERGY SENSITIVITY

	Base Case	Decreased Kiln Efficiency
Kiln Efficiency Kcal/Kg Cl	900	950
Electricity Use kWh/ton	130	130
Gas Volume Kg Nm^3/h	1850	1950
Preheater Temperature °C	360	410
Boiler Exhaust Temperature °C	200	200
Available Heat (000) KJ	414	573
Cycle Efficiency Percent	22	23
Cogeneration Capacity kW	25.3	36.6
Fuel Cost (540 Rs/ton) RS	128	135
Electricity Cost (1.0 Rs/kWh) RS	105	93
Total Energy Cost RS	233	228

TABLE - 4

CAPITAL COST SUMMARY FOR A 3300 kW COGENERATION SYSTEM

	Rs Lakhs	
	Material	Labour
Boiler	125	7
Turbine	215	4
Power House	18	8
Piping, steam & water	95	16
Electric & controls	19	8
Site work	2	5
Spare parts	15	-
TOTAL :	489	48

General construction (Indirect & Fee)	70
Indirect Project Engineering	49
G & A	8
TOTAL CAPITAL COST	664

TABLE 5
COGENERATION CASH FLOW ANALYSIS
NATIONAL COUNCIL FOR CEMENT AND BUILDING MATERIALS
(R.C. ERICKSON, UNIDO EXPERT)

SITE: ABC CEMENT, LTD.

ASSUMPTIONS:

Total Installed Cost:	664.00 Rs LAKH	Heat Soure	Preheat/Cooler Exhaust	Initial Elect. Pur. Price:	0.90 Rs/kwh
Loan Amount:	0.00 Rs LAKH	Size:	3040.00 kw	Initial Fuel Cost:	0.00 Rs/Mcal
Down Payment	664.00 Rs LAKH	Gross Heat Rate:	0.00 cal/kwh		
Loan Terms:		Recoverable Heat:	0.00 cal/kwh	Elect. Used On Site:	100.00 Percent
Int.	12.50 Percent	Plant Cap. Fact:	82.19 Percent	Initial Elect. Sale Price:	0.90 Rs/kwh
Term	8.00 Years			Standby Demand Charge:	360.00 Rs/kw/yr
Economic Life:	15.00 Years			O&M Charge:	0.13 Rs/kwh

YEAR:	1987	1988	1989	1990	1991	1992 (Rs LAKH)	1993	1994	1995	1996	1997
REVENUE:											
Displeaced Electricity:		196.99	216.69	238.36	262.19	288.41	317.25	348.98	383.87	422.26	464.49
Electricity Sold:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL REVENUES:		196.99	216.69	238.36	262.19	288.41	317.25	348.98	383.87	422.26	464.49
EXPENSES:											
Fuel:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O&M:		31.01	32.88	34.85	36.94	39.16	41.50	43.99	46.63	49.43	52.40
P&I:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Insurance:		5.31	5.63	5.97	6.33	6.71	7.11	7.54	7.99	8.47	8.97
Standby:		11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93
TOTAL EXPENCES:		48.26	50.44	52.75	55.19	57.79	60.54	63.46	66.55	69.83	73.30
PROFIT (Pre Tax):		148.73	166.25	185.61	207.00	230.62	256.71	285.52	317.32	352.43	391.18
TAX IMPACTS:											
[Depreciation]:	66.40	59.76	53.78	48.41	43.57	39.21	35.29	31.76	28.58	25.72	23.15
[Incentives]:	22.13	15.49	9.52	4.14							
TAXES: 50.00 percent	-44.27	36.74	51.47	66.53	81.72	95.71	110.71	126.88	144.37	163.35	184.02
PROFIT (After Tax)	44.27	111.99	114.78	119.08	125.28	134.91	146.00	158.64	172.95	189.08	207.17
CUMULATIVE CASH FLOW:	-619.73	-507.74	-392.96	-273.89	-148.61	-13.69	132.31	290.94	463.90	652.97	860.14

SIMPLE PAYBACK, YEARS:
Based on 5 Year Average 5.11

INTERNAL RATE OF RETURN:
Based on 10 Years 17.42%

TABLE 6
COGENERATION CASH FLOW ANALYSIS
NATIONAL COUNCIL FOR CEMENT AND BUILDING MATERIALS
(R.C.ERICKSON, UNIDO EXPERT)

SITE: ABC CEMENT, LTD.

ASSUMPTIONS:

Total Installed Cost:	664.00 Rs LAKH	Heat Source:	Preheat/Cooler Exhaust	Initial Elect. Pur. Price:	0.90 Rs/kwh
Loan Ammount:	442.70 Rs LAKH	Size:	3040.00 kw	Initial Fuel Cost:	0.00 Rs/Mcal
Down Payment	221.30 Rs LAKH	Gross Heat Rate:	0.00 cal/kwh		
Loan Terms:		Recoverable Heat:	0.00 cal/kwh	Elect. Used On Site:	100.00 Percent
Int.	12.50 Percent	Plant Cap. Fact:	82.19 Percent	Initial Elect. Sale Price:	0.90 Rs/kwh
Term	8.00 Years			Standby Demand Charge:	360.00 Rs/kw/yr
Economic Life:	15.00 Years			O&M Charge:	0.13 Rs/kwh

(Rs LAKH)

YEAR:	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
REVENUE:											
Displeaced Electricity:		196.99	216.69	238.36	262.19	288.41	317.25	348.98	383.87	422.26	464.49
Electricity Sold:		0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
TOTAL REVENUES:		196.99	216.69	238.36	262.19	288.41	317.25	348.98	383.87	422.26	464.49
EXPENSES:											
Fuel:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O&M:		31.01	32.88	34.85	36.94	39.16	41.50	43.99	46.63	49.43	52.40
P&I:	0.00	0.00	115.16	115.16	115.16	115.16	115.16	115.16	115.16	115.16	
Insurance:		5.31	5.63	5.97	6.33	6.71	7.11	7.54	7.99	8.47	8.97
Standby:		11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93	11.93
TOTAL EXPENCES:		48.26	165.60	167.91	170.36	172.95	175.70	178.62	181.71	184.99	73.30
PROFIT (Pre Tax):		148.73	51.09	70.45	91.83	115.46	141.55	170.35	202.16	237.27	391.18
TAX IMPACTS:											
(Depreciation):	66.40	59.76	53.78	48.41	43.57	39.21	35.29	31.76	28.58	25.72	23.15
(Incentives):	22.13	15.49	9.52	4.14							
TAXES: 50.00 percent	-44.27	36.74	-6.11	8.95	24.13	38.12	53.13	69.30	86.79	105.77	184.02
PROFIT (After Tax)	44.27	111.99	57.20	61.50	67.70	77.33	88.42	101.06	115.37	131.50	207.17
CUMULATIVE CASH FLOW:	-177.03	-65.04	-7.85	53.65	121.35	198.68	287.10	388.16	503.53	635.02	842.19

