Confederation of Indian Industry
CII-Sohrabji Godrej Green Business Centre

Asia-Pacific Partnership

Manual on Waste Heat Recovery in Indian Cement Industry

As part of World Class Energy Efficiency in Cement Industry

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ASIA-PACIFIC PARTNERSHIP ON CLEAN DEVELOPMENT & CLIMATE
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FORE WORD

Indian cement industry is the second largest manufacturer of cement with a present capacity of about 206 Million Tons per annum (MTPA). Cement capacity in the last 5 years has increased by over 30% and the projected growth rate in the next 5 years is about 20% increase from present levels of manufacture. Cement production, during March 2009, was 18.1 million ton, registering a growth of 10.43% over March 2008 production.

While energy efficiency has taken a top priority in Indian cement industry, the adoption of Waste Heat Recovery (WHR) systems in cement facilities has still a long way to go. Out of over 150 large cement kilns in the country, only about 5 cement kilns have adopted WHR systems.

Huge potential exists across the Indian cement industry to recover the waste heat and generate power. Cement industry being energy intensive, tapping waste heat can be an excellent opportunity to reduce the overall operating cost. Increased global GHG emissions are forcing the industrial sectors to operate in an energy efficient and environment friendly way. Implementation of waste heat recovery can substantiate fossil fuels used for power generation which will ultimately reduce GHG emissions.

With a view to promote WHR installations in India, CII is bringing out the WHR potential in Indian cement plants and the technologies available in the form of the manual.

While Green Cementech Conferences serve as a platform for deliberations and discussions, manuals like these go a long way in sharing of information among all stakeholders.

I am sure; this manual will receive an overwhelming response from the cross section of the industry.

(G. Jayaraman)

EXECUTIVE SUMMARY

With the present capacity of the Indian cement industry is about 206 Million Tons per annum (MTPA), Indian cement industry is the second largest manufacturer of cement, only next to China. Cement capacity in the last 5 years has increased by over 30% and the projected growth rate in the next 5 years is about 20% increase from present levels of manufacture. Cement sector is one of the fastest growing industrial sectors in India.

Indian cement industry is very advanced as far as energy efficiency is concerned. Some of the Indian cement plants operate with very low energy consumption levels, which are the best in the world. Latest technology adoption and continuous improvement has been the predominant factors for such high energy efficiency levels in Indian cement industry.

While energy efficiency has taken a top priority in Indian cement industry, the adoption of WHR systems in cement facilities has still a long way to go. Out of over 150 large cement kilns in the country, only about 5 cement kilns have adopted WHR systems.

CII's estimates indicate that the waste heat recovery potential in Indian cement industry is close to 415 MW while the installed capacity till date is only about 20 MW. This indicates the huge opportunity for adoption of waste heat recovery in Indian cement industry.

While the technology of waste heat recovery systems are accepted by the Indian cement manufacturers, the predominant reason for such low adoption has been the cost of technology and lack of attractive financial mechanisms.

Almost all the cement manufacturers in the country have captive power plants to meet their power demand. The reason for captive power generation is to lower the cost of power generation. Installing captive power plants would cost the cement manufacturers about Rs 40 Million per MW. On the other hand, installing WHR systems is costing the manufacturers about Rs 70 Million to Rs 80 Million per MW depending on the type of technology adopted and the WHR potential. This high initial investment is deterring manufacturers from adopting waste heat recovery systems.

The manual focuses on major WHR technologies successfully employed in the world and India in particular.

a) Description of technology

b) WHR installations in Indian cement industry

c) Major suppliers and contact information

d) Capital investment required (based on past installations in India)

e) Major technical or operating problems incurred

i. To identify existing applications of WHR in India; successes and problems.

ii. To identify barriers to deployment of WHR technologies; past, current and future, including water requirement, and its impact on the project both financially and technical.

The methodology adopted by CII in bringing out this manual had the following major steps:

- Detailed analysis based on CII's prior experience with the Indian cement industry
- Data analysis based on existing publicly available data and statistics
- Discussion with key cement manufacturing groups to understand their experiences and thoughts in adopting WHR in cement industry
- Discussion with technology providers on various technologies available and extent of adoption in Indian cement industry

HOW TO USE THIS MANUAL

- The objective of this manual is to bring out the Waste Heat Recovery potential available in the Indian Cement industry
- To set a clear target for implementing WHR system, various technologies available have been described in detail in this manual
- To facilitate easier implementation, references & details of the plants where WHR system is in practice have been provided
- The implementation of WHR system may be considered after detailed study of the potential available and the economical aspects. Therefore, this manual can only be treated as a guide document and not as an ultimate solution for installation of WHR system
- Suitable latest technologies may be considered for implementation of WHR in existing and future Cement plants. Further investigation and legal activities need to be done for the suitability of these technologies for Indian Cement Plants
- Therefore, Indian Cement Plants should view this manual positively and utilize the waste heat available to generate power and there by reducing operating cost

1 BACKGROUND OF INDIAN CEMENT INDUSTRY

1.0 History

The history of Indian Cement industry started with a manufacturing capacity of mere 0.85 MTPA (Million Metric Tons Per Annum) in 1914-15 when the first Cement plant was set-up at Porbandar, Gujarat. Over the time the Indian Cement industry has attained phenomenal growth to the current production level of 206 MTPA[1]. The Indian Cement industry, today, stands as the second largest cement manufacturer in the world. Apart from the manufacturing capacity, the Indian cement industry is regarded as one of the best in the world in terms of technology, quality, efficiency and productivity parameters.

1.1 Capacity

India is the 2nd largest producer of cement in the world. The total installed capacity is about 206 MPTA as on 31st December 2008.

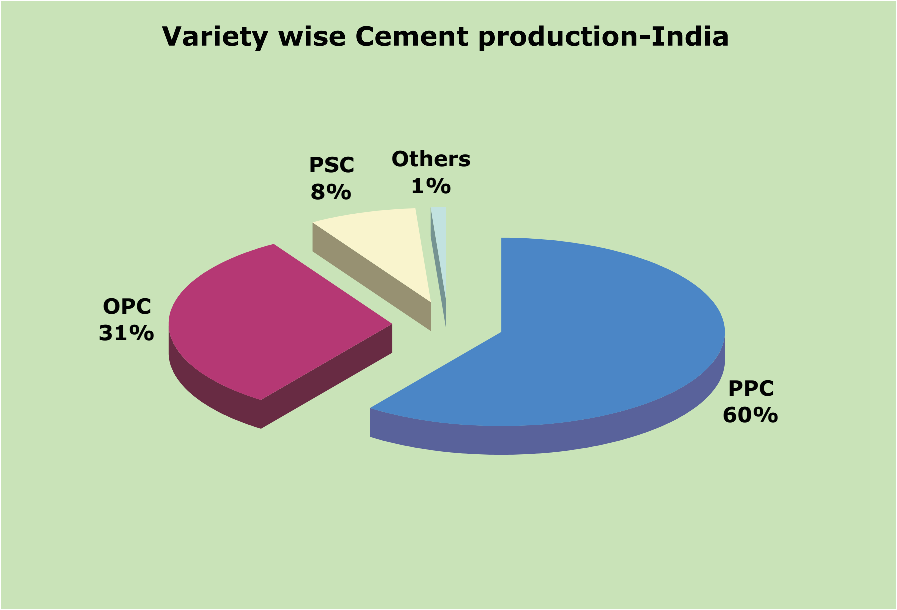
The industry added over 30 MT to its installed capacity, in just one year, during previous fiscal (April 2007–March 2008). The capacity utilization is close to 100%.

The Indian cement industry comprises of 52 cement manufacturing companies operating 132 large cement plants and more than 365 mini cement plants. The large plants contribute to over 96% of the total cement production in the country and the mini-cement plants are either undertaking massive expansion plans to compete with large plants or closing down. Indian cement industry comprises of both private and public sector ownership, but is predominantly dominated by private companies. The private sector cement companies contribute over 97 % of total cement production in the country. The per capita consumption of cement in the nation is just about 175 kg.

The industry produces cement varieties such as Ordinary Portland, Pozzulona Portland (Fly-ash based), Pozzulona blast furnace slag, Sulphate resistance, IRST 40, Oil well, Low heat, silicate, GPC and Special Cement.

[1] Source - www.ibef.org

The Chart below shows the Cement Production[2] distribution of various types of cement



1.2 Technological Advancements

At present, the quality of cement and standard of cement produced in India is in line with the cement produced else-where and can compete in international markets. The productivity parameters are now nearing the theoretical bests and the cement industry today is looking beyond for alternate types of cement.

Indian cement industry can legitimately be proud of its state-of-the-art technology and processes incorporated in most of its cement plants. For example 96 % of the cement is produced by the latest dry process technology. This technology up gradation has resulted in increasing the capacity and reducing the cost of production.

1.3 Importance to Economy

The cement industry accounts for approximately 1.3% of GDP and employs over 0.15 million people.

[2] Cement Manufactures Association (CMA)

Cement demand in the country grows at about 1.5 times the GDP. It is a significant contributor to the revenue collected by both the central and state governments through excise and sales taxes. Central excise collections from cement industry aggregated Rs. 45.23 billion in FY 2005 and accounted for 4.3% of total excise revenue collected by the government.

1.4 Cement industry & Climate change

Indian Cement industry contributes over 8% of the total carbon emissions in India. The emission of carbon-dioxide – both from high energy intensive operation in cement manufacture as well as calcination of lime stone, which is the basic raw material, makes the Cement industry one of the high impact industry as far as carbon emissions are concerned.

Indian cement industry, having realized its impact on the environment, has taken several strides in lowering its carbon emissions. Some of the major steps initiated in this direction are: adopting energy efficient practices in cement manufacture by employing latest energy efficient equipment and waste heat recovery, increased manufacture of blended cement and utilizing waste as fuel to lower impact on fossil fuels.

1.5 Energy Efficiency

Indian cement industry has been a fore-runner as far as energy efficiency in the cement manufacturing process is concerned. Some of the Indian cement plants are operating with the lowest specific energy consumption numbers in the world. The cost of energy had been the predominant driving factor for such advancements in energy efficiency.