SIMPLE PAYBACK, YEARS:
Based on 5 Year Average 2.36

INTERNAL RATE OF RETURN:
Based on 10 Years 47.03%

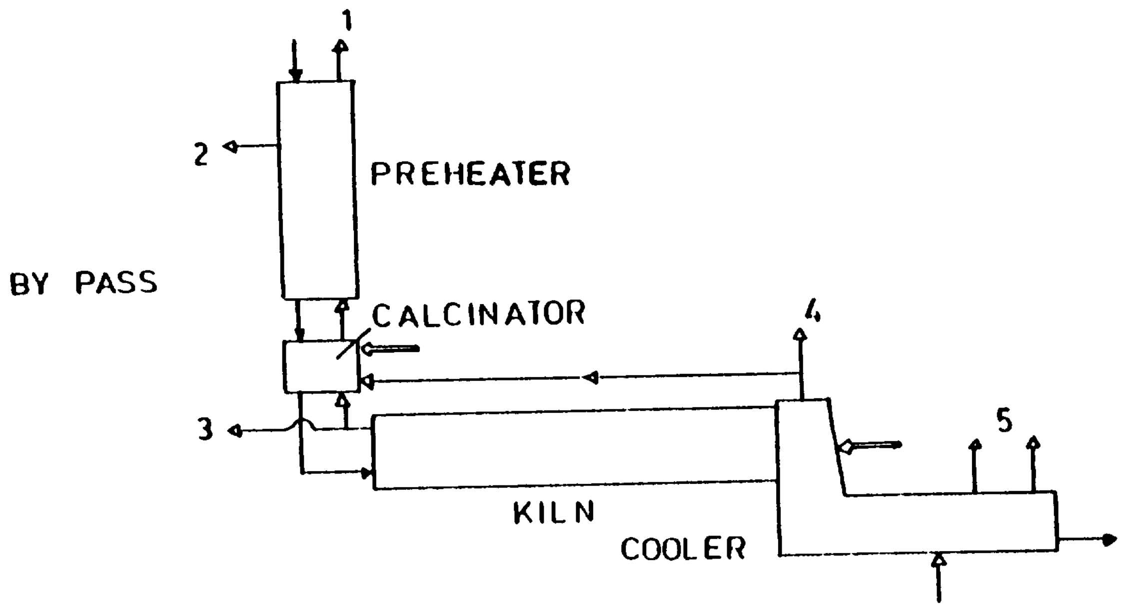


Figure 1 : Heat Recovery Extraction Points

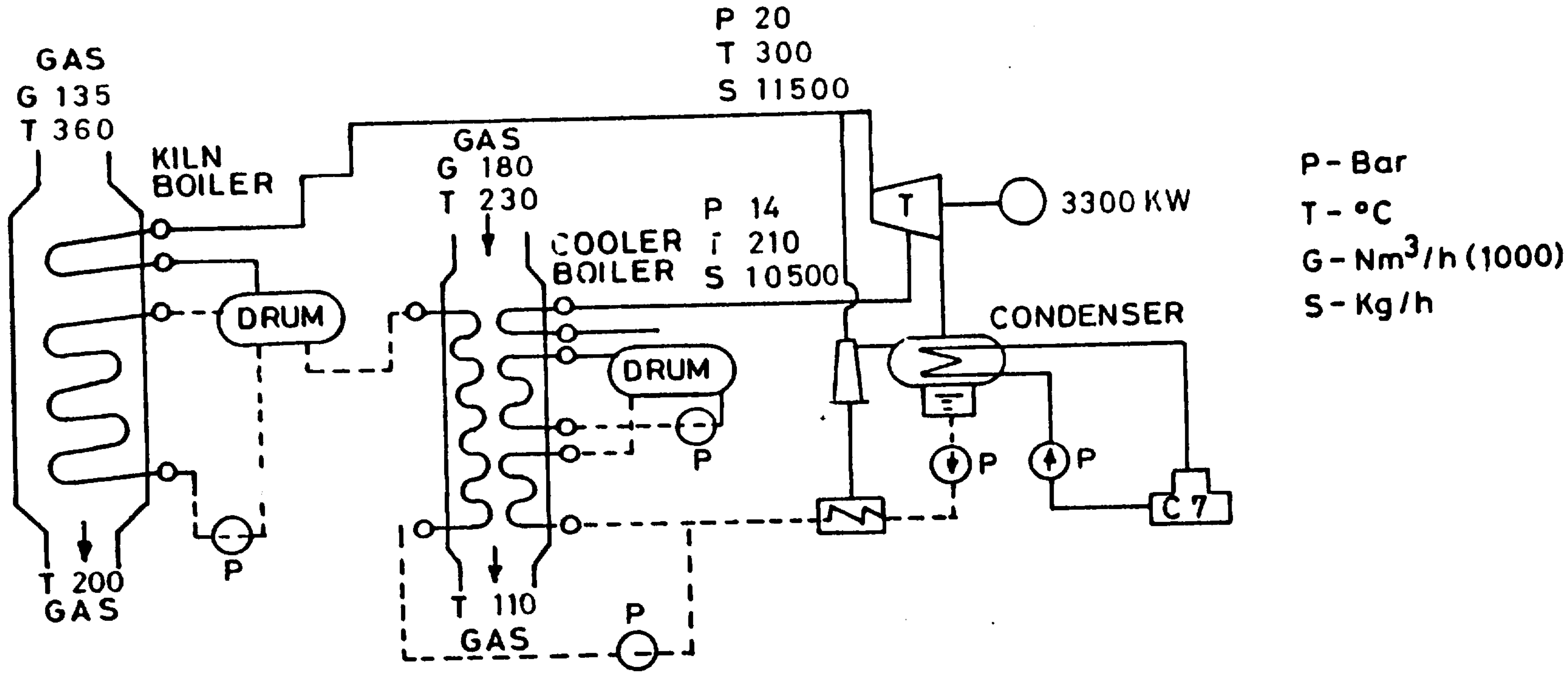


Figure 2 : Steam Cycle Schematic for 1800 TPH Capacity Cement Plant

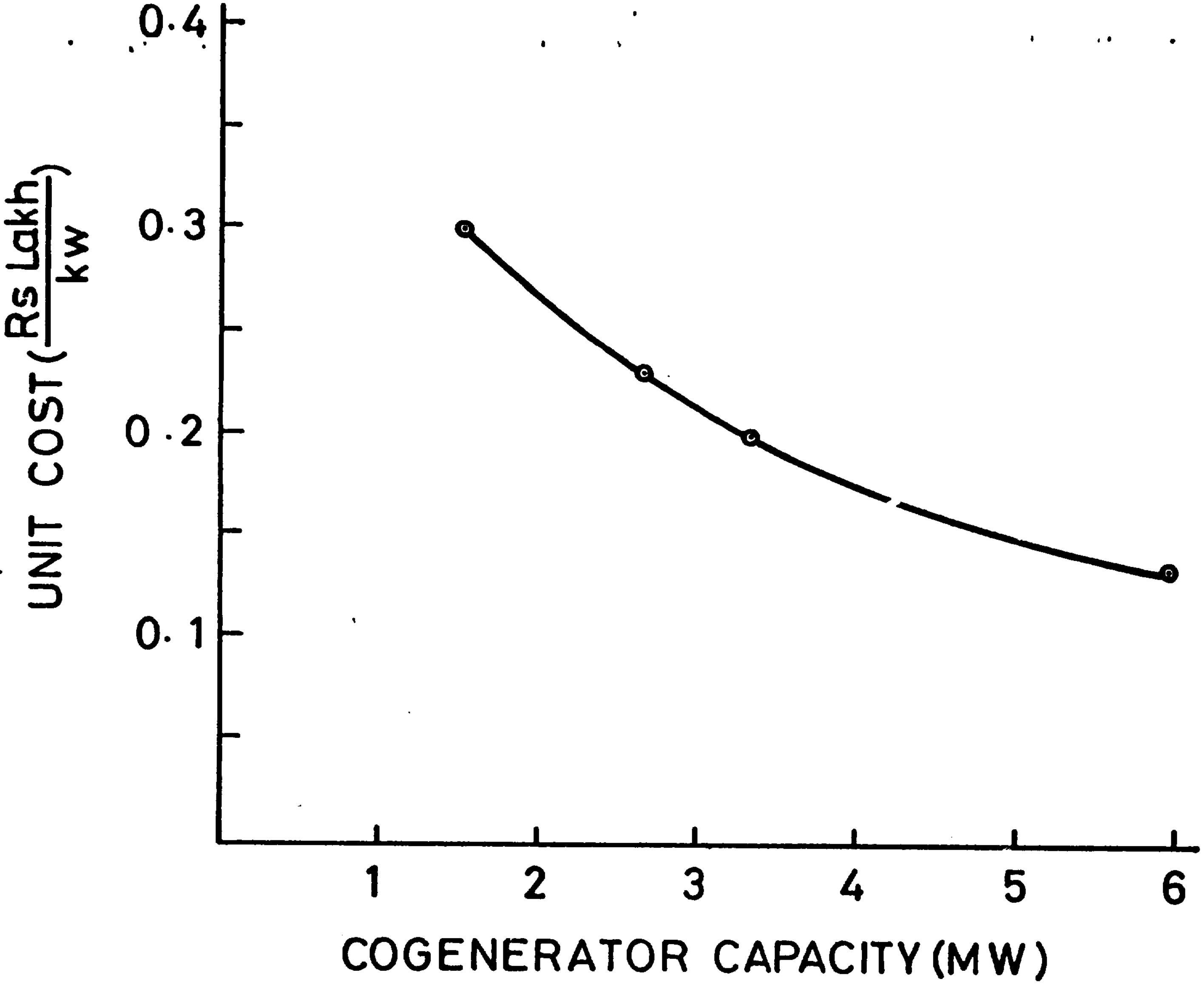


Figure 3 : Unit Cost of Cogeneration Capacity as a Function of Capacity

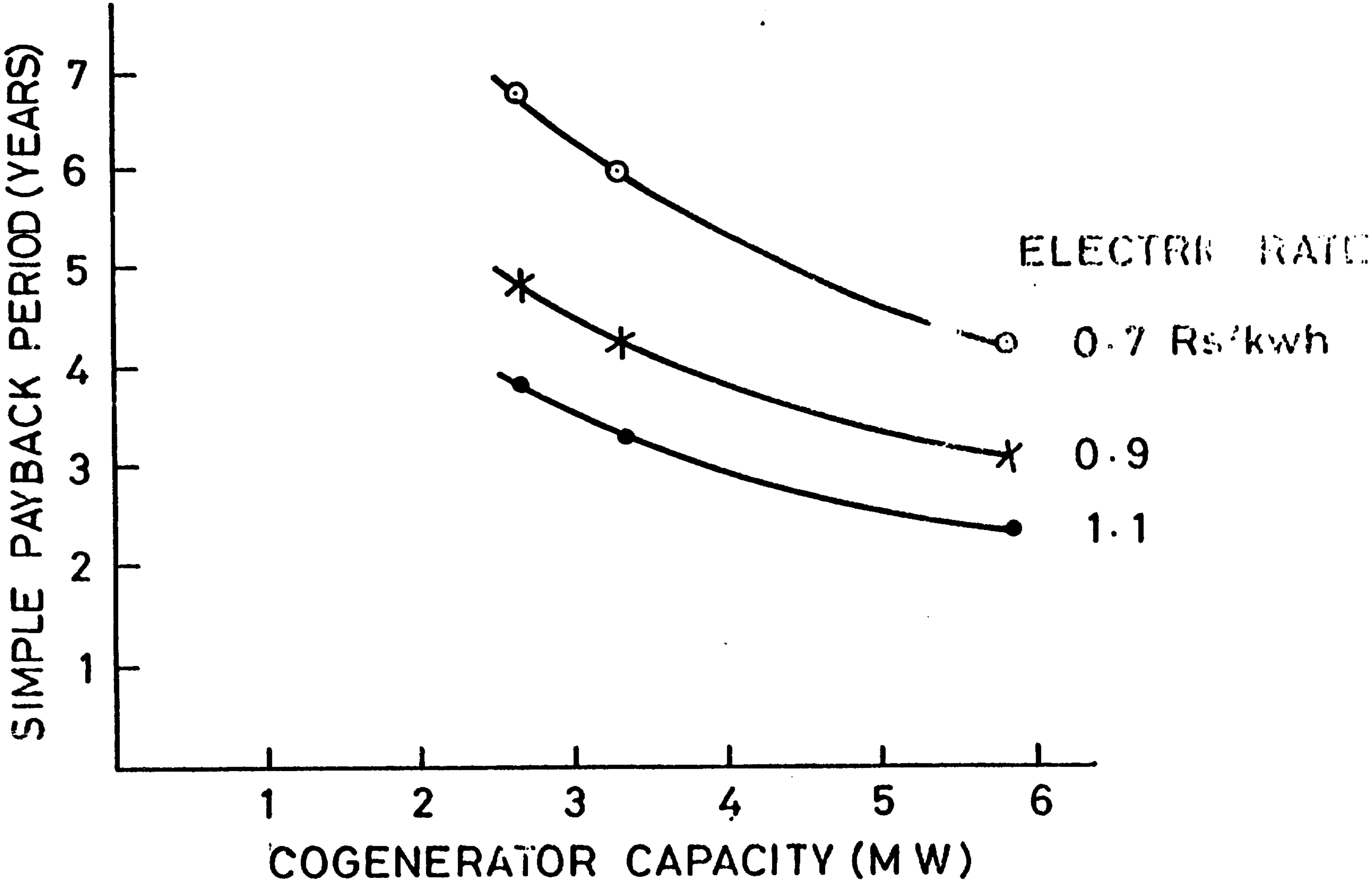


Figure 4 : Simple Payback vs Cogenerator Capacity and Electric Rate

APPENDIX B

CASE STUDIES

COGENERATION FEASIBILITY USING WASTE HEAT RECOVERY AT THE RAASI CEMENT WORKS

INTRODUCTION

In the past decade energy costs have been increasing rapidly with electrical energy costs generally increasing faster than fuel costs. During the past year world price for primary energy has declined. However, electrical energy costs typcally have not. The cement industry, being an energy intensive industry, has made steady progress in improving the fuel efficiency of kilns but has experienced increased electrical energy consumption per tonne of cement. One answer to rising electrical power costs in cement plants is the utilization of waste heat recovery cogeneration systems.

Cogeneration is the sequential production of two forms of useful energy, usually heat and electricity, from the same input fuel source. In the case of the cement plant, heat is first used in the process of producing clinker with waste heat being recovered for the production of electrical energy using a boiler, steam turbine system. Improvements in kiln energy efficiency have reduced the heat available for recovery in a waste heat boiler. However, sufficient energy is available in the exit gases from the preheater and the clinker cooler to provide the potential for a cost effective electrical power generation system.

PLANT APPLICATION

A feasibility analysis for the generation of electrical power using waste heat has been conducted for the Vishnupuram Cement Works owned by Raasi Cement Ltd. The plant is located at Wadapally, Dist. Nalgonda (Andhra Pradesh). The plant uses four-stage suspension preheater.

The operating production rate is 1450 tpd of clinker. Heat is available from both the preheater and the cooler exhaust streams. The utilization of this heat is summarized in Table-1. Using both exhaust streams at the production rate of 60 tph a power generation capacity of 2640 kw (gross), 2430 kw (net) could be installed. The estimated cost for the system is Rs. 605 lakhs. Given the average unit electrical cost of Rs. 0.7 Kwh a simple payback of 6.9 years is projected. This payback period could be reduced to 4.3 years depending on the financing scheme used.

The availability of power in the Andhra Pradesh is good with no current cut back in availability. The 2430 KW net power available from the plant is some what short of the critical power necessary to maintain kiln and coal grinding operations of 2500 KW. However, with proper load management, it should be sufficient to maintain steady kiln and coal grinding operations during power interruptions. Problems would only be encountered in start-up of large motors.

SYSTEM DESCRIPTION

A power generation system is proposed using steam as the working fluid with recovery of heat from the preheater exist gas and the cooler exhaust. These two heat sources should be integrated into a one multi-stage turbine-generator set as shown in Figure-1. The heat from the cooler exhaust stream is utilized as both a source of feed water preheat to the suspension preheater exhaust boiler and as direct steam production for injection into a lower pressure port of a multistage turbine. The split of energy usage from the cooler exhaust requires detailed information on various multistage turbine performance that will require careful analysis in the preliminary system design phase. However, this technology is well proven with more than ten such systems operating in Japan (Reference 1).

Boiler feed water returns from the condenser and is preheated by the cooler exhaust and continues to the boiler located in the preheater stream where it is evaporated and super heated. It is then introduced into the turbine to generate electricity.

At the same time, part of the return feed water flow is utilized in the boiler section in the cooler exhaust stream where it is evaporated and super heated at a lower pressure. This lower pressure steam is introduced into a later stage of the turbine to increase the quantity of power produced. The cooling water utilized in the condenser is circulated between the cooling tower and the condenser. For this 2640 kW gross generation, approximately 200 litres per minute of condensed make-up water will be required.

Dust loadings at the preheater exhaust stream do not pose a problem. Current waste heat recovery boilers are operating in the U.S. at higher dust loadings in systems using direct kiln exhaust or kiln by-pass gas with only one stage cyclone separation. To remove the more abrasive dust from the cooler exhaust, cooler ESP outlet gas is introduced into the boiler.

All of the kiln gas flow from the preheater passes through the heat recovery boiler where the temperature is reduced to 200°C. The gases will either by-pass the gas conditioning tower or pass through the tower without a requirement for use of the conditioning tower. There is sufficient energy remaining in the exhaust flow to provide drying of the raw material even at the 4% moisture experienced during the rainy season.

The cogeneration system would be controlled automatically with its own micro-processor for start-up and shut down of the turbine-generator set. Data concerning the waste heat boiler and turbine-generator are transmitted back to the central control room. The turbine-generator can be automatically restarted from the control room after short duration shut-downs of the kiln (where the kiln is kept hot). No power can be generated during shut-downs of the kiln.

Location of the waste heat boiler and power house is suggested as shown in Figure 2. For kiln 1, it is suggested that the waste heat boiler be located between the I.D. fan, ESP and chimney. This close location will avoid long additional gas ducting to carry preheater exhaust to the power house and back. For the purpose of cost estimating, a total of 100 meters of additional ducting at the cooler and preheater are assumed.

Operation of the cogeneration set is assumed to be a secondary function to the primary function of kiln operation. Experience in operating cogeneration systems is that they have more than 95% availability. The experience of a cogeneration system operating in Switzerland using preheater exit gas only is noted as follows (Reference 2). On no occasion has cement production been interrupted or decreased due to the waste heat recovery boiler or turbine-generator set. Availability has been about 94% referred to kiln operating time which could be improved. Operations and maintenance of the cogeneration system has been conducted without any increase in the number of personnel at the plant.

For the purpose of calculating a payback period on this system, an operations and maintenance cost of Rs. 0.13 Kwh was assumed. This cost included materials (i.e. chemicals for boiler feed water treatment), labour assigned for direct maintenance of the cogeneration system, and a sinking fund to allow major overhaul of the primary system components.

SYSTEM COST

A budgetory cost estimate has been made for the cogeneration system for kiln 1 and is presented in Table-2. Cost of the system is estimated to be Rs. 605 lakhs and to be made up of components manufactured in India. The cost estimate is based in part, on turbine-generator set data supplied by Bharat Heavy Electricals Ltd and cost break-down percentages experienced in construction of this type of an overall system.

ECONOMIC EVALUATION

The economics of the cogeneration system using both preheater and cooler waste heat are shown in Table-3. For these calculations, the current demand charge and average unit cost of electricity experienced at the Vishnupuram Plant are used. The current average electrical rate of Rs. 0.70 kwh is used with the net power production of 2430 KW and 7200 hours of annual operation to determine savings. Operations and maintenance cost is based on Rs. 0.13 kwh at 2640 KW gross power production. Since the plant will have to pay the demand charge based on the total plant demand, a cost is incurred to the system for the gross output of the system at the rate of Rs. 30 KW/month. The net annual savings are Rs. 88 lakhs. At an initial capital cost of Rs. 605 lakhs, a simple pay back of 6.9 years can be expected. At this long payback period, the system will not be cost effective.

Table 4 presents a cash flow analysis for the system using a 2:1 debt to equity ratio loan. It also accounts for taxes, depreciation using the WDB method, and an incentive based on the difference between the WDB and straight line depreciation method. The term of the loan is 10 years with a two year moratorium. The results are that the system will pay back the equity in 4.3 years.

If a cogeneration system is used with the new kiln, a simple pay back of 4.3 years as shown in Table-5 could be expected. If the system were financed at a 2:1 debt equity ratio, the pay back period could be reduced to approximately 2.2 years.

CONCLUSION

The cogeneration system utilizing both cooler and preheater exhaust heat recovery is technically feasible but does not appear to be economically feasile at the electric rates Raasi currently pays. It would be necessary that the system be based on heat recovery from both cooler and preheater exit gas streams and electric rate greater than Rs. 1.1/kwh. This is beause the unit costs of installed capaity increases with dereasing size systems making it more difficult for the system to become cost effective at the smaller size if only one of the streams is used. Also the available heat from both streams are necessary to approach meeting critical kiln operation electrical requirement.

Detailed design development will need to focus on optimization of the integration of preheater and cooler available heats and the steam flows and optimum steam temperatures and pressures in each stage of the turbine. In preliminary discussions with an equipment suppliers in India, it appears that all components of the system can be supplied by Indian companies. Following detailed engineering design and site preparations, the system should be able to be installed and commissioned in 12 to 15 months from award of major components contracts.