An average cement plant would be operating with energy cost being about 30 – 40% of the total manufacturing cost of cement. This is much higher compared to other western countries.

1.6 Blended Cement

Blended cement manufacture in India has been on an increasing trend. While in the year 2000, the production of blended cement in the country constituted only about 37% of the total cement manufacture, in the year 2006, blended cement constituted over 60% of the total cement market.

In spite of several efforts in this sector, Indian cement industry still offers substantial potential for energy saving and emission reduction.

1.7 Islands of excellence

A few corporate thought leaders have gone way ahead in areas of energy efficiency, technology adoption and sustainable development. Some of the best practices in the global cement industry have its origin from India.

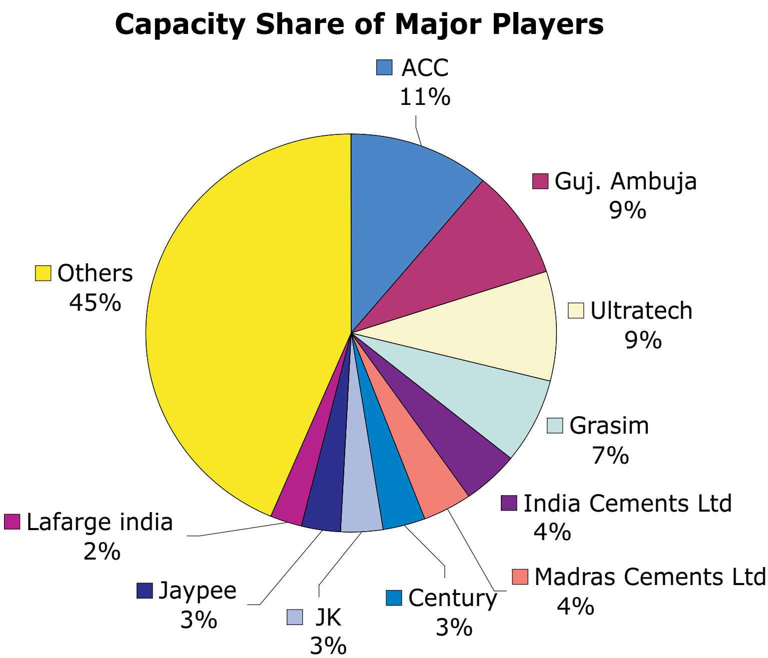
A few examples - Madras Cements Limited put up a cement plant in Alathiyur, Tamil Nadu a plant with the latest technology, operates with one of the lowest specific energy consumption in the world. Shree Cement Limited has played a major role in promoting sustainable development in the Indian cement industry. The Gujarat Ambuja – ACC group has led the industry in its efforts on waste fuel utilization to offset demand on fossil fuels. Another major cement manufacturing group, Grasim – Ultratech Cement has taken initiatives in the area of Waste Heat Recovery and has set an example for other cement units to adopt and replicate. India Cements Limited, another progressive and forward looking cement corporation, has installed the first WHR system in the country.

In spite of such progressive & forward-looking corporate groups setting examples in the Indian cement industry, the gap between the industry leaders and the laggard companies is very wide. For example, in terms of the specific electrical energy consumption, the difference between the best plant and the worst plant in the country is more than 100%.

There is a vital need, both to encourage the thought leaders in the industry to progress further & set newer benchmarks and practices; and to assist the companies following these units to adopt the best practices established by the leaders in the sector and to bridge the gap dividing them.

1.8 Major players

The following chart illustrates the Capacity share of the major players in India



1.9 Energy consumption

Cement industry is a highly energy-intensive industry, accounting for about 10 % of the coal and 6 % of the electricity consumed by the Indian industrial sector. Energy cost comprises of about 35-45% of the total manufacturing cost of cement.

The Indian cement plants on an average consume about 82 kWh of Electrical energy for producing one ton of cement. The average thermal energy consumption of Indian cement plants is about 723 kCal per kg of clinker. The major use of thermal energy is in the kiln and pre-calciner systems. Thermal energy is needed for the raw meal processing specifically for converting the raw mix to Clinker.

The technology adopted, number of stages of pre-heaters, capacity of plant, etc are some of the factors that govern the energy consumption of the cement plants.

1.10 Need for Waste Heat Recovery systems in Indian cement industry

1.10.1 Captive power in Cement industry

Captive Power refers to generation of power of its own, by the cement manufacturing facility for its internal consumption exclusively. Majority of cement plants operate with 100% captive power generation to avoid higher grid costs and to power shortages and power failures.

Coal is primarily used as a fuel as oil and gas are not economical in India. In some cases, power produced from wind farms are also used in addition to coal based captive power plant.

Major reasons for plants going for captive power could be any or all of the following reasons:

- Uninterrupted power supply for their operations
- Reliable source of power
- Better quality of power supply
- Reduced energy costs

1.10.2 Waste heat recovery an alternate Source of Captive Power generation

On an average, the Indian cement plant requires power of 9 Billion kWh per year. The coal needed for generating this much amount of power accounts to 15 Million Tons per year. To meet out the required coal quantity, the industry spends about Rs 55 Billion each year.

In order to bring down the cost towards energy, several cost reduction techniques such as using of pet coke and low grade coal, optimization of Indian coal with imported coals are being practiced.

Waste heat recovery is now emerging as an excellent addition to existing captive power generation. Other than reducing energy cost significantly, it can also be a reliable source of power. The concept of waste heat recovery is slowly picking up across the country.

1.10.3 Advantages of Waste Heat Recovery systems

Waste heat recovery offers several advantages to the Indian cement industry, some of them being as follows:

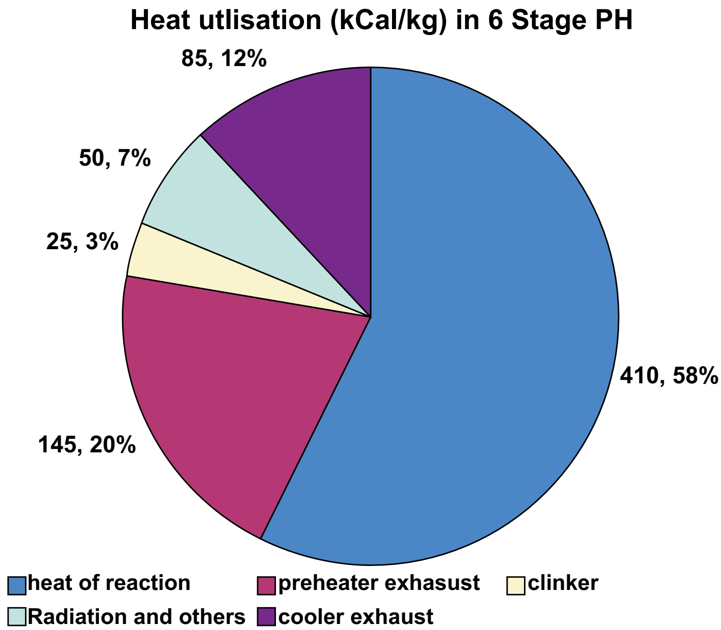
- To reduce fuel consumption, which in turn reduces fuel cost significantly
- To simultaneously meet the demand for electricity and heat in a most cost-effective manner
- To bring down the specific energy consumption of the plant significantly
- To bring about best energy efficient practice in the plant
- To provide economic competitive advantage in the market
- To mitigate the emission of Green house gases which are affecting the environment adversely

2 WHR POTENTIAL IN CEMENT MANUFACTURE

2.0 Waste heat recovery potential

Pyro processing is the only step in the process where thermal energy is supplied and utilised. Theoretically about 390 - 420 kcal of heat is required to form one kg of clinker depending on the quality of raw material, size of raw material, mineralogical structure.

However the practical heat consumption is much higher than this theoretical requirement and the break up is shown as below for 6 stage preheater with latest cooler.



It can be seen that only 58 % of the heat supplied is used for the theoretical heat and the rest goes out as losses.

Unavoidable losses include Radiation loss, loss for evaporation of residual moisture in fine coal and raw meal and some part of heat going with clinker from cooler, while the avoidable and recoverable heat loss includes preheater exhaust gas and cooler exhaust gas.

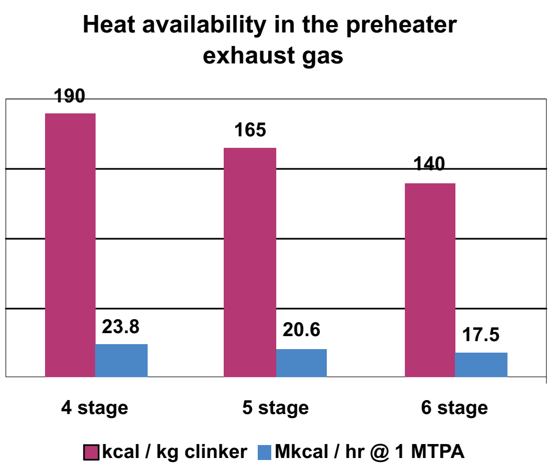
The heat availability in the preheater exhaust is a function of the preheater gas volume (depends on amount of excess air used for combustion, infiltration in to the circuit, specific heat consumption and type of fuel), gas temperature (depends on the heat transfer that is happening in the preheater i.e. number of stages / cyclones in the preheater, dust content), dust content in the pre heater gas (depends on the efficiency of the top stage cyclone).

The heat recovery potential in a cement plant will get subject to the following:

- Moisture content in the limestone i.e., heat requirement for raw mill
- Changes in the number of stages / cyclones
- Change in the efficiency of top stage cyclone
- Change in excess air
- Change in the infiltration air level

The number of preheater stages in a cement plant has a significant bearing on the overall thermal energy consumption and waste heat recovery potential. Higher the number of stages; better is the thermal energy consumption and lower would be the WHR potential.

The typical value of heat availability in the preheater exhaust gas for 1.0 MTPA cement plant (with similar raw material moisture levels and clinker cooler) is graphically represented in the figure

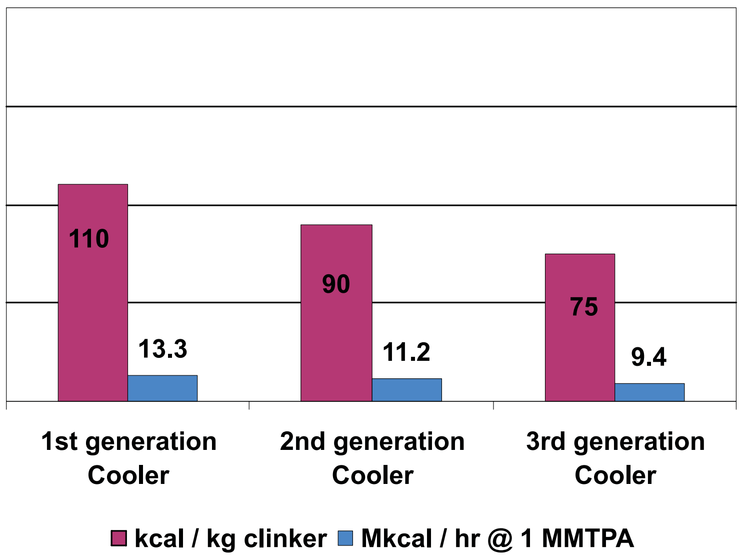


Selection on number of preheater stages is decided based on one or many of the factors such as heat requirement for coal mill & raw mill, efficiency of cooler, restriction on the preheater tower height, etc.

Another area of waste heat availability is cooler exhaust where excess air from cooler is mostly vented into the atmosphere.

The basic function of the cooler is to recover the heat from the hot clinker discharged from the kiln so that it can be handled by the subsequent equipments and does not cause any hindrance to further processing that is cement grinding. Rapid cooling also improves the quality of clinker and its grindability.

Fig Heat availability in the cooler exhaust gas



Waste heat recovery potential depends on the type / generation cooler installed and the utilisation of cooler gas for cement mill / raw mill & coal mill.

2.1 Technical barriers in utilizing waste heat

2.1.1 Moisture content in raw material

Limestone deposits according to its origin will have moisture content of varying from 2 % to 15 %. All the three types of rocks namely Ignititious, metamorphic & sedimentary deposits are available in India.

Lime stone deposits in coastal region such as Junagadh in Gujarat or those areas which has got converted from sea to land like Ariyalur belt of Trichirappalli are of primarily sedimentary origin and have moisture content more than 8 % even in hot summer. The moisture level increases with depth and rainy season.

Stone deposits of Gulburga belt of Karnataka, Yerraguntla or Nalgonda of Andra Pradesh and Kota of Rajastan have practically moisture content less than 2 % with maximum level of 5 % in rainy season. Their well developed crystalline structure (or Non Amorphous form) does not allow absorption of moisture even in heavy rain.

2.1.2 Heat requirement for raw mill

As discussed earlier, the quantity of moisture present in the kiln feed (entering the preheater) influences the specific heat consumption and kiln production rate to a large extent. This restricts the moisture content to less than 1 % in the kiln feed. Drying of raw material is done along with grinding by utilising pre heater hot gas / cooler hot gas as the heat source.

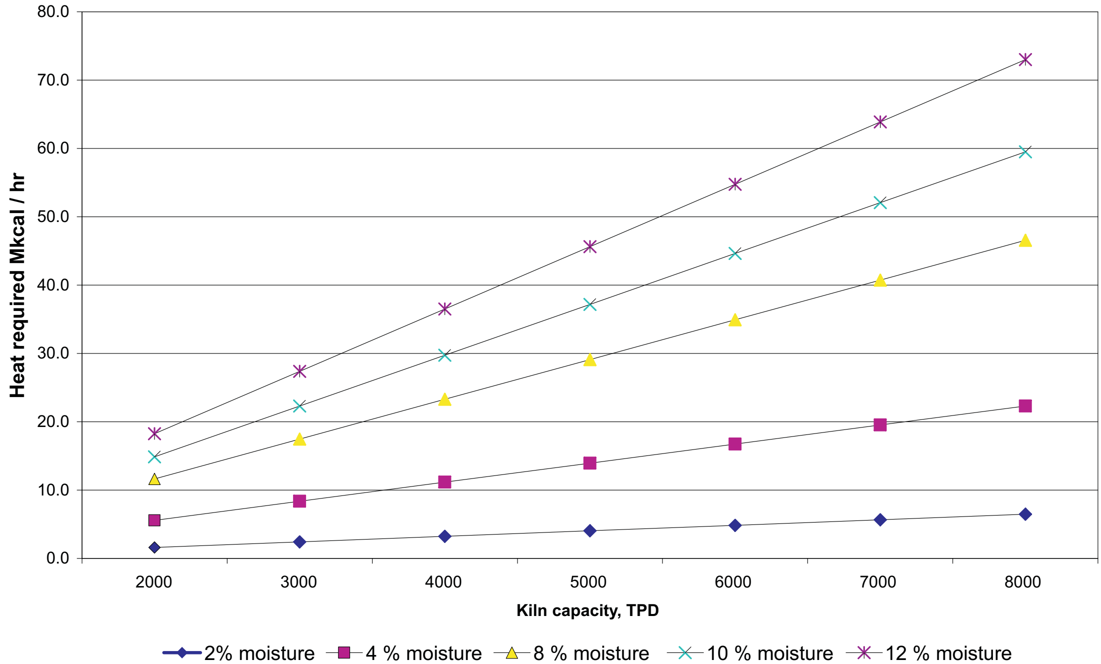
Theoretically about 540 kcal is required to evaporate or remove one kg of moisture (or water) from raw meal / limestone. However practically VRM's (Vertical Roller Mills) requires 900 to 1100 kcal of heat per kg of moisture and Ball mills required about 750 to 850 kcal of heat / kg of moisture due to loss in mill outlet gas, radiation loss, ingress of false air etc.

The following Table and graph gives the raw meal requirement & heat required in Mkcal / hr for various kiln production rates at different moisture levels with the following assumptions:

- Raw meal to clinker factor of 1.55
- Heat requirement of 950 kcal / kg of water for raw mill
- Raw mill running hrs per day : 22

Heat Requirement for Raw mill at different Kiln Production rate									
1	Kiln capacity	TPD	2000	3000	4000	5000	6000	7000	8000
2	Raw meal requirement	TPD	3382	5073	6764	8455	10145	11836	13527
3	Heat requirement	MkCal /hr							
a	@ 2 % moisture		1.6	2.4	3.2	4.0	4.8	5.7	6.5
b	@ 4 % moisture		5.6	8.4	11.2	13.9	16.7	19.5	22.3
c	@ 8 % moisture		11.6	17.5	23.3	29.1	34.9	40.7	46.6
d	@ 12 % moisture		18.3	27.4	36.5	45.6	54.8	63.9	73.0

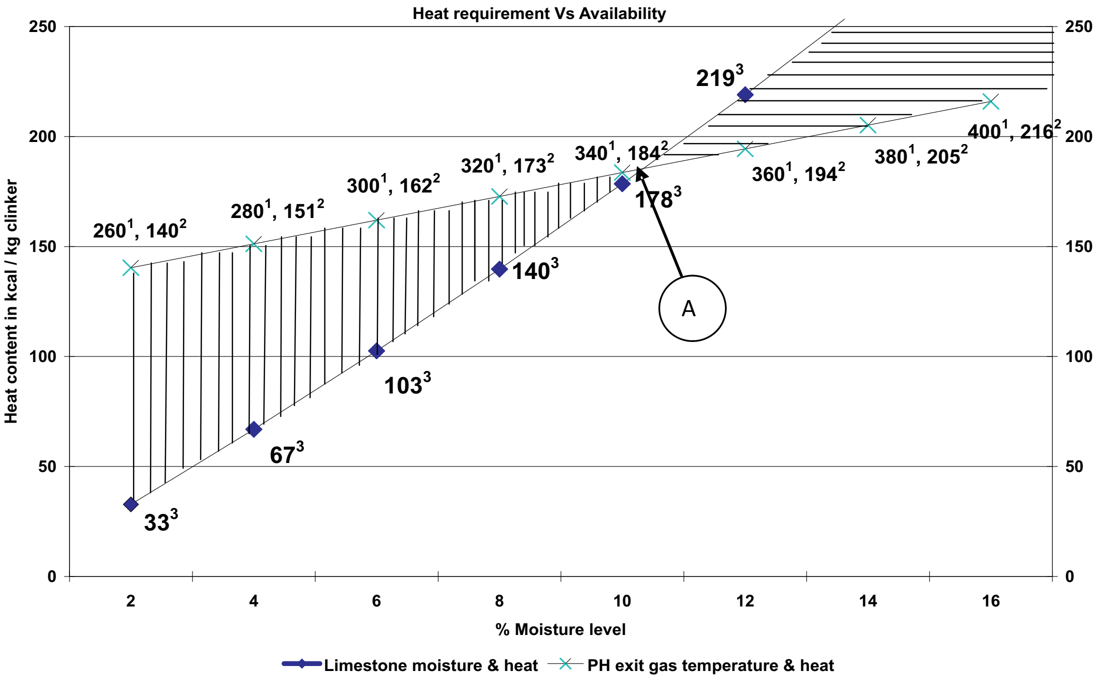
Heat requirement for Raw mill



Considering the fact that 3000 TPD kiln of 4 stage has heat availability of 23.8 MKcal /hr (from graph), the cement plant can handle moisture content of 10% and there will not be any extra / excess heat available. On the other hand if the limestone moisture is less than 4 % then the heat requirement will be around 5.6 Mkcal /hr and hence 18.2 Mkcal / hr (23.8 – 5.6) will be available for coal mill and waste heat recovery.

This relationship between minimum heat required and the preheater exit temperature is represented in the following graph.

The graph gives the correlation between the heat content available (kcal / kg clinker) in the preheater gas for different preheater outlet temperatures (Deg C) and the heat required for Raw mill (kcal / kg clinker) for different lime stone moisture levels. The assumption made is the preheater gas volume is about 1.5 Nm^3 / kg clinker.