References

1 Noguchi, K, Japan's Cement Industry Today, Rock Products, May, 1982

2 Lang, Th, and Mosimann, P., Production of Electrical Thermal Energy from Exhaust Gas Heat of Preheater Kilns, World Cement, June 1983

TABLE - 1

RAASI SYSTEM SIZING

	PREHEATER	COOLER
Gas Flow Nm^3/kg	1.85	2.4
Nm^3/h	1.11×10^5	1.44×10^5
Gas temperature °C	360	230
Boiler Exit Gas Temperature °C	200	110
Specific heat $\frac{kJ}{Nm^3 °C}$	1.4	1.3
Available heat kJ	2.49×10^7	2.25×10^7
Cycle efficiency %	22	18
Cogen Capacity KW	1519	1123
Total Cogeneration Capacity	2640 KW	

1) Referenced to clinker

TABLE - 2

RAASI COST SUMMARY

RS LAKHS

	Material	Labour
Boiler	114	7
Turbine	195	3
Power House	16	8
Piping, Steam & Water	86	14
Electric & Controls	18	7
Site Work	2	5
Spare Parts	14	
TOTAL	445	44

General Construction (Indirect & Fee)	64
Indirect Project Engineering	45
G & A	7
Total Capital Cost	605

TABLE - 3

RAASI SYSTEM SIMPLE PAYBACK

Capacity	2640 KW Gross	2430 KW Net
Operations & Maintenance	0.13 Rs/Kwh	
Demand charge	30 Rs/KW/month	
Average electric unit cost	0.70 Rs/Kwh	
Estimated System cost	Rs 605 lakhs	
Annual hours of operation	7200 hours	
Annual savings	Rs 122 lakhs	
O & M Cost	Rs 25 lakhs	
Demand charge	Rs 9 lakhs	
Net Savings	Rs 88 lakhs	

Simple payback $\frac{605}{88} = 6.88$ years

TABLE 4
COGENERATION CASH FLOW ANALYSIS
NATIONAL COUNCIL FOR CEMENT AND BUILDING MATERIALS
(R.C. ERICKSON, UNIDO EXPERT)

SITE: RAASI CEMENT LTD

ASSUMPTIONS:

Total Installed Cost:	605.00 Rs LAKH	Heat Source:	Preheat/Cooler Exhaust	Initial Elect. Pur. Price:	0.70 Rs/kwh
Loan Amount:	403.10 Rs LAKH	Size:	2431.00 kw	Initial Fuel Cost:	0.00 Rs/Mcal
Down Payment	201.70 Rs LAKH	Gross Heat Rate:	0.00 cal/kwh	Elect. Used On Site:	100.00 Percent
Loan Terms:		Recoverable Heat:	0.00 cal/kwh	Initial Elect. Sale Price:	1.00 Rs/kwh
Int.	12.50 Percent	Plant Cap. Fact:	82.19 Percent	Standby Demand Charge:	360.00 Rs/kw/yr
Term	8.00 Years			O&M Charge:	0.13 Rs/kwh
Economic Life:	15.00 Years				

YEAR:	1987	1988	1989	1990	1991	1992 [Rs LAKH]	1993	1994	1995	1996	1997
REVENUE:											
Displeaced Electricity:		122.52	134.77	148.25	163.07	179.38	197.32	217.05	238.76	262.63	288.90
Electricity Sold:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL REVENUES:		122.52	134.77	148.25	163.07	179.38	197.32	217.05	238.76	262.63	288.90
EXPENSES:											
Fuel:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O&M:		22.75	24.12	25.57	27.10	28.73	30.45	32.28	34.21	36.27	38.44
P&I:	0.00	0.00	104.86	104.86	104.86	104.86	104.86	104.86	104.86	104.86	
Insurance:		4.84	5.13	5.44	5.76	6.11	6.48	6.87	7.28	7.71	8.18
Standby:		8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75
TOTAL EXPENCES:		36.35	142.86	144.62	146.48	148.45	150.54	152.75	155.10	157.59	55.37
PROFIT (Pre Tax):		86.17	-8.09	3.63	16.60	30.93	46.78	64.30	83.65	105.04	233.52
TAX IMPACTS:											
[Depreciation]:	60.50	54.45	49.01	44.10	39.69	35.72	32.15	28.94	26.04	23.44	21.10
[Incentives]:	20.17	14.12	8.67	3.77							
TAXES: 50.00 percent	-40.33	8.80	-32.88	-22.12	-11.55	-2.40	7.31	17.68	28.80	40.80	106.21
PROFIT (After Tax)	40.33	77.37	24.79	25.75	28.15	33.33	39.47	46.62	54.85	64.24	127.31
CUMULATIVE CASH FLOW:	-161.37	-84.00	-59.20	-33.45	-5.30	28.02	67.49	114.11	168.96	233.19	360.50

SIMPLE PAYBACK, YEARS:
Based on 5 Year Average 4.26

INTERNAL RATE OF RETURN:
Based on 10 Years 25.71%

TABLE - 5

RAASI CEMENT KILN & SYSTEM ESTIMATES

Cogeneration capacity	5500 KW gross 5060 KW net
Estimated cost	Rs 784 lakhs
Annual electric savings (7200 h, 0.7 Rs/kwh)	Rs 255 lakhs
O&M cost (0.13 Rs/kwh)	Rs 51 lakhs
Demand charge	Rs 20 lakhs
Net savings	Rs 184 lakhs

Simple payback $\frac{784}{184} = 4.26$ years

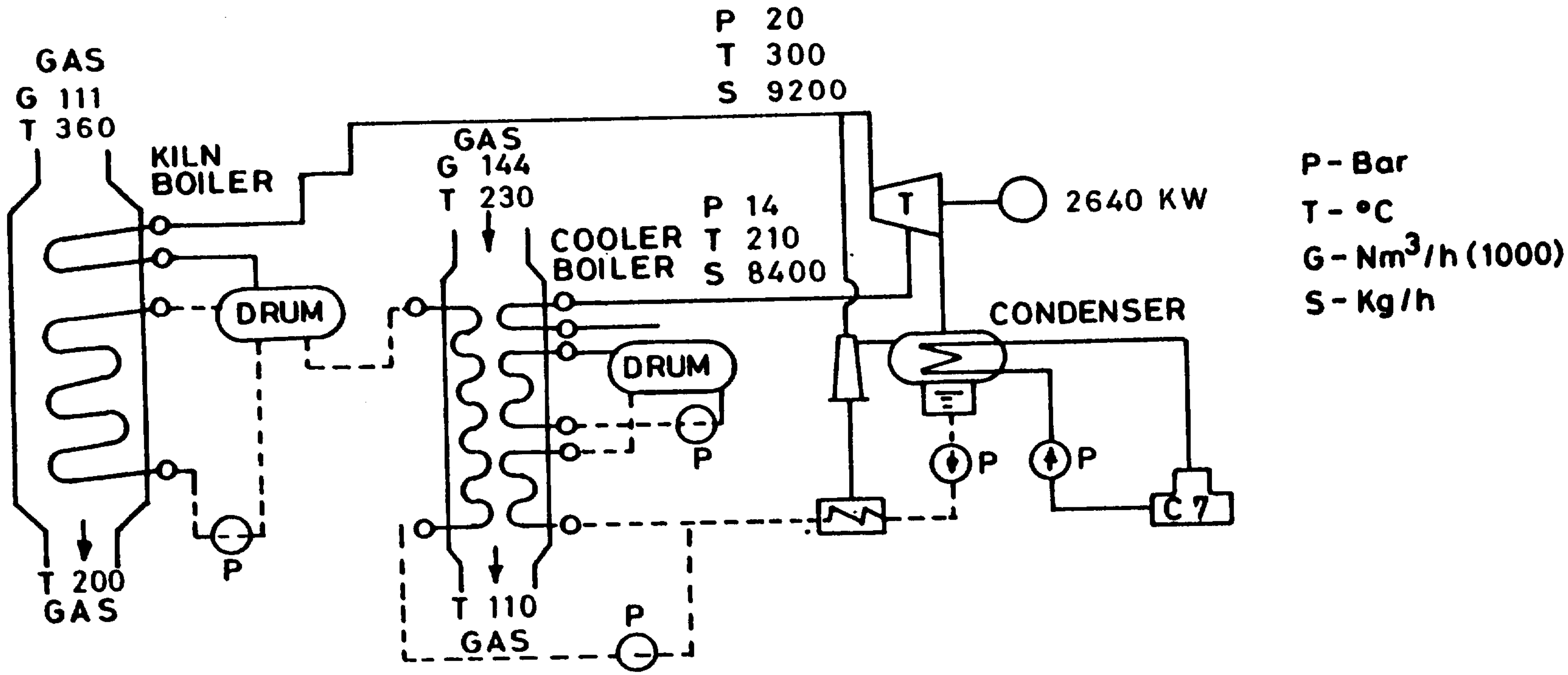


FIG 1 RAASI STEAM CYCLE SCHEMATIC

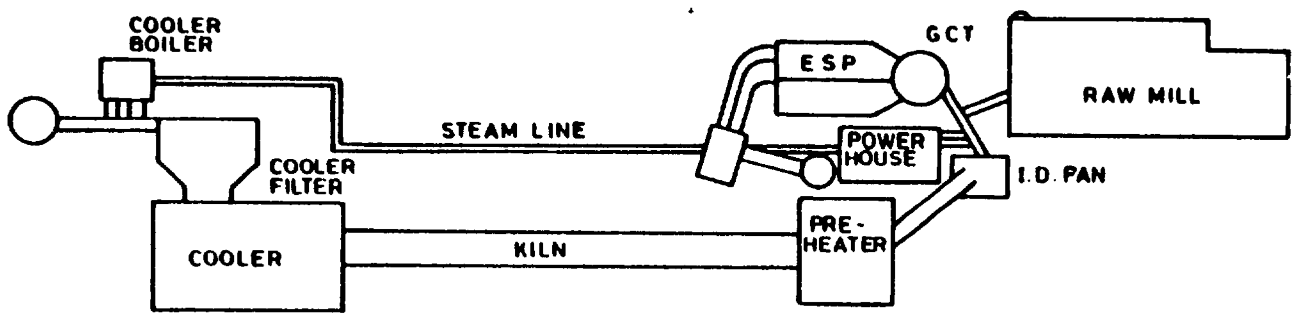


FIG 2 SUGGESTED BOILER AND POWER HOUSE LOCATION

COGENERATION FEASIBILITY USING WASTE HEAT RECOVERY AT THE VASAVADATTA CEMENT WORKS

INTRODUCTION

In the past decade energy costs have been increasing rapidly with electrical energy costs generally increasing faster than fuel costs. During the past year world price for primary energy has declined. However, electrical energy costs typcally have not. The cement industry, being an energy intensive industry, has made steady progress in improving the fuel efficiency of kilns but has experienced increased electrical energy consumption per tonne of cement. One answer to rising electrical power costs in cement plants is the utilization of waste heat recovery cogeneration systems.

Cogeneration is the sequential production of two forms of useful energy, usually heat and electricity, from the same input fuel source. In the case of the cement plant, heat is first used in the process of producing clinker with waste heat being recovered for the production of electrical energy using a boiler, steam turbine system. Improvements in kiln energy efficiency have reduced the heat available for recovery in a waste heat boiler. However, sufficient energy is available in the exit gases from the preheater and the clinker cooler to provide the potential for a cost effective electrical power generation system.

PLANT APPLICATION

A feasibility analysis for the generation of electrical power using waste heat has been conducted for the Vasavadatta Cement Works owned by Kesoram Industres Ltd. The plant is located at Sedam, Dist. Gulbarga (Karnataka). The plant uses five-stage suspension preheater with precalinator.

The design production rate is 1800 tpd of clinker. Heat is available from both the preheater and the cooler. The utilization of this heat is summarized in Table-1. Using both exhaust streams at the production rate of 75 tph a power generation capacity of 3304 kW (gross), 3040 kW (net) could be installed. The estimated cost for the system is Rs. 664 lakhs. Given the average unit electrical cost of Rs. 1.12 kWh a simple payback of 3.3 years is projected. This payback period could be reduced to 1.7 years depending on the financing scheme used.

The availability of power in the Karnataka State is also not reliable and the plant suffers from reductions in available power. The 3040 kW net power available from the plant is some what short of the critical power necessary to maintain kiln and coal grinding operations of 3700 kW. However, with proper load management, it should be sufficient to maintain steady kiln and coal grinding operations during power interruptions. Problems would only be encountered in start-up of large motors.

SYSTEM DESCRIPTION

A power generation system is proposed using steam as the working fluid with recovery of heat from the preheater exit gas and the cooler exhaust. These two heat sources should be integrated into a one multistage turbine-generator set as shown in Figure-1. The heat from the cooler exhaust stream is utilized as both a source of feed water preheat to the suspension preheater exhaust boiler and as direct steam production for injection into a lower pressure port of a multistage turbine. The split of energy usage from the cooler exhaust requires detailed information on various multi-stage turbine performance that will require careful analysis in the preliminary system design phase. However, this technology is well proven with more than ten such systems operating in Japan (Reference 1).

Boiler feed water returns from the condenser and is preheated by the cooler exhaust and continues to the boiler located in the preheater stream where it is evaporated and super heated. It is then introduced into the turbine to generate electricity.

At the same time, part of the return feed water flow is utilized in the boiler section in the cooler exhaust stream where it is evaporated and super heated at a lower pressure. This lower pressure steam is introduced into a later stage of the turbine to increase the quantity of power produced. The cooling water utilized in the condenser is circulated between the cooling tower and the condenser. For this 3304 kW gross generation, approximately 250 litres per minute of condenser make-up water will be required.

Dust loadings at the preheater exhaust stream do not pose a problem. Current waste heat recovery boilers are operating in the U.S. at higher dust loadings in systems using direct kiln exhaust or kiln by-pass gas with only one stage cyclone separation. To remove the more abrasive dust from the cooler exhaust, cooler ESP outlet gas is introduced into the boiler.

All of the kiln gas flow from the preheater passes through the heat recovery boiler where the temperature is reduced to 200°C. The gases will either by-pass the gas conditioning tower or pass through the tower without a requirement for use of the conditioning tower. There is sufficient energy remaining in the exhaust flow to provide drying of the raw material even at the 4% moisture experienced during the rainy season.

The cogeneration system would be controlled automatically with its own microprocessor for start-up and shut down of the turbine-generator set. Data concerning the waste heat boiler and turbine-generator are transmitted back to the central control room. The turbine-generator can be automatically restarted from the control room after short duration shut-downs of the kiln (where the kiln is kept hot). No power can be generated during shut-downs of the kiln.

Location of the waste heat boiler and power house is suggested as shown in Figure 2. For kiln 1, it is suggested that the waste heat boiler be located between the I.D. fan, preheater tower and the coal mill. This is necessary to avoid long additional gas ducting to carry preheater exhaust to the power house and back. Since kiln 2 would have the I.D. fan on the same side of the structure as the power house, the waste heat recovery boiler and turbine-generator could both be located in the power house between the existing and proposed kilns. For the purposes of cost estimating, a total of 100 meters of additional ducting at the cooler and preheater are assumed. A separate system would be utilized for each kiln.

Operation of the cogeneration set is assumed to be a secondary function to the primary function of kiln operation. Experience in operating cogeneration systems is that they have more than 95% availability. The experience of a cogeneration system operating in Switzerland using preheater exit gas only is noted as follows (Reference 2). On no occasion has cement production been interrupted or decreased due to the waste heat recovery boiler or turbine generator set. Availability has been about 94% referred to kiln operating time which could be improved. Operations and maintenance of the cogeneration system has been conducted without any increase in the number of personnel at the plant.

For the purpose of calculating a payback period on this system, an operations and maintenance cost of Rs. 0.13 Kwh was assumed. This cost included materials (i.e. chemicals for boiler feed water treatment), labour assigned for direct maintenance of the cogeneration system, and a sinking fund to allow major overhaul of the primary system components.

SYSTEM COST

A budgetory cost estimate has been made for the cogeneration system for kiln 1 and is presented in Table-2. Cost of the system is estimated to be Rs. 664 lakhs and to be made up of components manufactured in India. The cost estimate is based in part, on turbine-generator set data supplied by Bharat Heavy Electricals Ltd and cost break-down percentages experienced in construction of this type of an overall system. If systems for both kiln 1 and kiln 2 are constructed, some cost savings can be expected in the power house and site work.

ECONOMIC EVALUATION

The economics of the cogeneration system using both preheater and cooler waste heat are shown in Table-3. For these calculations, the current demand charge and average unit cost of electricity experienced at the Vasavadatta Plant are used. The current average electrical rate of Rs. 1.12 kwh is used with the net power production of 3040 KW and 7200 hours of annual operation to determine savings. Operations and maintenane cost is based on Rs. 0.13 kwh at 3304 KW gross power production. Since the plant will have to pay the demand charge based on the total plant demand, a cost is incurred to the system for the gross output of the system at the rate of Rs. 35 KW/month. The net annual savings are Rs. 200 lakhs. At an initial capital cost of Rs. 664 lakhs, a simple pay back of 3.3 years can be expected.

Table 4 presents a cash flow analysis for the system using a 2:1 debt to equity ratio loan. The term of the loan is 10 years with a two year moratorium. It also accounts for taxes, depreciation using the WDB method, and an incentive based on the difference between the WDB and straight line depreciation method. The results are that the system will pay back the equity in 1.7 years.

CONCLUSION

The cogeneration system utilizing both cooler and preheater exhaust heat recovery is technically feasible and economically feasible at the electric rates Vasavadatta currently pays. It appears neessary that the system must be based on heat recovery from both cooler and preheater exit gas streams. This is beause the unit costs of installed capaity increase with dereasing size systems making it more difficult for the system to become cost effective at the smaller size if only one of the streams is used. Also the available heat from both streams are necessary to approach meeting critical kiln operation electrical requirement.

Detailed design development will need to focus on optimization of the integration of preheater and cooler available heats and the steam flows and optimum steam temperatures and pressures in each stage of the turbine. In preliminary discussions with an equipment suppliers in India, it appears that all components of the system can be supplied by Indian companies. Following detailed engineering design and site preparations, the system should be able to be installed and commissioned in 12 to 15 months from award of major components contracts.

References

1 Noguchi, K, Japan's Cement Industry Today, Rock Products, May, 1982

2 Lang, Th, and Mosimann, P., Production of Electrical Thermal Energy from Exhaust Gas Heat of Preheater Kilns, World Cement, June 1983

TABLE 1

VASAVADATTA SYSTEM SIZING

	Preheater	Cooler
Gas flow Nm^3/kg	1.85	2.4
Nm^3/hr	1.39×10^5	1.80×10^5
Gas temperature ^oC	360	230
Boiler Exit Gas Temp ^oC	200	110
Specific heat $\frac{KJ}{Nm^3 \, ^oC}$	1.4	1.3
Available heat KJ	3.11×10^7	2.81×10^7
Cycle efficiency %	22	18
Cogen capacity KW	1900	1404
Total Cogeneration Capacity		**3304 KW**

TABLE 2

VASAVADATTA COST SUMMARY

	Rs Lakhs	
	Material	Labour
Boiler	125	7
Turbine	215	4
Power House	18	8
Piping, Steam and Water	95	16
Electric and Controls	19	8
Site Work	2	5
Spare Parts	15	-
Total	**489**	**48**

General construction (Indirect & Fee)	70
Indirect Project Engineering	49
G&A	8
Total Capital Cost	**664**

TABLE 3

VASAVADATTA SYSTEM SIMPLE PAYBACK

Capacity 3304 KW gross	3040 KW net
Operations & Maintenance	Rs. 0.13 kwh
Demand Charge	Rs. 35 KW/month
Average Eletric Unit Cost	Rs. 1.12 kwh
Estimated System cost	Rs. 664 lakhs
Annual hours of Operation	7200 hours
Savings	Rs. 245 lakhs
Other cost	Rs. 31 lakhs
Demand Charge	Rs. 14 lakhs
Net Savings	Rs. 200 lakhs
Simple Payback	$\frac{664}{200}$ = 3.32 yrs

TABLE 4
COGENERATION CASH FLOW ANALYSIS
NATIONAL COUNCIL FOR CEMENT AND BUILDING MATERIALS
(R.C. ERICKSON, UNIDO EXPERT)

SITE: VASAVADATTA CEMEMT WORKS

ASSUMPTIONS:

Total Installed Cost:	664.00 Rs LAKH	Heat Source:	Preheat/Cooler Exhaust	Initial Elect. Pur. Price:	1.12 Rs/kwh
Loan Ammount:	442.70 Rs LAKH	Size:	3040.00 kw	Initial Fuel Cost:	0.00 Rs/Mcal
Down Payment	221.30 Rs LAKH	Gross Heat Rate:	0.00 cal/kwh		
Loan Terms:		Recoverable Heat:	0.00 cal/kwh	Elect. Used On Site:	100.00 Percent
Int.	12.50 Percent	Plant Cap. Fact:	82.19 Percent	Initial Elect. Sale Price:	1.12 Rs/kwh
Term	8.00 Years			Standby Demand Charge:	420.00 Rs/kw/yr
Economic Life:	15.00 Years			O&M Charge:	0.13 Rs/kwh

YEAR:	1987	1988	1989	1990	1991	1992 [Rs LAKH]	1993	1994	1995	1996	1997
REVENUE:											
Displeaced Electricity:		245.14	269.65	296.62	326.28	358.91	394.80	434.28	477.71	525.48	578.03
Electricity Sold:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL REVENUES:		245.14	269.65	296.62	326.28	358.91	394.80	434.28	477.71	525.48	578.03
EXPENSES:											
Fuel:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O&M:		31.01	32.88	34.85	36.94	39.16	41.50	43.99	46.63	49.43	52.40
P&I:	0.00	0.00	115.16	115.16	115.16	115.16	115.16	115.16	115.16	115.16	
Insurance:		5.31	5.63	5.97	6.33	6.71	7.11	7.54	7.99	8.47	8.97
Standby:		13.92	13.92	13.92	13.92	13.92	13.92	13.92	13.92	13.92	13.92
TOTAL EXPENCES:		50.24	167.59	169.90	172.35	174.94	177.69	180.61	183.70	186.98	75.29
PROFIT (Pre Tax):		194.90	102.07	126.72	153.94	183.97	217.11	253.67	294.01	338.50	502.74
TAX IMPACTS:											
[Depreciation]:	66.40	59.76	53.78	48.41	43.57	39.21	35.29	31.76	28.58	25.72	23.15
[Incentives]:	22.13	15.49	9.52	4.14							
TAXES: 50.00 percent	-44.27	59.82	19.38	37.0[illegible]	55.19	72.38	90.91	110.96	132.71	156.39	239.79
PROFIT (After Tax)	44.27	135.07	82.68	89.63	98.75	111.59	126.20	142.72	161.30	182.11	262.95
CUMULATIVE CASH FLOW:	-177.03	-41.96	40.73	130.36	229.11	340.70	466.90	609.61	770.91	953.02	1215.97

SIMPLE PAYBACK, YEARS:
Based on 5 Year Average 1.71

INTERNAL RATE OF RETURN:
Based on 10 Years 63.07%

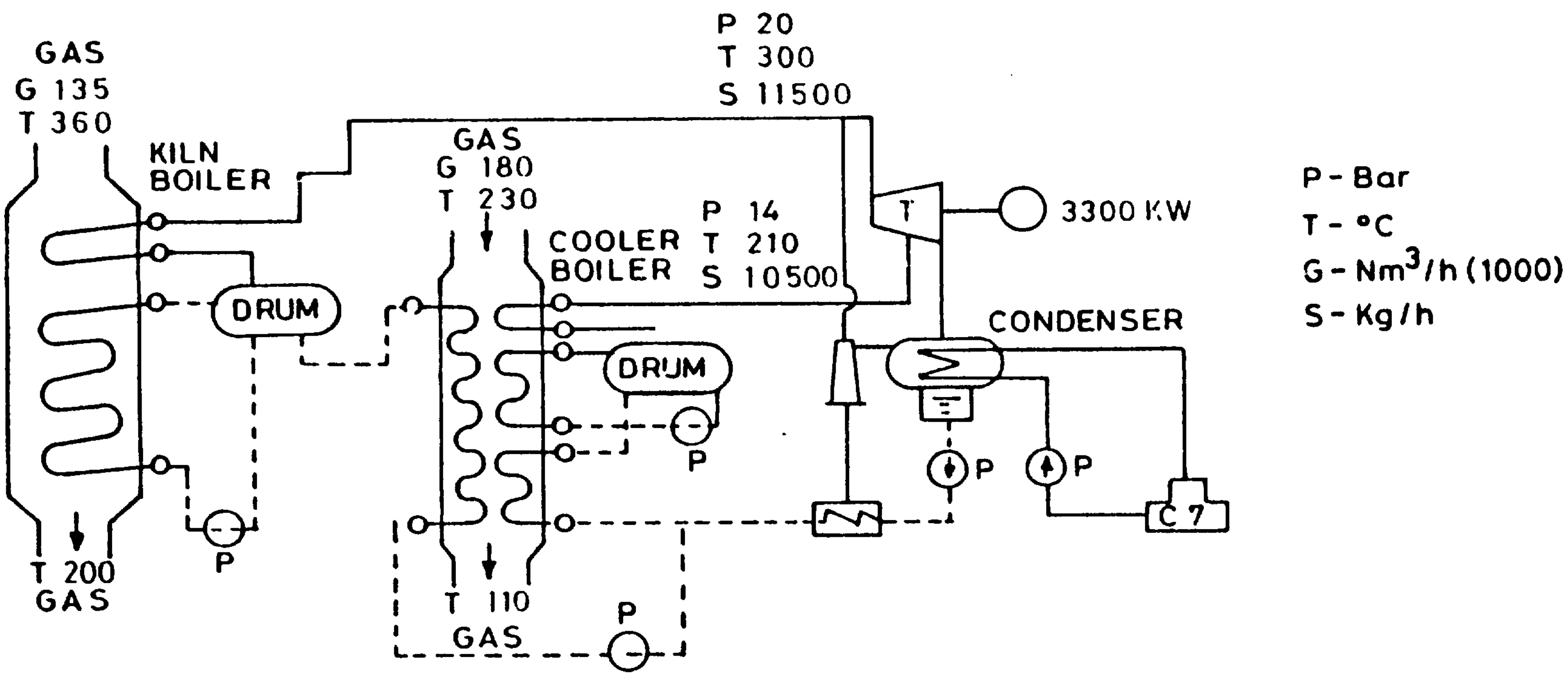


FIG 1 VASAVADATTA STEAM CYCLE SCHEMATIC

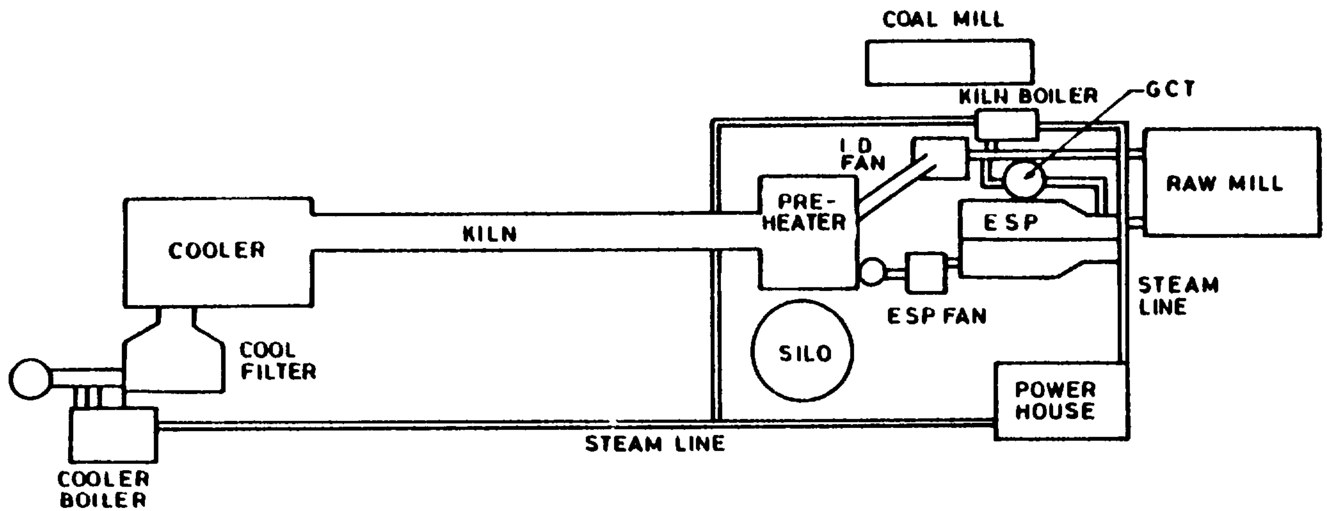


FIG 2 SUGGESTED BOILER AND POWER HOUSE LOCATIONS

COGENERATION FEASIBILITY USING WASTE HEAT RECOVERY AT THE LARSEN & TOUBRO AWARPUR CEMENT WORKS

INTRODUCTION

In the past decade energy costs have been increasing rapidly with electrical energy costs generally increasing faster than fuel costs. During the past year world price for primary energy has declined. However, electrical energy costs typcally have not. The cement industry, being an energy intensive industry, has made steady progress in improving the fuel efficiency of kilns but has experienced increased electrical energy consumption per tonne of cement. One answer to rising electrical power costs in cement plants is the utilization of waste heat recovery cogeneration systems.