Notes :

1. 260[1] - To be read as preheater exit gas temperature 260 Degree Centigrade.
2. 140[2] – To be read as heat content available in the preheater gas in kcal / kg clinker
3. 33[3] - To be read as heat requirement for raw mill @ 2 % moisture level in kcal / kg clinker

The intersecting point (Point A) at 190 kcal / kg is the maximum point at about 340 DegC and 10% moisture. From this curve the following conclusions can be made:

 - If the operating conditions are falling under this region of vertical lines it means that waste heat is available for recovery

- If the operating conditions are falling under this region of horizontal lines it means that waste heat is not at all available and we need to provide extra heat in addition to heat in preheater gas to raw mill.

- If the preheater exit temperature is less than 340, waste heat is available only if the moisture is less than 10 %.
- For 4 % moisture content heat requirement is 67 kcal / kg clinker hence waste heat is available with almost entire range 260 deg C (7 stage) to 400 deg C (4 stage - old design). Higher the temperature more will be the heat available for waste heat recovery.
- For moisture more than 10% we need to maintain minimum 340 Deg C at preheater outlet temperature even without waste heat recovery.

Data corresponding to the graph:

Another area of heat requirement in the cement manufacturing process is the heat required for grinding cement additives. The following tables gives the various additives used in the cement manufacture during cement grinding stage with their characteristics:

Heat requirement for Various Moisture levels									
Moisture in Limestone	%	2	4	6	8	10	12	14	16
Heat required	Kcal / kg clinker	32.8	66.9	102.5	139.7	178.5	219.0	261.5	306.0

Heat available at different preheater exit temperatures									
Preheater exit temp	Deg C	260	280	300	320	340	360	380	400
Heat available	Kcal / kg clinker	140.4	151.2	162.0	172.8	183.6	194.4	205.2	140.4

Hence it can be concluded that moisture level in the limestone deposit play a major role in installing WHR technology by affecting the heat availability in the preheater gas.

2.1.3 Heat requirement for Cement Additives:

Another area of heat requirement in the cement manufacturing process is the heat required for grinding cement additives. The following tables gives the various additives used in the cement manufacture during cement grinding stage with their characteristics:

Characteristics of Cement Additives (other than Limestone)				
Sl no	**Material**	**% of addition in cement**	**% moisture level**	**Heat requirement**
1	Gypsum	3- 5 %		
A	Chemical		8 - 20	Met from grinding & Clinker heat
B	Salt pan		5 – 8	
C	Mineral		3 – 10	
2	Fly ash	15-35 %		
A	Dry fly ash		<2.0 %	Not needed
B	Wet fly ash		15.0 – 30.0 %	**Extra Heat required**
3	Slag	35-65%	<12%	**Extra Heat required**

It is evident from the table that the plants which are using the cement additives such as wet fly ash and slag necessarily need heat for removing the moisture as follows:

- For Wet fly ash 95 kcal of heat is needed for every kg of cement considering 30 % wet fly ash addition & 25 % moisture in fly ash & evaporation heat of 950 kcal / kg water
- For slag 65 kcal of heat is needed for every kg of cement considering 50 % wet fly ash addition & 12 % moisture in fly ash & evaporation heat 950 kcal / kg water

In most of the cement plants cooler vent air is used for this application and coal fired / HSD fired hot air generator is also used.

2.1.4 Quality / grade of heat:

Heat transfer is a function of both quantity of hot fluid and temperature difference between the two fluids entering the Waste Heat Recovery Boiler or any heat transfer equipment.

$$\mathbf{Q \ \alpha \, M \, , \Delta T}$$

Where,

Q is the rate of heat transfer in kcal /hr or kJ / hr

M is the quantity of hot fluid, kg /hr or Nm^3 /hr

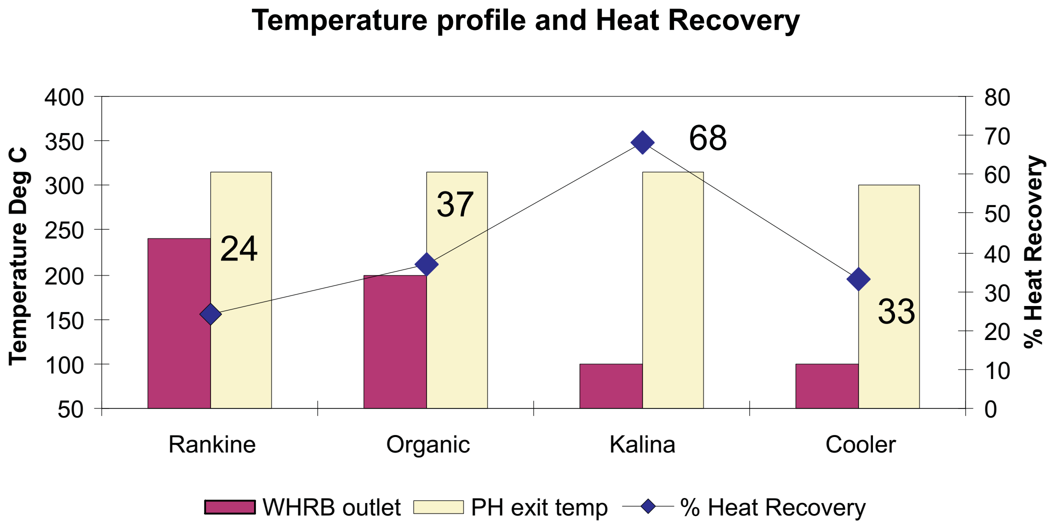
ΔT is the temperature difference between the two fluids

The improved design characteristics of preheater with effective heat transfer have resulted in the reduction of exit gas temperature. As discussed already, temperature available in the 5 stage preheater varies between 290 to 320 deg C depending on capacity utilization, operating efficiency, dust concentration.

With the available technology in Waste Heat Recovery such as Rankine, Organic Rankine (more details of WHR technologies are highlighted in chapter 5 of this report), recovery of heat up to temperatures of 240 Deg C and 200 Deg C respectively is possible in the preheater section.

The variation in the preheater exit temperature would be generally within +/- 5 deg C during normal running as the other process parameters like oxygen content, kiln feed are maintained constant.

Cooler exit temperatures, on the other hand, will vary ± 20 Deg C and the temperature range is about 280 to 350 deg C. This heat content also varies greatly as it is affected by Clinker dust carry over, clinker bed thickness, clinker quality which does not remain constant.



The graph shows the recovery of heat from various technologies for the same preheater outlet temperature of 316 Deg C (5 stages). Cooler exit gas is considered as the preheating source in combination with the preheater waste heat recovery boiler and hence 33 % heat recovery is considered for cooler air for all the systems.

Most the clinker manufacturing units in India have 2 and more kilns in the same location or site to meet the clinker demand. It may be noted that though the heat availability in individual kiln / cooler may be less, the total heat availability in the locating including all the kilns may work out a sizable quantity to work out waste heat recovery potential.

2.1.5 Presence of dust

The kiln feed enters the riser duct (connecting duct) coming from cyclone stage 2 and is carried by the gas to top stage cyclone where it is separated. Raw meal dust is carried down wards and the gas from cyclone 1 will go to preheater fan.

Depending on the efficiency of the top stage or Cyclone-1, part of the kiln feed will be going along the gas stream. This adds on to the specific heat consumption as the heated material is leaving the kiln system and also increases the power consumption of the preheater fan as the presence of dust increases the density and pressure drop.

Dust also results in formation of coating in the preheater fan impeller during operation due its clay content, though this phenomenon is observed in a particular temperature range (more than 320 deg C) the severity of the problem is large to the extent that is results in stoppage of the kiln to clean the coating to avoid damage to the preheater fan machinery due to excessive vibration in the enough to stop the plant.

The cyclone efficiency varies between 88 % to as high as 97 % resulting in dust concentration to vary from 125 grams / Nm3 to 35 grams / Nm3. Another characteristic of this dust is that, it is too fine than the kiln feed itself as it is exited from a high efficiency cyclone.

The following table gives the characteristics (size) of the kiln feed and preheater dust.

	Particle size, µm	**5**	**10**	**20**	**45**	**63**	**90**	**212**
% cumulative weight (passing)	Kiln feed, Plant A	11	22	42	63	72	89	99
	PH outlet dust, Plant A	25	39	66	83	91	100	100

Influence of dust in waste heat recovery

- Presence of dust will affect the heat transfer rate by forming coating over the heat transfer areas in the Waste Heat recovery Boiler which in turn will affect the efficiency of the cycle.
- Presence of dust can result in abrasion there by failure of tubes / heat transfer equipment
- Dust may form coating / blockage

Problem of dust can be handled by

- Improving the efficiency of the top stage cyclone in the case of preheater
- Reducing the aeration velocity at the top of clinker bed in the case of cooler by increasing the grate area or maintaining optimum cooler loading
- Installing pre expansion chambers which will help to remove the bigger size particles
- Improving the distribution of the gas inside the Waste Heat Recovery Boiler (WHRB) to maintain uniform dust concentration and gas velocity and to avoid excessive wear in any particular location due to turbulence
- Carefully designing the WHRB such that the gas velocity is within acceptable range

2.1.6 Water Availability for waste heat recovery

Typically cement manufacturing process with dry technology does not require any water directly for the process except the case that water is used for reducing the gas temperature in the preheater side (if the heat is not used for raw mill / coal mill) in the gas conditioning tower (GCT) and in the cooler & cement mill to control the exit temperature of the gas stream.

Water is used for cooling purpose – mechanical parts like bearings etc., and dust suppression and domestic usage. Typically for a 1.0 MTPA plant fresh water requirement is about 300 to 400 m3 /day depending on the hardness of water, climate and process as mentioned earlier excluding the captive power plants installed in the units.

Majority of the Indian cement plants have their own coal based captive power plants to meet the power demand of the cement process as mentioned earlier require water to the tune of 4 – 6 m3 / hr / MW if water cooled condenser is used. In the areas where water scarcity is prevailing or cost of water is high plants have installed air cooled condenser which consumes only 0.3 to 1.0 m3/ hr / MW with little drop in power generation capacity.

Waste heat recovery power plant with Rankine cycle will also be requiring similar volumes of water. Hence the additional water requirement can be handled by the existing set up or the plants can adopt air cooled condenser as the alternate option when availability of water becomes a criteria.