Cogeneration is the sequential production of two forms of useful energy, usually heat and electricity, from the same input fuel source. In the case of the cement plant, heat is first used in the process of producing clinker with waste heat being recovered for the production of electrical energy using a boiler, steam turbine system. Improvements in kiln energy efficiency have reduced the heat available for recovery in a waste heat boiler. However, sufficient energy is available in the exit gases from the preheater and the clinker cooler to provide the potential for a cost effective electrical power generation system.

PLANT APPLICATION

A feasibility analysis for the generation of electrical power using waste heat has been conducted for the Awarpur Cement Works owned by Larsen & Toubro Ltd. The plant is located at Gadchandur, Dist. Chandrapur (Maharashtra). The plant uses four-stage suspension preheater with precalinator. The design production rate is 3200 tpd of clinker. Heat is available from both the preheater and the cooler exhaust streams. The utilization of this heat is summarized in Table-1. Using both exhaust streams at the production rate of 133 tph a power generation capacity of 5865 kW (gross), 5395 kW (net) could be installed. The estimated cost for the system is Rs. 835 lakhs. Given the average unit electrical cost of Rs. 0.92 kWh a simple payback of 3.0 years is projected. This payback period could be reduced to 1.5 years depending on the financing scheme used.

The availability of power in the Maharashtra State is reliable and the plant does not expect to suffer from reductions in available power. The 5395 kW net power available from the plant is some what short of the critical power necessary to maintain kiln and coal grinding operations of 6000 kW. However, with proper load management, it should be sufficient to maintain steady kiln and coal grinding operations during power interruptions. Problems would only be encountered in start-up of large motors.

SYSTEM DESCRIPTION

A power generation system is proposed using steam as the working fluid with recovery of heat from the preheater exist gas and the cooler exhaust. These two heat sources should be integrated into a one multistage turbine-generator set as shown in Figure-1. The heat from the cooler exhaust stream is utilized as both a source of feed water preheat to the suspension preheater exhaust boiler and as direct steam production for injection into a lower pressure port of a multistage turbine. The split of energy usage from the cooler exhaust requires detailed information on various multistage turbine performance that will require careful analysis in the preliminary system design phase. However, this technology is well proven with more than ten such systems operating in Japan (Reference 1).

Boiler feed water returns from the condenser and is preheated by the cooler exhaust and continues to the boiler located in the preheater stream where it is evaporated and super heated. It is then introduced into the turbine to generate electricity.

At the same time, part of the return feed water flow is utilized in the boiler section in the cooler exhaust stream where it is evaporated and super heated at a lower pressure. This lower pressure steam is introduced into a later stage of the turbine to increase the quantity of power produced. The cooling water utilized in the condenser is circulated between the cooling tower and the condenser. For this 5865 kW gross generation, approximately 445 litres per minute of condenser make-up water will be required.

Dust loadings at the preheater exhaust stream do not pose a problem. Current waste heat recovery boilers are operating in the U.S. at higher dust loadings in systems using direct kiln exhaust or kiln by-pass gas with only one stage cyclone separation. To remove the more abrasive dust from the cooler exhaust, cooler ESP outlet gas is introduced into the boiler.

All of the kiln gas flow from the preheater passes through the heat recovery boiler where the temperature is reduced to 200°C. The gases will either by-pass the gas conditioning tower or pass through the tower without a requirement for use of the conditioning tower. There is sufficient energy remaining in the exhaust flow to provide drying of the raw material even at the 4% moisture experienced during the rainy season.

The cogeneration system would be controlled automatically with its own micro-processor for start-up and shut down of the turbine-generator set. Data concerning the waste heat boiler and turbine-generator are transmitted back to the central control room. The turbine-generator can be automatically restarted from the control room after short duration shut-downs of the kiln (where the kiln is kept hot). No power can be generated during shut-downs of the kiln.

Location of the waste heat boiler and power house is suggested as shown in Figure 2. For kiln 1, it is suggested that the waste heat boiler be located after the I.D. fan between preheater tower and the raw material mill. This is necessary to avoid long additional gas ducting to carry preheater exhaust to the power house and back. The cooler boiler would be located after the cooler ESP and a power house would be located between the two boilers next to the kiln. For the purpose of cost estimating, a total of 100 meters of additional ducting at the cooler and preheater are assumed. A separate system would be utilized for each kiln. An identical system could also be built for kiln 2. This kiln would provide an easier installation since the preheater boiler and power house could be located next to the I D fan.

Operation of the cogeneration set is assumed to be a secondary function to the primary function of kiln operation. Experience in operating cogeneration systems is that they have more than 95% availability. The experience of a cogeneration system operating in Switzerland using preheater exit gas only is noted as follows (Reference 2). On no occasion has cement production been interrupted or decreased due to the waste heat recovery boiler or turbine generator set. Availability has been about 94% referred to kiln operating time which could be improved. Operations and maintenance of the cogeneration system has been conducted without any increase in the number of personnel at the plant.

For the purpose of calculating a payback period on this system, an operations and maintenance cost of Rs. 0.13 kWh was assumed. This cost included materials (i.e. chemicals for boiler feed water treatment), labour assigned for direct maintenance of the cogeneration system, and a sinking fund to allow major overhaul of the primary system components.

SYSTEM COST

A budgetory cost estimate has been made for the cogeneration system for kiln 1 and is presented in Table-2. Cost of the system is estimated to be Rs. 835 lakhs and to be made up of components manufactured in India. The cost estimate is based, in part, on turbine-generator set data supplied by Bharat Heavy Electricals Ltd and cost break-down percentages experienced in construction of this type of an overall system.

ECONOMIC EVALUATION

The economics of the cogeneration system using both preheater and cooler waste heat are shown in Table-3. For these calculations, the current demand change and average unit cost of electricity experienced at the Vasavadatta Plant are used. The current average electrical rate of Rs. 0.92 kWh is used with the net power production of 5395 kW and 7200 hours of annual operation to determine savings. Operations and maintenance cost is based on Rs. 0.13 kWh at 5865 kW gross power production. Since the plant will have to pay the demand charge based on the total plant demand, a cost is incurred to the system for the gross output of the system at the rate of Rs. 30 kW/month. The net annual savings are Rs. 281 lakhs. At an initial capital cost of Rs. 835 lakhs, a simple pay back of 3.0 years can be expected.

Table 4 presents a cash flow analysis for the system using a 2:1 debt to equity loan. The term of the loan is 10 years with a two year moratorium. It also accounts for taxes, depreciation using the WDB method, and an incentive based on the difference between the WDB and straight line depreciation method. The results are that the system will pay back the equity in 1.5 years.

CONCLUSION

The cogeneration system utilizing both cooler and preheater exhaust heat recovery is technically feasible and economically feasible at the electrical rates Larsen & Toubro currently pays. It appears neessary that the system must be based on heat recovery from both cooler and preheater exit gas streams. This is beause the unit costs of installed capaity increases with dereasing size systems making it more difficult for the system to become cost effective at the smaller size if only one of the streams is used. Also the available heat from both streams are necessary to approach meeting critical kiln operation electrical requirement.

Detailed design development will need to focus on optimization of the integration of preheater and cooler available heats and the steam flows and optimum steam temperatures and pressures in each stage of the turbine. In preliminary discussions with an equipment suppliers in India, it appears that all components of the system can be supplied by Indian companies. Following detailed engineering design and site preparations, the system should be able to be installed and commissioned in 12 to 15 months from award of major components contracts.

References

1 Noguchi, K, Japan's Cement Industry Today, Rock Products, May, 1982

2 Lang, Th, and Mosimann, P., Production of Electrical Thermal Energy from Exhaust Gas Heat of Preheater Kilns, World Cement, June 1983

TABLE 1

LARSEN & TOUBRO SYSTEM SIZING

		Preheater	Cooler
Gas Flow	Nm^3/kg	1.85	2.25
	Nm^3/h	$2.46x10^5$	$2.99x10^5$
Temperature	°C	340	260
Boiler Exit Gas Temperature °C		200	110
Specific Heat	$\frac{KJ}{Nm^3 °C}$	1.4	1.3
Available Heat	KJ	$4.82x10^7$	$5.84x10^7$
Cycle efficiency %		22	18
Cogenerator Capacity	KW	2947	2918
Total Capacity	KW	5865	

1 Referenced to Clinker

TABLE 2

LARSEN & TOUBRO COST SUMMARY
(Rs Lakhs)

	Material	Labour
Boiler	157	9
Turbine	270	5
Power House Piping	23	10
Steam & Water	119	20
Electric & Controls	24	10
Site Work	2	7
Spare Parts	19	
Total	614	61

General Construction (Indirect & Fee)	88
Indirect Project Engineering	62
G & A	10
Total Capital Cost	835

TABLE 3

LARSEN & TOUBRO SYSTEM SIMPLE PAYBACK

Capacity	5865 kW Gross	5395 kW net
Operations & Maintenance		0.13 Rs/kWh
Demand Charge		30 Rs/kW/month
Average Electric Unit Cost		0.92 Rs/kWh
Estimated System Cost		Rs. 835 lakh
Annual hours of Operation		7200 hours

Annual Savings	Rs	357 lakhs
O&M Cost	Rs	55 lakhs
Demand Charge	Rs	21 lakhs
Net Savings	Rs	281 lakhs

Simple Payback $\frac{835}{281}$ = 2.97 years

TABLE 4
COGENERATION CASH FLOW ANALYSIS
NATIONAL COUNCIL FOR CEMENT AND BUILDING MATERIALS
(R.C. ERICKSON, UNIDO EXPERT)

SITE: L & T CEMENT

ASSUMPTIONS:

Total Installed Cost:	835.00 Rs LAKH	Heat Source:	Preheat/Cooler Exhaust	Initial Elect. Pur. Price:	0.92 Rs/kwh
Loan Ammount:	556.70 Rs LAKH	Size:	5395.00 kw	Initial Fuel Cost:	0.00 Rs/Mcal
Down Payment	278.30 Rs LAKH	Gross Heat Rate:	0.00 cal/kwh		
Loan Terms:		Recoverable Heat:	0.00 cal/kwh	Elect. Used On Site:	100.00 Percent
Int.	12.50 Percent	Plant Cap. Fact:	82.19 Percent	Initial Elect. Sale Price:	0.92 Rs/kwh
Term	8.00 Years			Standby Demand Charge:	360.00 Rs/kw/yr
Economic Life:	15.00 Years			O&M Charge:	0.13 Rs/kwh

YEAR:	1987	1988	1989	1990	1991	1992 [Rs LAKH]	1993	1994	1995	1996	1997
REVENUE:											
Displeaced Electricity:		357.36	393.09	432.40	475.64	523.21	575.53	633.08	696.39	766.03	842.63
Electricity Sold:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL REVENUES:		357.36	393.09	432.40	475.64	523.21	575.53	633.08	696.39	766.03	842.63
EXPENSES:											
Fuel:		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O&M:		55.04	58.34	61.84	65.55	69.49	73.66	78.08	82.76	87.73	92.99
P&I:	0.00	0.00	144.82	144.82	144.82	144.82	144.82	144.82	144.82	144.82	
Insurance:		6.68	7.08	7.51	7.96	8.43	8.94	9.48	10.04	10.65	11.29
Standby:		21.17	21.17	21.17	21.17	21.17	21.17	21.17	21.17	21.17	21.17
TOTAL EXPENCES:		82.89	231.41	235.34	239.50	243.91	248.58	253.54	258.79	264.36	125.45
PROFIT (Pre Tax):		274.47	161.68	197.06	236.14	279.30	326.94	379.54	437.59	501.66	717.18
TAX IMPACTS:											
[Depreciation]:	83.50	75.15	67.64	60.87	54.78	49.31	44.38	39.94	35.94	32.35	29.11
[Incentives]:	27.83	19.48	11.97	5.20							
TAXES: 50.00 percent	-55.67	89.92	41.04	65.49	90.68	115.00	141.28	169.80	200.83	234.66	344.03
PROFIT (After Tax)	55.67	184.55	120.64	131.57	145.46	164.30	185.66	209.74	236.77	267.01	373.15
CUMULATIVE CASH FLOW:	-222.63	-38.08	82.56	214.13	359.59	523.89	709.55	919.29	1156.06	1423.07	1796.22