2.1.7 Lay out constraint & down time for hook up

Locating of WHRB systems near the preheater area could be one of the challenging factors that may arise while considering recovery for old plants. Preheater side WHRB will be under heavy suction (about 450 to 600 mm WC below atmosphere pressure) and it will be better to have the WHR boiler near to the preheater tower to avoid the false air ingress into the system and to reduce the auxiliary / additional power consumption that may arise due to additional length.

Excellent demand prevailing throughout the year has tightened the shut down time / Maintenance time available for the kiln section in the Indian Cement industry. Most of the Indian Cement plants have the kiln running hrs more than 8000 hrs per annum and availability as high as 93 % even with 100 -120 % capacity utilization.

Any hook up of WHR system with the plant has to be done within 15 days of annual shut down which calls for exhaustive planning and execution, requirement of additional resources such as machinery etc.

3 WASTE HEAT RECOVERY TECHNOLOGIES FOR CEMENT INDUSTRY

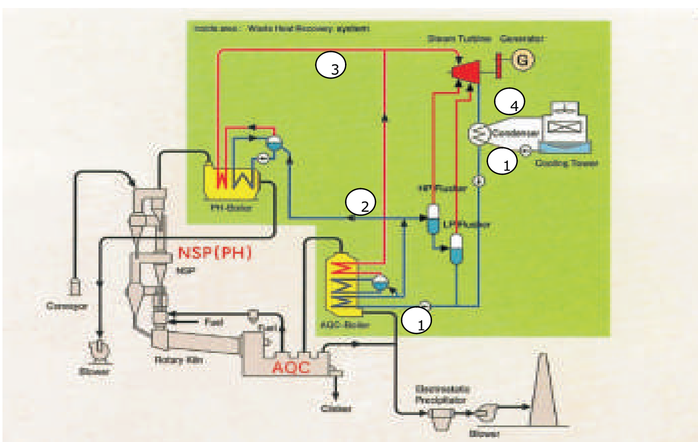
3.0 Types of WHR technologies

The following are the types of WHR technologies available / used by cement plants for generating power from waste heat sources such as hot gases from the clinker cooler, the pre-heater exhaust and DG exhaust.

3.1 Rankine Cycle

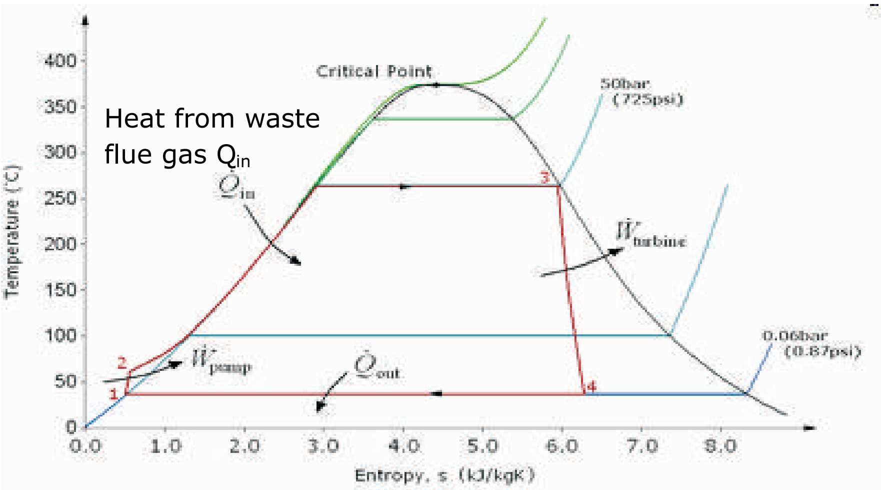
Rankine cycle is a thermodynamic cycle which converts heat into work (power in this case). The heat is supplied externally to vaporize the working fluid (water) in the boiler into high pressure steam which expands in the turbine to produce power by rotating it. The expanded vapor is condensed to low pressure liquid in the condenser and is recycled back to the boiler for continuing the cycle.

The waste heat recovery (WHR) system, effectively utilize the available waste heat from exit gases of pre-heater and clinker cooler. The WHR system consists of Suspension pre-heater (SP) boiler, Air Quenching Chamber (AQC) boiler, steam turbine generator, distributed control system (DCS), water-circulation system and dust-removal system etc. The figure below demonstrates the working of Rankine cycle



Source: Kawasaki technology for WHR

The Chart below exemplifies the Entropy diagram of Rankine cycle



3.1.1 Working Principle

Process 1-2: The working fluid (i.e. water) is pumped from low to high pressure, as the fluid is a liquid at this stage the pump requires little input energy.

Process 2-3: The high pressure liquid enters into AQC & SP boiler where it is heated at constant pressure by using waste hot flue gas from clinker cooler and pre-heater respectively to become a dry saturated vapour.

Process 3-4: The dry saturated vapour expands through a turbine, generating power. This decreases the temperature and pressure of the vapour, and some condensation occurs.

Process 4-1: The wet vapour then enters a condenser where it is condensed at a constant pressure and temperature to become a saturated liquid. The pressure and temperature of the condenser is fixed by the temperature of the cooling coils as the fluid is undergoing a phase-change.

3.1.2 Features of Rankine Cycle system

The following are the features of Rankine cycle system for WHR applications:

- At the temperature profiles available in cement industry for WHR, these systems would be operating at lower pressures
- Among the various WHR technologies available, the power generation in this system is low
- Lesser heat recovery
- Low cost of installation
- Cycle is proven and easy to operate
- Has several installations all over the world
-

3.2 Organic Rankine Cycle (ORC)

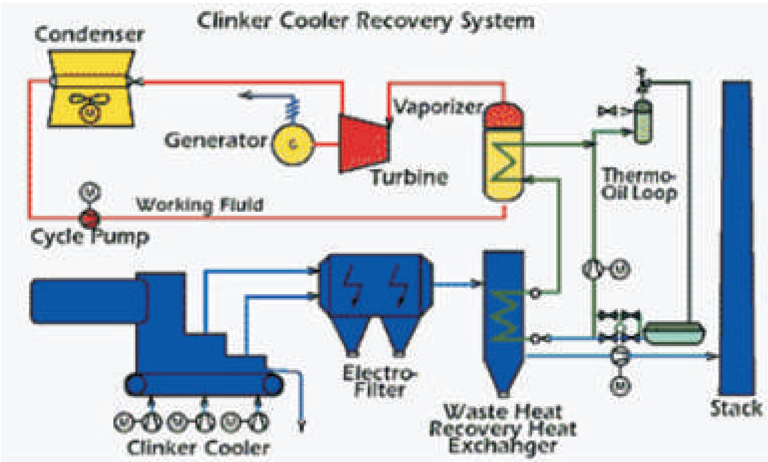
The ORC uses a high molecular mass organic fluid. It recovers heat from even low temperature sources. Due to this, it finds its applications in cement industries, geothermal, solar ponds, etc. Heat available in the low temperature gas of the clinker cooler exhaust can be recovered effectively by installing waste heat Power plant based on ORC.

This cycle is an environmentally affable and is well suited to work with lower temperatures to generate electricity on a continuous basis without interfering with the clinker production process. The low temperature heat is converted into useful work, which in-turn converted into electricity.

The ORC power plant consists of following cycles/circuits

- Clinker cooling gas exhaust cycle
- Waste heat heater with thermal oil circuit
- Pentane circuit
- Air condensing cycle

The diagram below illustrates Working of the ORC system



Source: Ultra tech – 4MW – CDM – PDD using organic Rankine Cycle Cementech – 2006 (ppt)

3.2.1 Working Principle

Clinker cooling exhaust air Cycle: In this system, the atmospheric air is drawn by the fans and is passed into the cooler for cooling the clinker. Heat exchange takes place between atmospheric air and the hot clinker. Part of the air is used for combustion of fuel in the kiln and excess air is vented into the atmosphere after dust removal in an Electro static precipitator. The waste heat available in this exhaust air is tapped in the Waste Heat Oil Heater (WHOH). The WHOH is a conventional shell and tube heat exchanger. The hot air passes through bundles of tubes consisting of low pressure thermal oil and transfers the heat to the oil.

Waste heat heater with thermal oil circuit: Due to heat exchange in WHOH the temperature of thermal oil increases approximately from 1200C to 2700C. This hot thermal oil is pumped to Pentane circuit and transfers the heat to pentane.

Pentane circuit: The pentane circuit consists of Pentane Vaporizer, Pre-heater, Turbine and Generator. The Pentane is heated from 550C to 1600C in Evaporator & Pre-heater by exchanging heat with thermal oil.

The high pressure Pentane vapor expands in turbine and the turbine in turn drives the conventional AC Generator and generates Power. The Pentane from the turbine is cooled in the Air Condensing System and re-circulated to pentane vaporizer.

3.2.2 Advantages of ORC system

- ORC uses low temperature waste heat available in clinker cooler effectively to generate electricity
- High cycle efficiency
- Zero water consumption for running the ORC, where air condensing is used
- Very high turbine efficiency (up to 85 percent)
- Low mechanical stress of the turbine, due to the low peripheral speed
- Low RPM of the turbine allowing the direct drive of the electric generator without reduction gear
- No erosion of blades, due to the absence of moisture in the vapor nozzles
- Long life
- Man power required is very less

3.3 Kalina Cycle

The Kalina cycle was developed by Dr. Alex Kalina as a means of improving the overall efficiency of combined cycle plants. The main benefit of the Kalina cycle is that the heat addition to the process happens at variable and very low temperatures. The temperature range required for the boiling of the ammonia-water mixture in the Kalina process is 900C - 1000C minimum.