SIMPLE PAYBACK, YEARS:
Based on 5 Year Average 1.49

INTERNAL RATE OF RETURN:
Based on 10 Years 71.18%

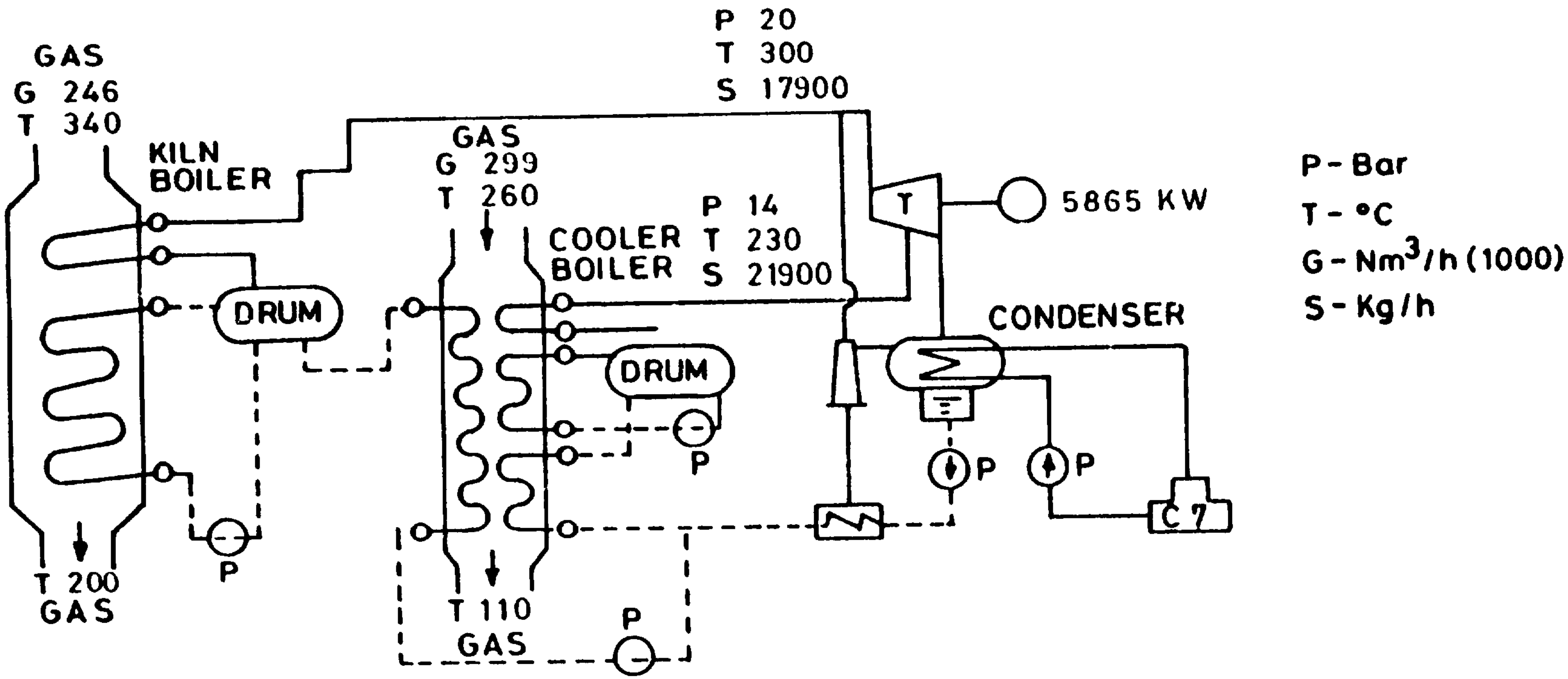


FIG.1 LARSEN & TOUBRO STEAM CYCLE SCHEMATIC

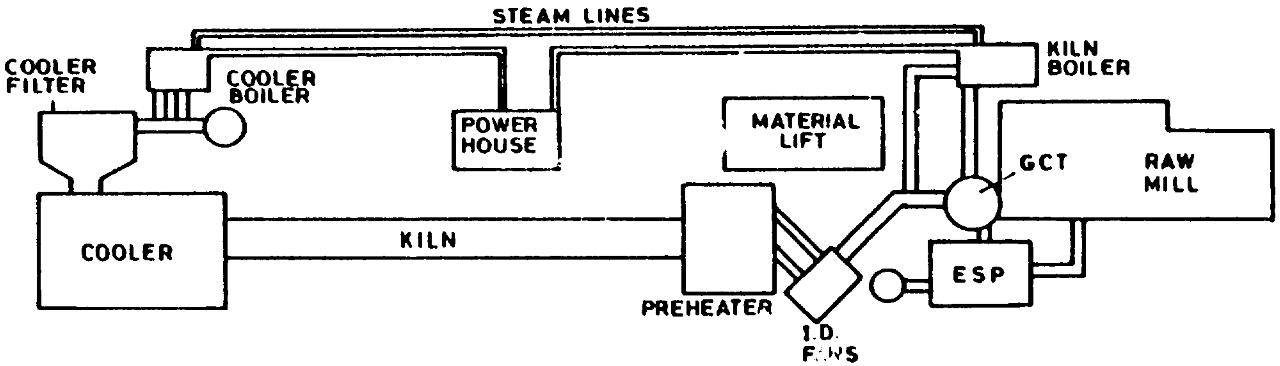


FIG 2 SUGGESTED BOILER AND POWER HOUSE LOCATIONS

APPENDIX C

LECTURE MATERIALS

TECHNOLOGY, APPLICATIONS & ECONOMICS OF COGENERATION IN THE CEMENT INDUSTRY

ROBERT ERICKSON
CONSULTANT, U S A
UNIDO
NCB

INTRODUCTION

SPEAKER'S BACKGROUND

WHAT COGENERATION IS

WHERE COGENERATION IS APPLICABLE IN THE CEMENT INDUSTRY

TECHNOLOGIES AVAILABLE

ECONOMIC EVALUATION

SPEAKER'S BACKGROUND

PRIVATE CONSULTANT IN COGENERATION APPLICATION FEASIBILITY AND PRELIMINARY DESIGN IN INDUSTRIAL AND COMMERCIAL BUSINESS SECTOR APPLICATIONS.

CONSULTANT TO THE UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION [UNIDO] ASSIGNED TO THE NATIONAL COUNCIL FOR CEMENT AND BUILDING MATERIALS

PROJECT PURPOSE: IDENTIFICATION OF POTENTIAL AREAS FOR WASTE HEAT RECOVERY AND SELECTION OF APPROPRIATE COGENERATION TECHNIQUES FOR INDIAN CEMENT PLANTS

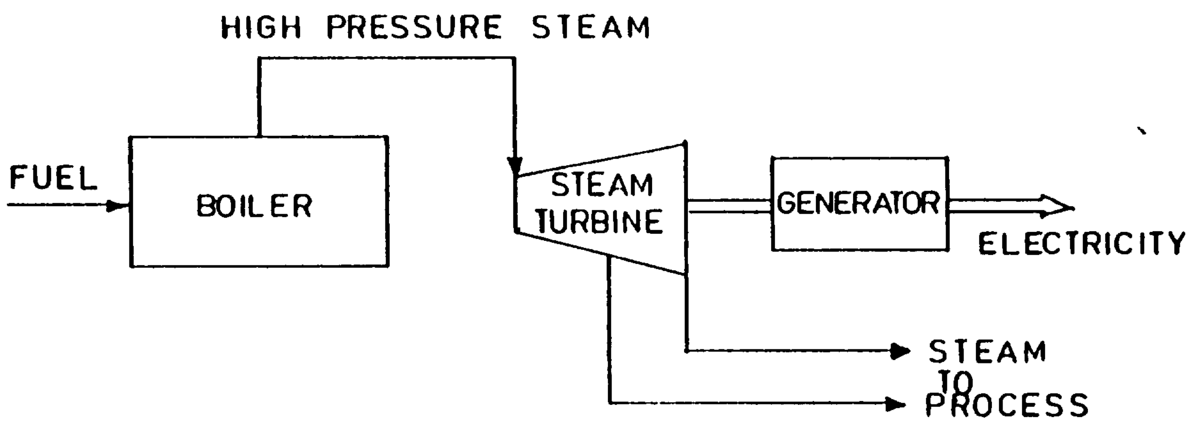
WHAT COGENERATION IS

COGENERATION IS THE SEQUENTIAL PRODUCTION OF TWO FORMS OF ENERGY _USUALLY PROCESS HEAT & ELECTRICITY FROM THE SAME INPUT FUEL

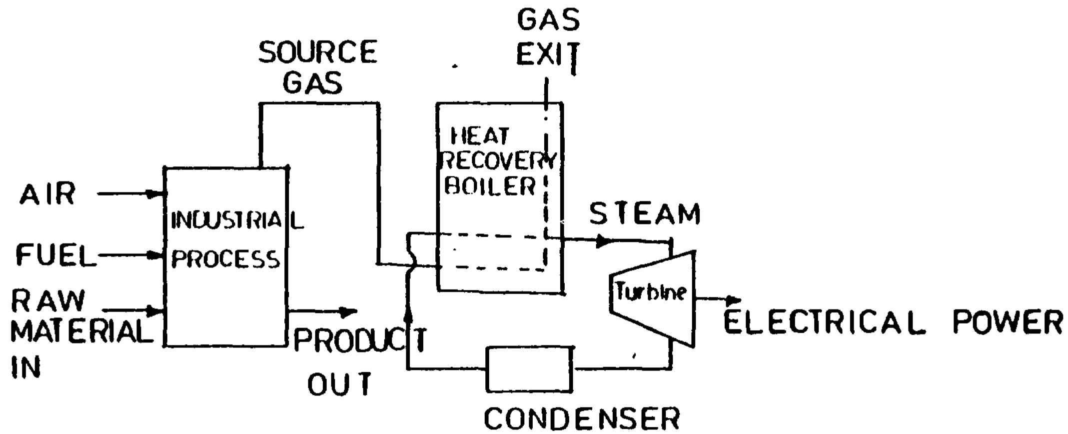
TOPPING CYCLE : ELECTRICITY IS PRODUCED FIRST & HEAT IS RECOVERED TO MEET PROCESS REQUIREMENTS

BOTTOMING CYCLE : PROCESS HEAT IS PRODUCED FIRST & RECOVERED HEAT IS USED TO PRODUCE STEAM THAT IS USED TO GENERATE ELECTRICITY