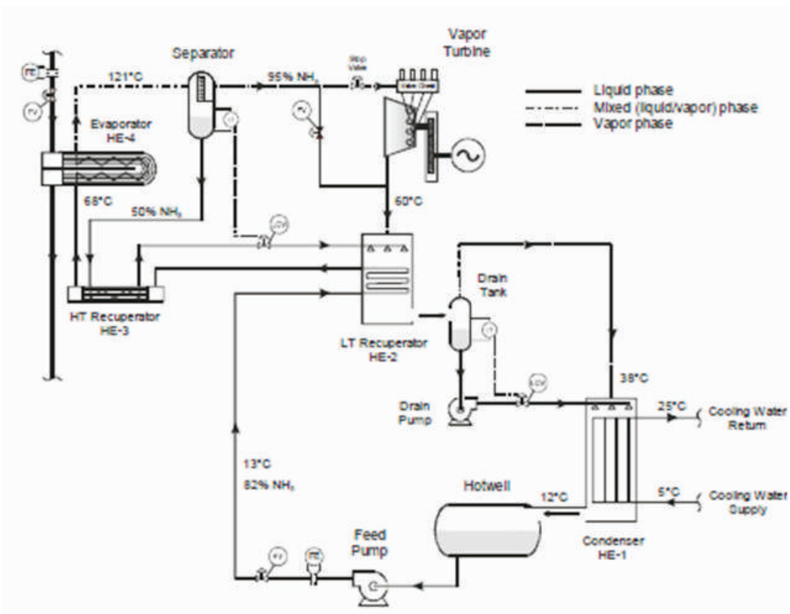
3.3.1 Components

The main components of Kalina Cycle include a vapor turbine-generator, evaporator, separator, condenser, recuperator exchangers and feed pump. The working fluid is an ammonia-water mixture. In this mixture 82% is ammonia by weight and rest is water.

The conspicuous efficiency advantage characteristic of the Kalina cycle is realized from the heat exchange processes of the heat acquisition in the evaporator and the heat rejection in the condenser. Additional efficiency is achieved by the recuperator exchangers.

These gains are made possible by the variable boiling and condensing characteristics of the ammonia-water mixture working fluid as it varies in concentration at different points in the cycle.

The diagram below gives the schematic layout of the Kalina cycle



Source: Notes from the North: a Report on the Debut Year of the 2 MW Kalina Cycle® Geothermal Power Plant in Húsavík, Iceland

3.3.2 Working principle of the Kalina cycle

Starting at the outlet of the water-cooled condenser, the cycle working fluid is an 82% ammonia-water saturated liquid mixture at 5.4 bar and 12.4°C. This stream is pumped to a high pressure by the feed pump. The feed stream is preheated in the low temperature (LT) and high-temperature (HT) recuperators to 68°C before entering the evaporator.

In the evaporator, the working fluid is heated to 121°C against a design brine temperature of 124°C. The ammonia-water is partially vaporized to a quality of 75 percent (75% vapor, 25% liquid). This mixed-phase fluid is sent to the separator where the vapor component (high in ammonia) is separated from the liquid component (low in ammonia).

The high-pressure rich saturated vapor from the separator drives the turbine as the vapor rapidly expands and cools to a low-temperature, low-pressure exhaust. The lean saturated liquid from the separator is cooled in the HT recuperator where the sensible heat energy in this stream is used to preheat the feed stream to the evaporator. The flow of this fluid is controlled by a level control valve which maintains the liquid level in the separator. This liquid flow is then directed to the inlet of the LT recuperator where it combines with the rich vapor exhaust from the turbine. This liquid stream is sprayed into the exhaust vapor stream, and the two streams unite to reform the basic fluid mixture of 82%. The temperature of the liquid stream from the HT recuperator is 48°C, and vapor stream from the turbine is 60°C.

These two streams, now as a mixed-phase fluid, are cooled in the LT recuperator where the latent and sensible heat energy is used to preheat the feed stream. As this fluid cools, some of the vapor stream from the turbine condenses. The liquid that exits the LT recuperator is collected in a drain tank while the remaining vapor goes directly to the condenser. At this point, the vapor has high ammonia content, while the liquid in the drain tank has low ammonia content. The temperature of both the vapor and liquid streams is 38°C.

The liquid in the drain tank is pumped up to the inlet of the condenser to be sprayed into the vapor stream. Spraying this lean liquid into a rich vapor aids the condensation of the vapor by absorption process. The process is repeated in a closed loop arrangement.

3.4 Performance of WHR units

Performance of WHR plants depends upon the following parameters

- Flow rate of flue gas (waste heat source)
- Inlet temperature of the flue gas into the WHR system
- Concentration of dust in the gas
- Limitation in the outlet temperature of the gas from WHR system (Requirement of heat for raw material to remove moisture)
- Variation in the quantity and inlet temperature of the flue gas due to process fluctuations
- Failure of the running equipments
- Breakdown in the kiln section
- Hook up time for the WHR system after starting the kiln
- Depends upon the operation and maintenance of the WHR system
- Availability of the skilled workers

4 WHR INSTALLATIONS IN INDIA

4.1 Installation / Technology adopted

There are only few cement industries in India with waste heat recovery technology for power generation. The following are the cement plants using the WHR technology

1. India cements, Vishnupuram
2. JK cements, Nimbahera
3. KCP cements, Macherla
4. Shree cements, Beawar
5. Ultra tech cement (APCW), Tadipatri

4.1.1 The India Cements Ltd, Vishnupuram:

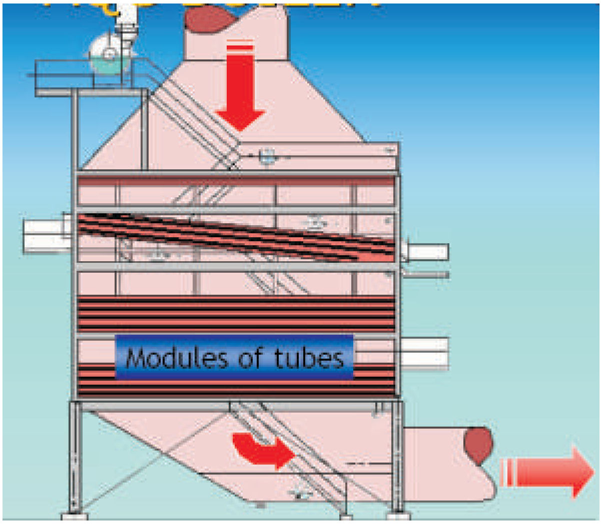
The India Cements Ltd (ICL) has one of its units located at Vishnupuram, Wadapally, Nalgonda District in Andhra Pradesh. The plant has 2 kiln lines of capacities for producing 1800 & 5200 TPD. The plant also has a captive power generation capacity of 16.0 MW diesel generators for standby.

ICL has installed for the first time in the country, a 7.7 MW WHR power plant based on **"Rankine Cycle"** to utilize waste heat available in the clinker cooler and pre-heater.

The Kawasaki heavy industries, Japan are the waste heat recovery supplier for the plant. The project was partly funded from the New Energy Industrial Development Organization (NEDO) of the Government of Japan and was envisaged as a Model Project for waste heat recovery in the Indian cement industry. The temperature of the waste heat gas coming out from the pre-heater & clinker cooler is 350 0C & 360 0C respectively.

The technology encompasses two 15 bar waste heat recovery boilers of 28 TPH and 14 TPH capacities. The steam generated from these boilers is passed to a 7.7 MW turbine generator with the resultant electricity fed to the cement plant. The boilers are installed at the pre-heater exhaust (PH boiler) and at the cooler exhaust from the kiln (AQC boiler). The boilers and turbine are manufactured by Kawasaki of Japan.

The PH boiler is a forced circulation type boiler with a capacity of 28 TPH. The exhaust gas of the pre-heaters are 350oC and once cooled in the boiler exit at 220oC and are then used in raw material drying. Due to the high dust content of the pre-heater gases and their adhesive properties a hammering device is installed in the boiler to remove the dust that adheres to the boiler surfaces and improve heat exchange. The AQC boiler utilizes gases from the cooler attached to the kiln; these gases enter the boiler at 360oC. These gases typically have a high content of clinker dust and therefore a pre-dust collector is introduced before the gases enter the boiler.



4.1.2 JK Cement, Nimbahera

JK Cement Ltd has its manufacturing facility located at Nimbahera, Chittorgarh District, Rajasthan. The facility commenced its operations in 1974 and has a current capacity of 2.8 MTPA. Three kilns are in operation producing clinker at 1200, 1800 & 4800 TPD.

To effectively utilize the waste heat of the exit gases from pre-heater, clinker cooler and diesel generators, the plant team has installed a waste heat recovery captive power plant consisting of WHR boilers, steam turbine and generator. In the plant there are 6 WHR boilers (4 for the pre-heater exit gas, 1 for clinker cooler and 1 for DG exit gas) and 13.2 MW steam turbine generator.

Waste heat recovery system by utilizing pre-heater exit gases

The average temperature of the exit gases from the pre-heater is around 3600C and it would reduce to 220 0C at the outlet of the WHR boiler. The WHR boiler would be installed between the outlet of pre-heater top cyclone and the inlet of pre-heater Induced Draft (I.D) fan.

The boiler installed in pre-heater line is designed to have enough heat transfer surface by the arrangement of number of tubes which are provided with a forced de-dusting equipment to avoid coating trouble of tubes due to high dust concentration in the pre-heater exit gases.

Waste heat recovery system by utilizing AQC exit gases

The temperature of the exit gases from the clinker cooler is expected to be around 300 0C which would reduce to 80 0C at the outlet of the boiler. The boiler would be installed at the outlet of the AQC exit gas line and recovers the heat from the cooler exit gas before releasing into atmosphere. Specially designed finned tubes are adopted as heat exchanger tubes for the boiler which is compact in size.

Waste heat recovery system by utilizing diesel generator exit gases

The WHR boiler would be installed at the outlet of diesel generator exit gas system and recovers the heat from the exit gases before the release to the atmosphere. Specially designed finned tubes are adopted as heat exchanger tubes for the boiler. Considering the efficiency of boiler, the exit gases from DG sets are induced into boiler by I.D. fan, installed in the downstream of the boiler. No dust is contained in the exit gases but soot blowers with steam jet are installed to clean the tubes periodically.

4.1.3 KCP cements, Macherla

KCP cements are located in Macherla, Guntur district, Andhra Pradesh. The plant is having 1 kiln line of capacity for producing clinker at 1800 TPD.

The plant is having captive power generation capacity of which run on diesel generators. But the captive power generation is used only when the grid power fails/emergency.

The plant is producing 2.35 MW power by using waste heat available in the clinker cooler and pre-heater using “Rankine Cycle” for the power generation with the waste heat available in the clinker cooler and pre-heater.

The system was supplied by M/s. Transparent Energy Systems pvt. Ltd. The temperature of the waste heat gas coming out from the pre-heater & clinker cooler is 335^{0}C & 300^{0}C respectively.

The hot gases from clinker and pre-heater are passed through the waste heat recovery boiler (WHRB1 & WHRB2) respectively. Water is circulated into the WHRB. Latent heat from the hot gas is transferred to the water and is converted to steam. The steam is expanded in the turbine and then it is condensed and the condensed water is passed through the WHRG and the process repeats.

4.1.4 Shree Cement Ltd, Beawar

Shree Cement Ltd (SCL) has installed a waste heat recovery system in its Unit-1 at Beawar to recover the waste heat from the pre-heater exit gases, currently being dissipated into the atmosphere, for steam generation. SCL has integrated the waste heat recovery system with its captive power plant and the steam generated in waste heat recovery is utilized for pre-heating the feed water in the LP & HP heater of existing power plant.

Waste heat recovery system generates steam of 27.6 TPH at a temperature of 375 0C and pressure of 27 kg/cm2. This steam is utilized in the captive power plant for feed water preheating.

With and without this waste heat recovery system, the difference in power output from the captive power plant is about 5-6 MW. The fuel saving from this project is anticipated at over 20000 tons per annum and carbon dioxide emission reduction would be over 76000 tons per annum.

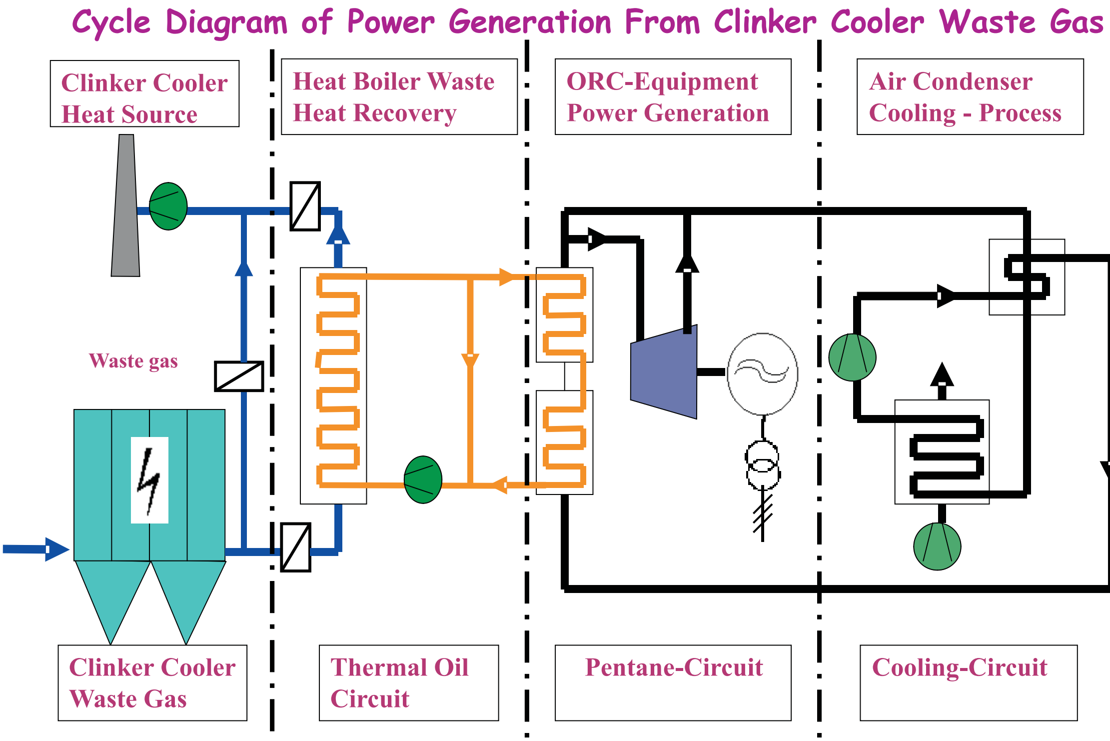
4.1.5 Ultratech cement (Andhra Pradesh cement works), Tadipatri:

Ultratech Cement Ltd, Tadipatri is the first plant in India to install “Organic Rankine Cycle” technology based Waste Heat Recovery project. The advantages of Organic Rankine Cycle system are:

- High vapour turbine efficiency at low speed
- Condensing near atmospheric pressure

- Smaller size air cooled condenser
- Moisture free turbine expansion

This system was installed to recover the waste heat available in the clinker cooler. The plant is producing 4 MW power by using waste heat available in the clinker cooler.



There were two agencies involved in this project. Waste heat recovery unit was supplied by Transparent Energy Systems, Pune and Energy Converter was supplied by ORMAT Systems Limited, Israel.

The temperature of the cooling gas coming out from the electro static Precipitator is at 320^{0}C and the flow rate is 505 T/hr.

The high pressure Pentane vapor expands in the two stage turbine and the turbine in turn drives the conventional 6.6 kV AC Generator and generates Power. The Pentane from the turbine is cooled in the Air Condensing System. The power plant is generating 21.8 million units per annum and is consumed in plant itself.

Waste Heat Recovery Unit Input Parameters (Design):

- Mass Flow rate of gas : 485 Tons / Hr
- Volumetric Flow : 375,500 Nm3/ Hr
- Inlet temperature of Gas : 320 °C
- Outlet temperature of gas : 150 °C
- Max. Dust loading : 90 mg / Nm3
- Ave. Dust particle size : 45 Microns
- Air pressure after ESP : -30 mm WC

The total investment required for the project was Rs 310 Million.

4.2 Challenges faced by cement plants installing WHR systems

- Significant In house Engineering requirement
- WHR - Vendor identification in India
- Execution by in house contracts
- Interfacing between OEC & WHR system
- Location of unit to minimize distances – layout considerations
- Hook up during Plant shutdown

4.3 Technical & Financial barriers in Operation

- Presence of dust in flue gas
- Hot gas availability & Load factor
- Adaptability of existing equipment
- False air ingress and addition power consumption
- Non availability of Indigenous suppliers & Service providers
- Non availability of funds and lack of financial support

5 BARRIERS IN ADOPTING WHR SYSTEMS IN INDIAN CEMENT INDUSTRY

The concept of WHR in Indian cement industry has been under discussion over the last several years. Various barriers were evaluated and the cement industry today is reasonably aware of the benefits and cautions to be taken up for successful implementation of WHR systems. This understanding has been through various initiatives – detailed discussions with technology providers, case studies of installations globally and nationally, and a thorough understanding of existing cement operation and integration of WHR systems.

Adoption of WHR system in existing cement manufacturing facility poses multiple barriers and the implementation team should be equipped to overcome these carriers. Some of the barriers are as under:

5.1 Technical barriers in Operation & the possible solutions

5.1.1 Presence of dust in flue gas

- Dust content of the exit gases from the cement manufacturing process, is high with typical values of 30 to 100 g/Nm3.
- The preheater dust is sticky in nature, forms coating over the surface of the heat transfer tubes in the boiler. This affects the heat transfer and reduces the power generated.
- The Clinker dust in the cooler exit air is highly abrasive in nature, erodes the heat transfer area affecting the operation of the system.

The problems due to dust is handled in the following ways:

i. Preheater dust can be largely reduced by installing high efficiency cyclone at the top stage or improving the efficiency of the existing cyclones.

ii. Altering the design of the heat transfer surfaces (vertical tubes in place of horizontal tubes) to avoid coating.

iii. Installation of dust separation chamber like ESP incase of cooler dust.

iv. Considering adequate margin of safety to take care of erosion and abrasion due to dust

v. Installation of dust removal or cleaning mechanisms like tumbling hammer.

5.1.2 Hot gas availability & Load factor

Uninterrupted supply of waste gases from clinkerization process at consistent quality (sufficient temperature) is needed for trouble free operation of waste heat recovery system.

- As the Waste heat in exhaust gases from the clinkerization process is used in drying of raw material and coal, availability of Waste heat to the WHR is affected due to variation in moisture levels in raw material and coal.
- Variations in the process, changes in production level affect the quality & quantity of flue gas resulting in variation of the power generation in WHR.
- In general it takes about 4 – 24 hours to achieve the rated production level in the kiln system after any planned or unplanned shutdown depending on the nature and time of shut down. This inurns affect the quantity of waste heat from the kiln and hence the performance of the system.

Variations in the performance of the WHR system due the above problems can be minimized to certain extent by taking due care while designing the system with respect to moisture level. Improved automation and skilled manpower can help to achieve maximum power generation in line with the variations in the process parameters.

5.1.3 Adaptability of existing equipment

Installation of WHR system in the cooler and preheater side will call for capacity enhancement or additional load on the existing equipments such as preheater fan, cooler vent fan etc to handle WHR system without affecting the present production levels. This is due to the additional pressure drop, false air ingress due to installation of WHR systems.

If adequate margin is not available, these equipments are to be considered for replacement with revised technical specification and the economics have to be taken care.

5.1.4 False air ingress and additional power consumption

The preheater boiler is operating under negative suction created by the preheater fan for the passage of combustion gas produced in the kiln and calciner. This negative pressure can result in atmospheric air ingression, if holes are present.

This atmospheric air ingression (known as false air) reduces the heat content, quantity of steam generated and increases the power consumption of fan. Therefore, air infiltration into the boilers will affect economics of WHR by increasing its operation costs.

Installation of additional equipments and pressure drop increases the specific power consumption of the process and the same has to be taken into account for economics of power generation.

Standard operating procedures with close monitoring of false air ingression, auxiliary power consumption and power consumption for clinker will eliminate the above problems.

5.1.5 Non-availability of Indigenous suppliers & Service providers

Limited number of suppliers and non-availability of Indigenous suppliers / service providers for installation, operation, maintenance of WHR system is one of the major challenging factors affecting the installation or adoption of the technology. Creating the awareness about the market potential and the overall benefits, support from the Government & financial agencies can attract the indigenous supplier towards this market.