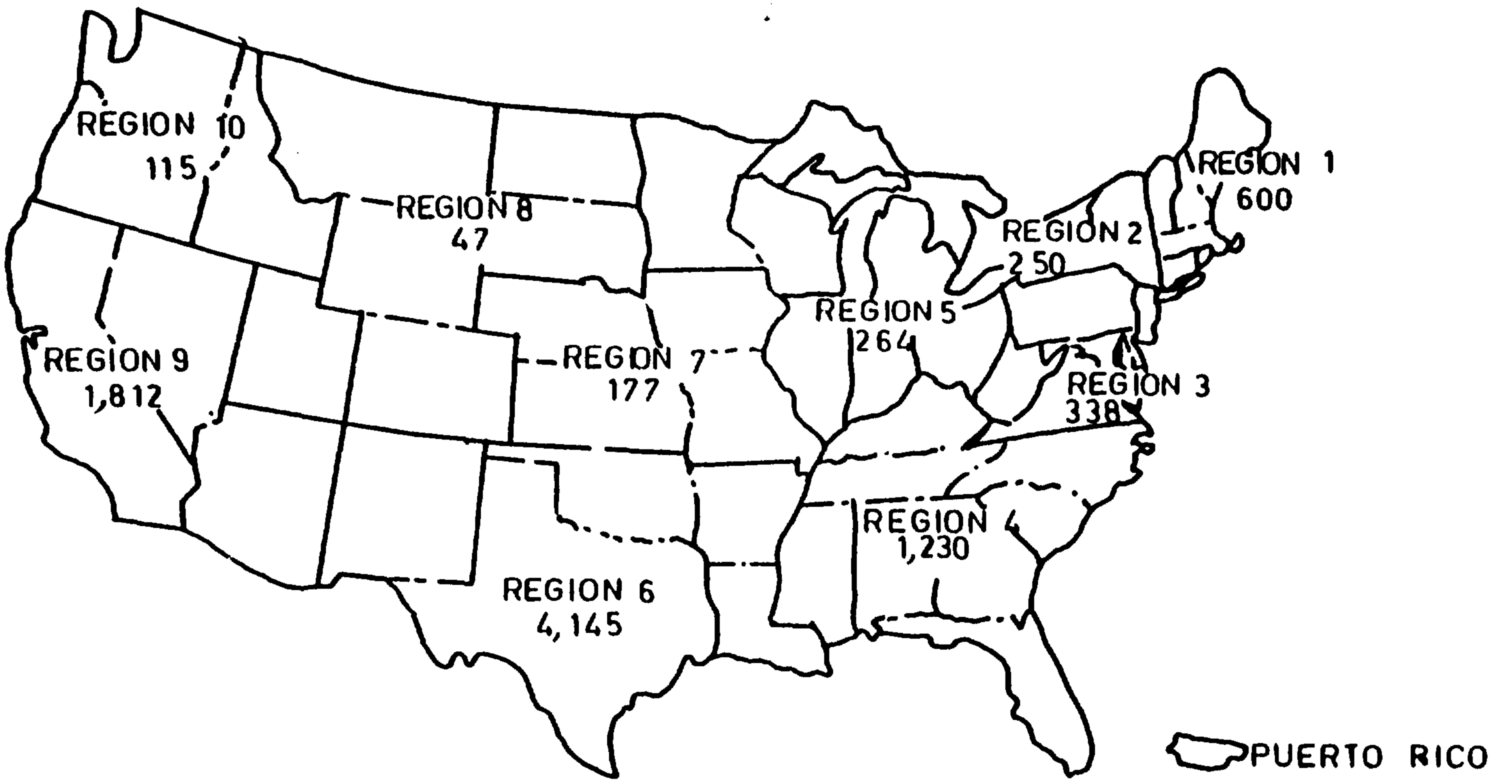
EXTRACTION/NONCONDENSING STEAM TURBINE



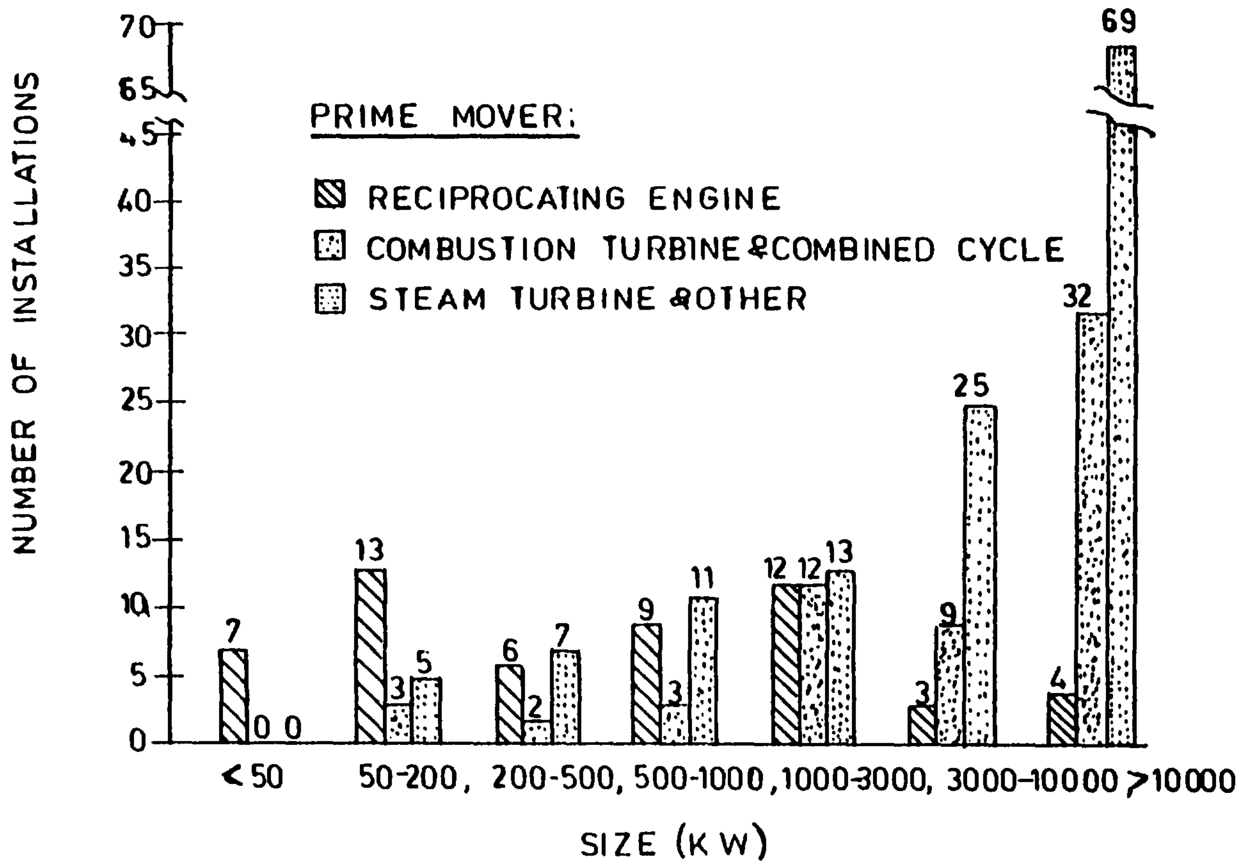
BOTTOMING SYSTEM USING STEAM OR ORGANIC FLUIDS



INSTALLED U.S CAPACITY (MW) BY FEDARAL REGION

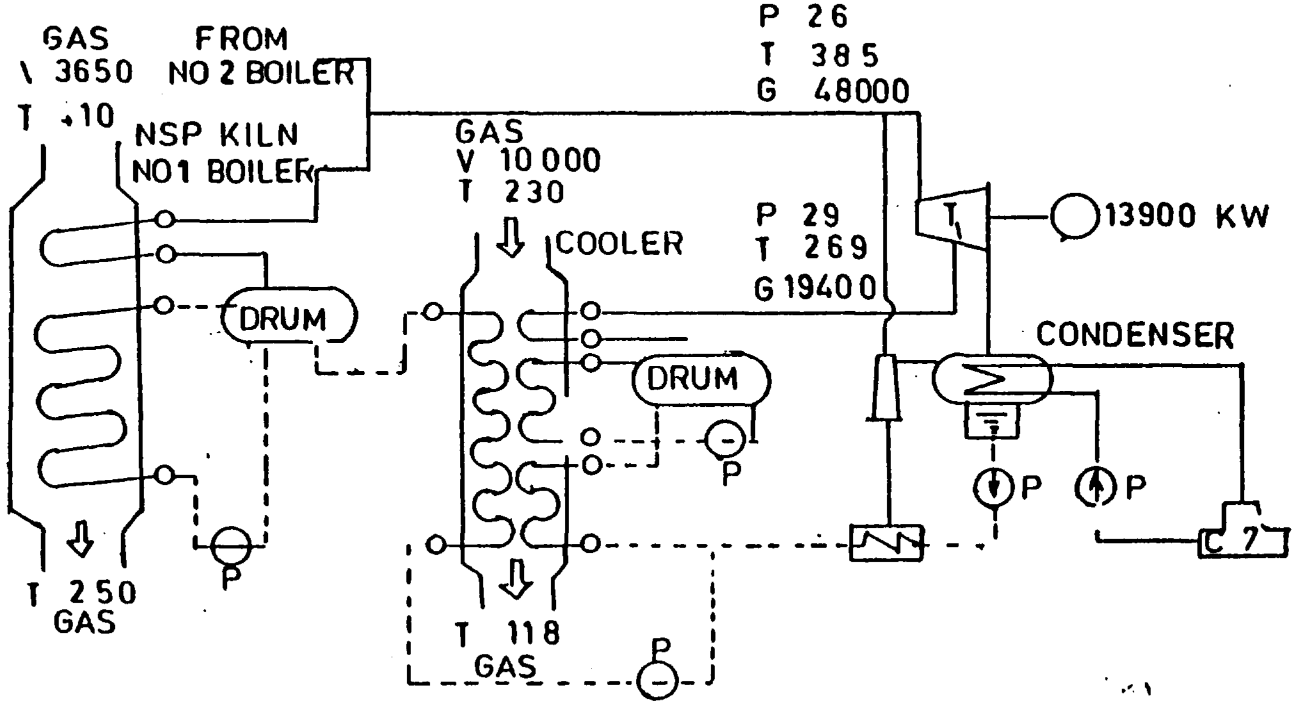


NUMBER OF INSTALLATIONS U.S SIZE & PRIME MOVER



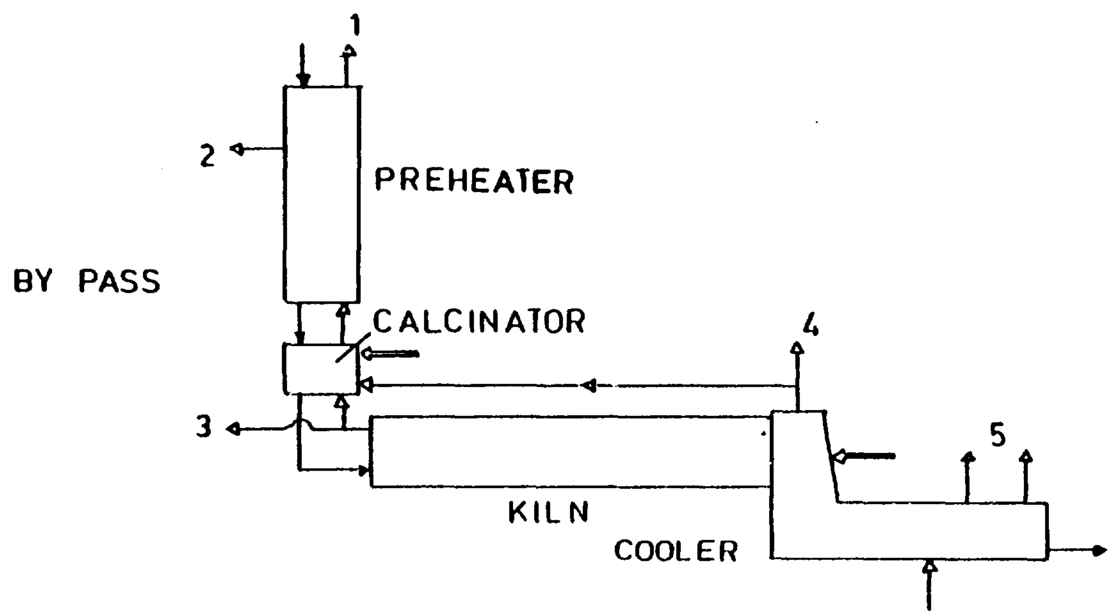
CEMENT INDUSTRY APPLICATIONS

UNITED STATES	KILN EXHAUST HEAT RECOVERY INTEGRATED THARMAL PLANT, WASTE HEAT RECOVERY.
SWITZERLAND	PREHEATER EXHAUST HEAT RECOVERY
JAPAN	PREHEATER AND COOLER EXHAUST HEAT RECOVERY STEAM AND ORGANIC FLUID RANKINE CYCLES



GAS
V 3650
T 410
FROM
NO 2 BOILER
NSP KILN
NO1 BOILER
DRUM
P
T 250
GAS
GAS
V 10 000
T 230
COOLER
DRUM
P
T 118
GAS
P
P 26
T 385
G 48000
P 29
T 269
G 19400
13900 KW
CONDENSER
P
P

EXTRACTION POINTS FOR EXHAUST STREAMS



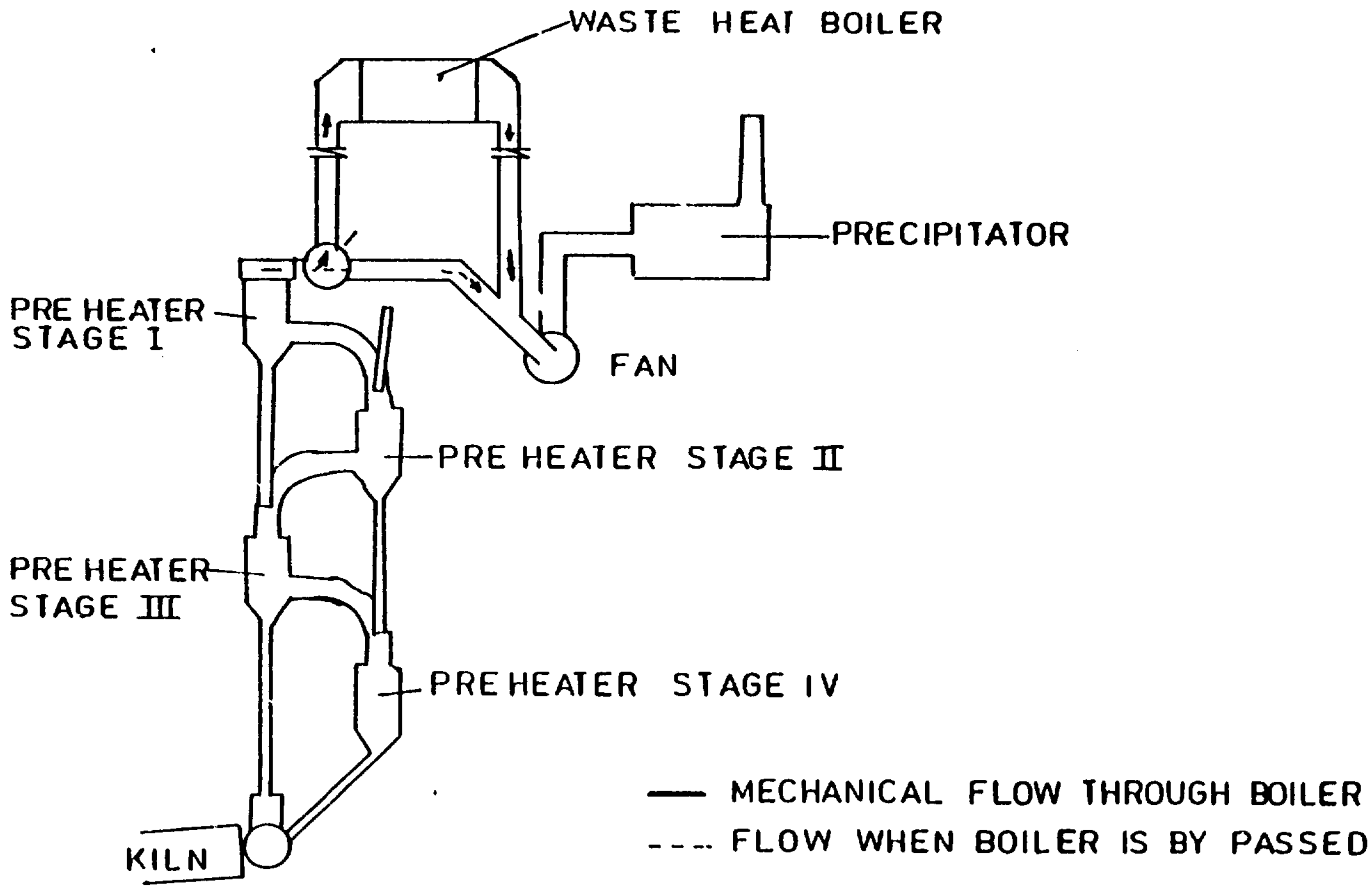
CHARACTERISTIC DATA OF POTENTIAL EXHAUST GAS STREAMS

POINT OF GAS EXTRACTION	Designation	SPEC. MASS FLOW 2) m^3/kg	Temperature °C	Underpressure in bar	Dust Content 1) g/m^3
1	Preheater Exit Gas	0,6 - 1,8	280 600	20 80	20-100
2	Preheater intermediate Gas	0,1 - 0,4	500-800	30 70	50 -150
3	Kiln exit gas By pass gas	0,1 - 0,5	1000-1200	2 -10	50 -300
4	hot air from cooler (secondary air)	0,1 -0,3	700- 900	0,1- 0,5	5 - 200
5	Exhaust air from cooler	0,4 -1,8	150 -400	0,1 -0,5	5 - 20