5.2 Financial barriers

One of the major financial barriers as far as adoption of WHR systems is concerned is the large capital requirement and unattractive funding mechanisms. India today has 5 WHR systems installed and running as on date. Almost all the funding for these projects came from the company's internal resources. Companies which are cash-rich are in a position to adopt WHR systems today.

Another major driver for the installation of WHR systems in Indian cement industry is the benefit the company can tap from the international carbon markets through the Clean Development Mechanism (CDM) route. All the projects implemented till date have registered / in the process of registering for CDM benefits. Low IRR compared to the benchmark IRR values has been one of the major factors substantiating financial barrier for WHR based CDM projects.

6 ESTIMATION OF WASTE HEAT RECOVERY POTENTIAL

6.0 Basic data & Assumptions:

1. Kiln capacity : 3000 tonnes per day
2. No of stages in the preheater : 5
3. Preheater exit gas details
   a. Volume (m_{PH}) : 1.5 Nm^3 /kg clinker
   b. Specific heat capacity(CP_{PH}): 0.36 kcal / kg / Deg C
   c. Temperature T_{PH1}: 316 Deg C
4. Cooler exit gas details
   a. Volume (m_C): 1.0 Nm^3 /kg clinker
   b. Specific heat capacity C_{PC}: 0.317 kcal / kg / Deg C
   c. Temperature T_C : 300 Deg C
5. Limestone moisture content LM : 2 %
6. Raw mill running hrs : 22 hrs / day
7. Kiln running days per annum : 335 days
8. Heat transfer efficiency of WHR boiler - EFF_{WHR} : 85 %
9. Heat transfer efficiency of AQC boiler – EFF_{AQC}: 85 %
10. TG system efficiency EFF_{TG} : 33 %
11. Specific heat consumption : 700 kcal / kg clinker
12. Raw coal moisture : 15 %
13. Raw meal to clinker factor : 1.55

14. Heat requirement for moisture in raw mill & Coal mill: 950 kcal / kg water

15. Calorific value of fine coal used in the : 5000 kcal / kg coal

16. Coal mill running hrs per day : 20

17. PH gas temperature at WHRB outlet T_{PH2}: 240 Deg C

18. Cooler exit temperature at AQC boiler outlet T_{C2} : 120 deg C

6.1 Calculations

1. Heat available in the preheater gas :

Q_{PH}	: $m_{PH} * CP_{PH} * T_{PH1}$
	: 1.5 * 0.36 * 316
	: 170.6 kcal / kg clinker

2. Heat required for Raw mill

a. Raw mill capacity	: 3000 * 1.55 * 24 / 22
	: 5073 TPD
	: 211 TPH
	: 1.688 kg / kg clinker
b. Moisture in raw mill	: [211 * 100 / (100 - 2)] – 211
	: 4.3 TPH
	: 34.4 kg / MT clinker
c. Heat requirement for raw mill	: 34.4 * 950 / 1000
	: 32.7 kcal / kg clinker
	: 33 kcal / kg clinker

3. Heat requirement for coal mill

a. Coal requirement

Specific coal consumption	: 700 / 5000
	: 0.14 kg coal / kg clinker
Coal mill capacity	: 0.14 * 125 * 24 / 20
	: 21 TPH

4. Moisture evoparation in coal mill : {21 * 100 /(100 – 15)}– 21

: 3.7 TPH

: 30 kg / MT clinker

5. Heat requirement for raw mill : 30 * 950 / 1000

: 28.5 kcal / kg clinker

: 29 kcal / kg clinker

Excess heat available in the preheater:

Heat available in the PH gas minus heat required for Coal mill & raw mill

Excess heat available (preheater) : 170.6 – (29 + 33)

: 108.6 kcal / kg clinker

6. Heat available in the Cooler exit gas :

Q_C : $m_C * C_{PC} * T_C$

: 1.0 * 0.317 * 300

: 95.1 kcal / kg clinker

7. Total excess or waste heat available :

Extra heat available in the preheater + cooler

: 108.6 + 95.1

: 203.7 kcal / kg clinker

8. Heat recoverable in Preheater side Boiler

Q_{WHRB} : $m_{PH} * C_{PPH} * (T_{PH1} - T_{PH2})$

: 1.5 * 0.36 * (316 – 240)

: 41.0 kcal / kg clinker

9. Heat recoverable in Cooler side Boiler

Q_{AQC} : $m_C * C_C * (T_{c1} - T_{c2})$

: 1.0 * 0.317 * (300 – 120)

: 57.0 kcal / kg clinker

Heat available to steam for power generation :

: Q_{WHRB} * EFF_{WHR} + Q_{AQC} * EFF_{AQC}

: 41.0 * 0.85 + 57.0 * 0.85

: 83.3 kcal / kg clinker

10. Power generation possible :

Heat available in the steam

TG efficiency : 83.3 * 0.33

: 27.5 kcal / kg clinker

: 0.03197 kWh / kg Clinker

: 31.97 kWh / MT of clinker

: 4.0 MW

11. Water requirement for Water cooled condenser :

Heat to be removed in the condenser :

: 83.3 * (100 – 33)/ (0.85*100)

: 66 kcal / kg clinkerMake up

Water requirement : 56 / 540

: 0.1222 kg water / kg clinker

: 15.3 TPH

: 3.8 MT /MW

7 MAJOR SUPPLIERS AND THEIR SYSTEMS

7.0 Suppliers of Rankine Cycle WHR systems

Kawasaki plant systems

Kobe Head Office
1-1 Higashikawasaki-cho 3-chome, Chuo-ku,
Kobe, Hyogo 650-8670, Japan
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http://www.khi.co.jp

Transparent energy systems private limited

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PUNE-411 037. INDIA.
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e mail: info@ormat.com, http://www.ormat.com/

7.1 Kalina Cycle Suppliers

Siemens AG

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http://w1.siemens.com/entry/cc/en/

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9 CONCLUSION

The Indian cement industry is keen to adopt WHR systems in a big way. The technical specialization within the Indian cement industry is advanced; the plant operating team can overcome the technical barriers analyzed. The major deterrent in faster adoption of WHR systems has been the financial barrier.

The potential for WHR in Indian cement industry is very high. In conclusion, CII's estimates indicate that the waste heat recovery potential in Indian cement industry is close to 415 MW while the installed capacity till date is only about 20 MW. This indicates the huge opportunity for adoption of waste heat recovery in Indian cement industry.

The manual focuses on major WHR technologies successfully employed in the world and India in particular.

a) Description of technology

b) WHR installations in Indian cement industry

c) Major suppliers and contact information

d) Major technical or operating problems incurred

   i. To identify existing applications of WHR in India; successes and problems.

   ii. To identify barriers to deployment of WHR technologies; past, current and future, including water requirement, and its impact on the project both financial and technical.

e) Capital investment required (based on past installations in India)

We are sure that the Indian Cement plants will make use of the waste heat available and install WHR systems. This will substantially reduce the operating cost. CII looks forward for more and more installations of Waste Heat Recovery system across Indian Cement industry.

About CII

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the growth of industry in India, partnering industry and government alike through advisory and consultative processes.

CII is a non-government, not-for-profit, industry led and industry managed organisation, playing a proactive role in India's development process. Founded over 113 years ago, it is India's premier business association, with a direct membership of over 7500 organisations from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 83,000 companies from around 380 national and regional sectoral associations.

CII catalyses change by working closely with government on policy issues, enhancing efficiency, competitiveness and expanding business opportunities for industry through a range of specialised services and global linkages. It also provides a platform for sectoral consensus building and networking. Major emphasis is laid on projecting a positive image of business, assisting industry to identify and execute corporate citizenship programmes. Partnerships with over 120 NGOs across the country carry forward our initiatives in integrated and inclusive development, which include health, education, livelihood, diversity management, skill development and water, to name a few.

Complementing this vision, CII's theme "India@75: The Emerging Agenda", reflects its aspirational role to facilitate the acceleration in India's transformation into an economically vital, technologically innovative, socially and ethically vibrant global leader by year 2022.

With 64 offices in India, 9 overseas in Australia, Austria, China, France, Germany, Japan, Singapore, UK, USA and institutional partnerships with 211 counterpart organisations in 87 countries, CII serves as a reference point for Indian industry and the international business community.

About CII-Godrej GBC

CII – Sohrabji Godrej Green Business Centre (CII – Godrej GBC), a division of Confederation of Indian Industry (CII) is India's premier developmental institution, offering advisory services to the industry on environmental aspects and works in the areas of Green Buildings, Energy Efficiency, Water Management, Renewable Energy, Green Business Incubation and Climate Change activities.

The Centre sensitises key stakeholders to embrace green practices and facilitates market transformation, paving way for India to become one of the global leaders in green businesses by 2015.

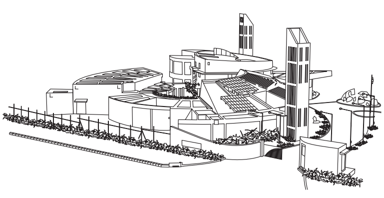
About Asia-Pacific Partnership

The Asia Pacific Partnership on Clean Development & Climate is an innovative new effort to accelerate the development and deployment of clean energy technologies. APP partners Australia, Canada, China, India, Japan, Republic of Korea and The United States have agreed to work together and with private sector partners to meet goals for energy security, national air pollution reduction, and climate change in ways that promote sustainable economic growth and poverty reduction.

The partners will also cooperate on the development, diffusion and deployment of longer-term transformational energy technologies that will promote economic growth while enabling significant reductions in green house gas intensities. The partnership will be consistent with and contribute to partners' efforts under the UNFCCC and will compliment, but not replace the Kyoto protocol.

“Foster GHG Emission Reduction Technologies in Indian Cement Industry” is an initiative of CII-Godrej GBC to carry out GHG emission inventorization in Indian Cement plants and explore & identify possible opportunities to reduce the same. This activity is supported and part funded by U.S Department of State as part of the Asia Pacific Partnership (APP) on Clean Development and Climate. This seminar is one of a number of public awareness programs planned as part of this project. For further details on this project, please get in touch with kiran.ananth@cii.in.

For more details, kindly contact



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