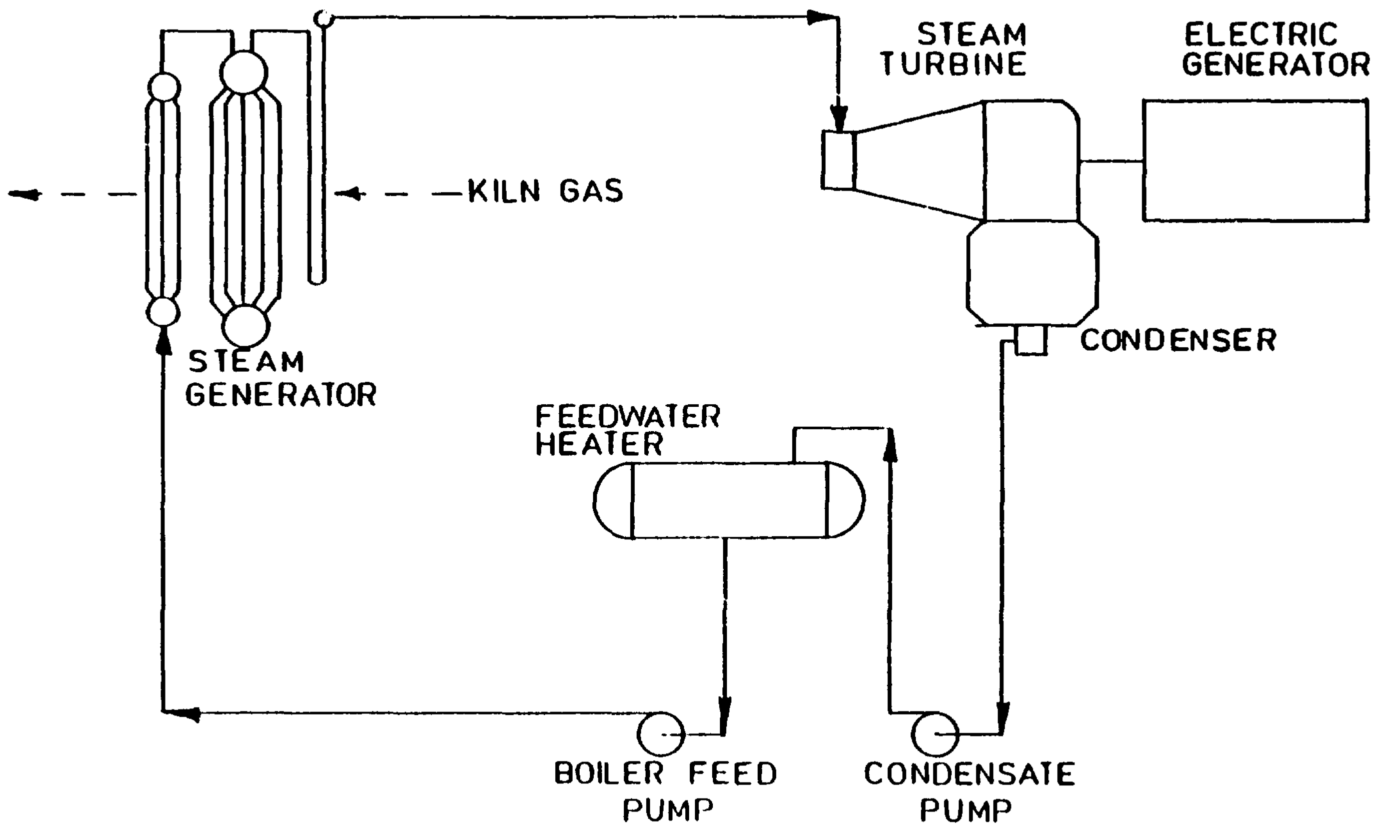
1) AT STANDARD TEMP. AND PRESSURE (0°C, 1.013 bar)

2) REFERRED TO CLINKER

RETROFIT OF WASTE HEAT BOILER INTO CEMENT PLANT



SCHEMATIC OF STEAM POWER CYCLE



TYPICAL SYSTEM SIZING

(PER TPH)

	PREHEATER HEAT RECOVERY	COOLER HEAT RECOVERY
GAS FLOW Nm^3/h	1850	2400
TEMPERATURE °C	360	230
BOILER EXIT GAS TEMPERATURE °C	200	110
SPECIFIC HEAT $\frac{KJ}{Nm^3 °C}$	1.4	1.3
AVALABLE HEAT [000] KJ	414	374
CYCLE EFFICIENCY PERCENT	22	18
COGENERATION CAPACITY Kw	25[illegible]	18.7

TOTAL SYSTEM ENERGY SENSITIVITY [PER TPH]

	BASE CASE	DECREASED KILN EFFICIENCY
KILN EFFICIENCY Kcal/kg Cl	900	950
ELECTRICITY USE Kwh/Ton	130	130
GAS VOLUME Nm^3/h	1850	1950
PREHEATER TEMPERATURE °C	360	410
BOILER EXHAUST TEMPERATURE °C	200	200
AVAILABLE HEAT [000] KJ	414	573
CYCLE EFFICIENCY PERCENT	22	23
COGENERATION CAPACITY Kw	25.3	36.6
FUEL COST [540 Rs/ton] Rs	128	135
ELECTRICITY COST [1.0 Rs/kwh] Rs	105	93
TOTAL ENERGY COST Rs	233	228

SYSTEM ALLOWABLE COST

ASSUMPTIONS:

COGENERATOR CAPACITY 43 KW.		PLANT SIZE 1200TPD	
ELECTRICITY COST	: 1Rs/KWH	DEMAND CHARGE	30 Rs/KW/MONTH
OPERATIONS AND MAINTENANCE	0.13 Rs/KWH	OPERATING HOURS	7200

PAY BACK REQUIREMENT: 3.5 SIMPLE PAY BACK

RESULTS: COGENERATION CAPACITY 2150 KW

ELECTRICITY SAVINGS	Rs 1.42 CRORES
O & M COST	Rs 0.20 CRORES
DEMAND CHARGE	Rs 77 LAKHS
ANNUAL SAVINGS	Rs 1.21 CRORES

ALLOWABLE COST FOR 3.5 YEAR SIMPLE PAYBACK: Rs 4.2 CRS

COGENERATION SYSTEM CAPITAL COST SUMMARY
(2150 KW Rs Lakh)

	MATERIAL	LABOUR
BOILER	97	6
TURBINE	168	3
POWER HOUSE	14	6
STEAM & WATER	74	12
ELECTRIC & CONTROLS	15	6
SITE WORK	1	4
SPARE PARTS	12	
TOTAL	381	36
TOTAL		
GENERAL CONSTRUCTION (INDIRECT & FEE)	54	
INDIRECT PROJECT ENGINEERING	39	
G & A	6	
TOTAL CAPITAL COST	516	

EFECT OF FINANCING ON PAY BACK PERIOD

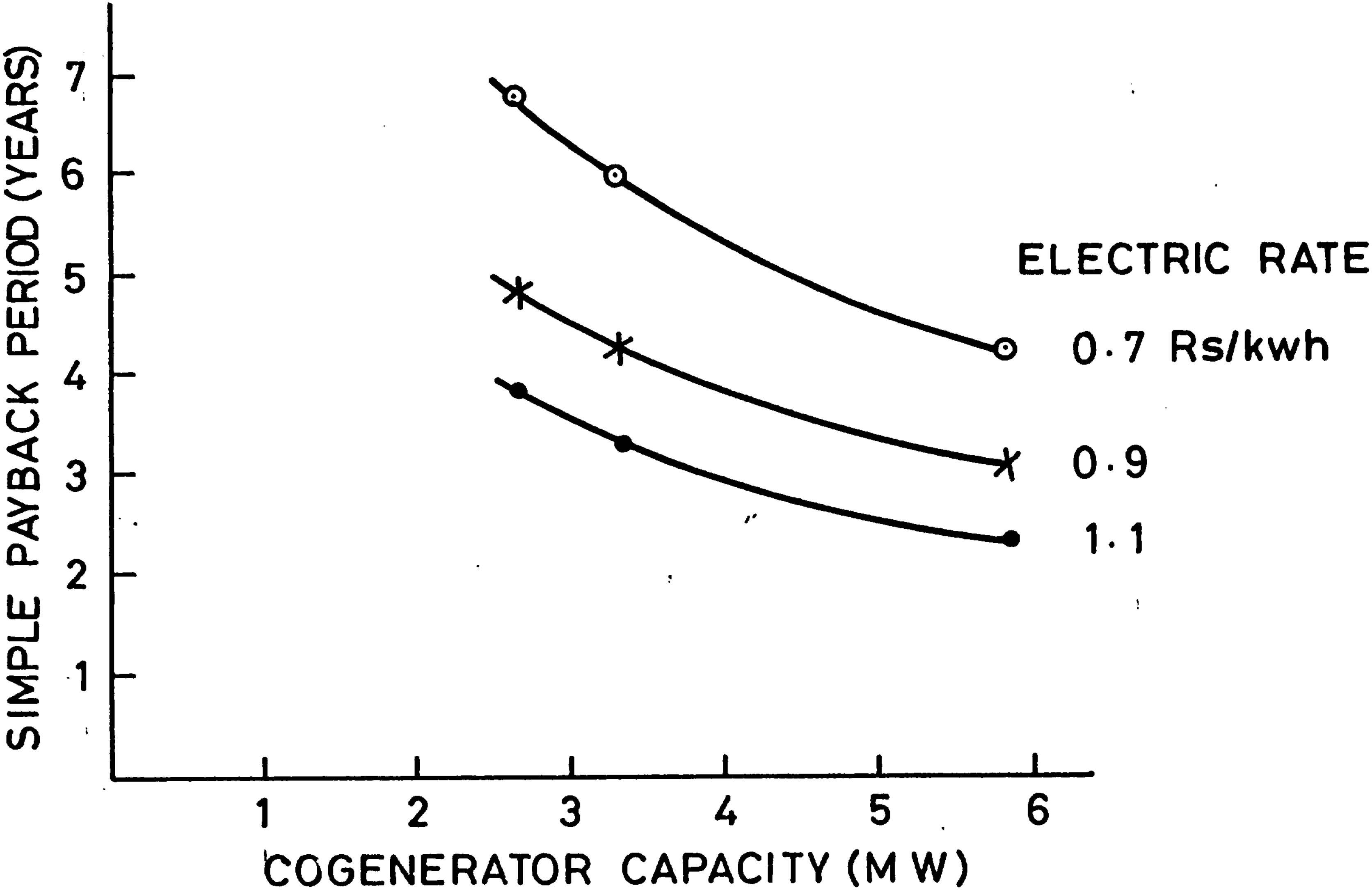
ASSUMPTIONS	33.3% EQUITY	12.5% INTEREST RATE
	66.7% FINANCED	10 YEAR LOAN
	Rs 5.16 CRORES COST	2 YEAR MORATORIUM

RESULTS	Rs 1.72 CRORES INITIAL QUALITY
	Rs 3.44 CRORES LOAN
	Rs 0.82 CRORES ANNUAL PAYMENT
	ANNUAL ENERGY COST SAVINGS Rs 1.21 CRORES

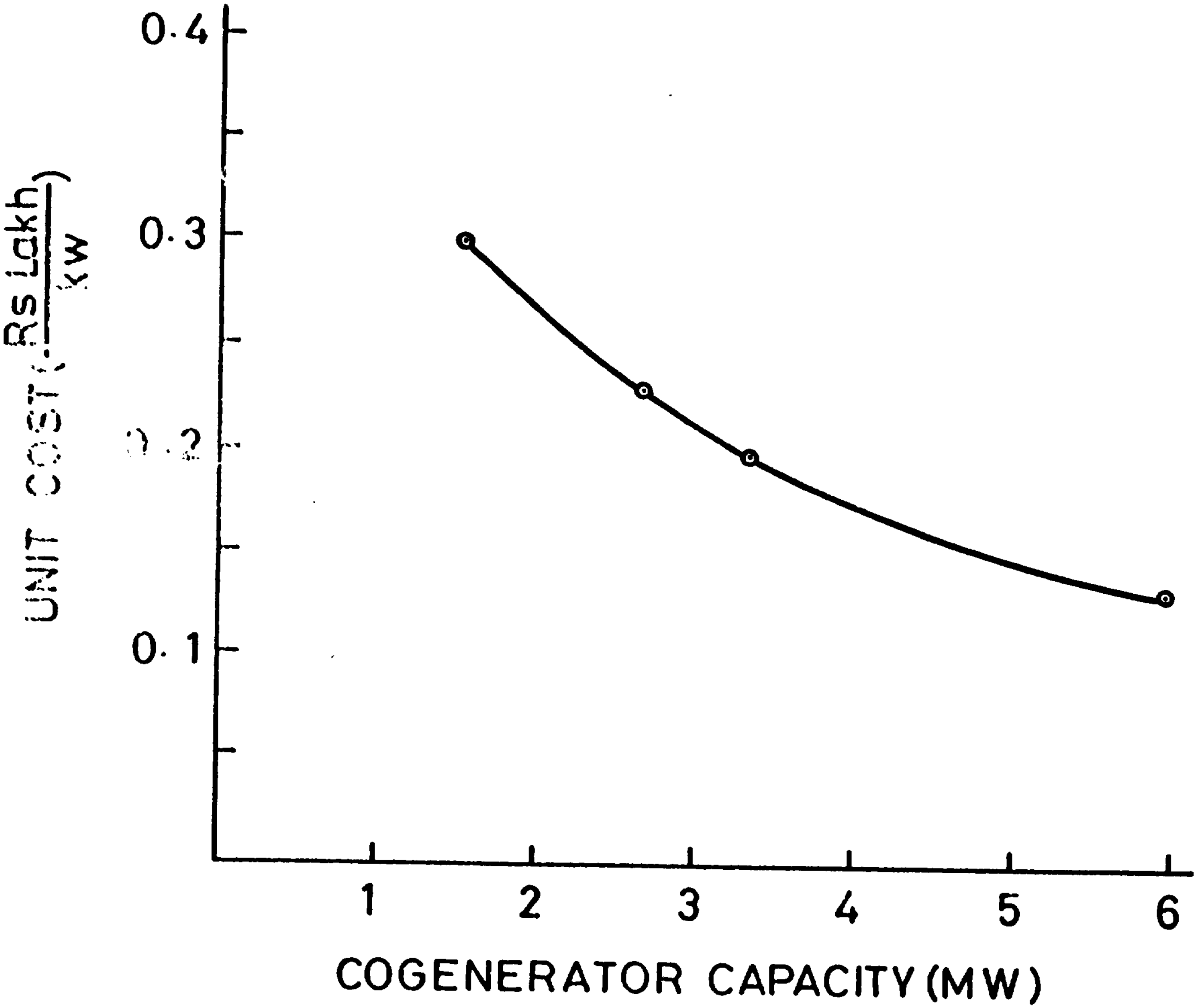
PAY BACK IS AT THE END OF TWO YEARS OF OPERATION

FOLLOWING YEARS SAVINGS ARE Rs 0.41 CRORES.

SIMPLE PAYBACK PERIOD Vs SIZE, ELECTRIC RATE



INSTALLED COST PER KILOWATT Vs CAPACITY



CONCLUSIONS

HEAT RECOVERY TECHNOLOGIES FOR KILN, PREHEATER & COOLER EXHAUST STREAMS HAVE BEEN DEMONSTRATED THROUGHOUT THE WORLD

KILN MINIMUM ELECTRICAL DEMAND REQUIREMENTS CAN BE MET WITH WASTE HEAT RECOVERY POWER GENERATION

ELECTRIC ENERGY PRODUCTION COST PER TON OF CEMENT CAN BE REDUCED BY Rs 25-40

SENSITIVITY TO TOTAL ENERGY COST DUE TO VARIATIONS IN KILN OPERATION CAN BE REDUCED

DUE TO INITIAL JUDGEMENTS ON CAPITAL COST APPLICATIONS APPEAR FEASIBLE ON PLANTS WITH A CAPACITY OF 1000 TPD OR GREATER AND WITH TEMPERATURES OF 350°C OR ABOVE IN ATLEAST ONE OF THE HEAT RECOVERY GAS STREAMS