Heat Transfer Analysis of Recuperative Air Preheater

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***Abstract*— The recuperative air preheater is a general term used to describe any device designed to heat air before another process with the primary objective of increasing the thermal efficiency of the process. The grate preheater consists of a chamber containing a chain-like high-temperature steel moving grate, attached to the cold end of the rotary kiln. Preheater can be widely applied in the new construction and transformation of medium and large cement plant. Its main applications are in cement industries for regeneration of heat which is passed from kiln. The working principle of preheater is an amount of heat passed from the kiln line to preheater, where in preheater heat shall be raised with the help of stages done in preheater and again the maximum heat shall be reverted to the kiln as it is a regenerative process. The main issues are to Increase of production capacity, Reduction of specific heat consumption. In this work the amount of heat which is passed to air as a waste heat, that waste heat shall be recovered with the help of waste heat recovery system and making the process with the regenerative form where there shall be no wastage in the heat.In industry there are 4 stage preheater as well 5 stages preheater with that the maximum heat which is passed from kiln shall be regenerated with the help of variant flows such as conduction, convection as well as radiation. The maximum amount of heat shall be recovered through precalciner. One way to enhance the thermal efficiency of waste heat recovery is to use recuperation to recover some of the heat energy from exhaust gases. The direction of flow shall be deposited to the kiln processing and again heating process shall be done this procedure is called reheating process. Coal contribute major share of fuel used in the cement industry.**

The amount of heat recovered is calculated by different parameters such as preheater calculations, kiln calculations using the principles of conduction, convection and radiation. The method of calculations for preheater as well as kiln is to be record with the means of values which shall be taken from digital display from control room and calculations done manually. Whereas for the conduction, convection, radiation the calculations are done through Heat transfer spread sheet calculations. The various parameters which shall be calculated from the above experiments are thermal resistance, heat transfer coefficient, waste heat recovery, false air calculations. The performance of air preheater in terms of the above said parameters are presented and discussed in this thesis.

***Index Terms*— rotary kiln, modern kiln, multi-stage cyclone preheater, calciner, air duct**

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I. INTRODUCTION

An air preheater (APH) is a general term used to describe any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process. The grate preheater consists of a chamber containing a chain-like high-temperature steel moving grate, attached to the cold end of the rotary kiln. A dry-powder raw mix is turned into hard pellets of 10–20 mm diameter in a nebulising pan, with the addition of 10-15% water. The pellets are loaded onto the moving grate, and the hot combustion gases from the rear of the kiln are passed through the bed of pellets from beneath. This dries and partially calciner the raw mix very efficiently. The pellets then drop into the kiln. Very little powdery material is blown out of the kiln. Because the raw mix is damped in order to make pellets, this is referred to as a "semi-dry" process. The grate preheater is also applicable to the "semi-wet" process, in which the raw mix is made as Slurry, which is first de-watered with a high-pressure filter, and the resulting "filter-cake" is extruded into pellets, which are fed to the grate. In this case, the water content of the pellets is 17-20%. Grate preheater were most popular in the 1950s and 60s, when a typical system would have a great 28 m long and 4 m wide, and a rotary kiln of 3.9 x 60 m, making 1050 tonnes per day, using about 0.11-0.13 tonnes of coal fuel for every tonne of clinker produced. Systems up to 3000 tonnes per day were installed. The key component of the gas-suspension preheater is the cyclone. A cyclone is a conical vessel into which a dust-bearing gas-stream is passed tangentially. This produces a vortex within the vessel. The gas leaves the vessel through a co-axial "vortex-finder". The solids are thrown to the outside edge of the vessel by centrifugal action, and leave through a valve in the vertex of the cone. Cyclones were originally used to clean up the dust-laden gases leaving simple dry process kilns. If, instead, the entire feed of raw mix is encouraged to pass through the cyclone, it is found that a very efficient heat exchange takes place: the gas is efficiently cooled, hence producing less waste of heat to the atmosphere, and the raw mix is efficiently heated. This efficiency is further increased if a number of cyclones are connected.

Components Of Preheater: Kiln Fuels:Fuels that have been used for primary firing include coal, petroleum coke, heavy fuel oil, natural gas, land fill off-gas and oil refinery flare gas. High carbon fuels such as coal are preferred for kiln firing, because they yield a luminous flame. The clinker is brought to its peak temperature mainly by radiant heat transfer, and a bright (i.e. high emissivity) and hot flame is essential for this. In favourable circumstances, high-rank bituminous coal can produce a flame at 2050 °C.

Natural gas can only produce a flame of, at best 1950 °C, and this is also less luminous, so it tends to result in lower kiln output.In addition to these primary fuels, various combustible waste materials have been fed to kilns, notably used tires, which are very difficult to dispose of by other means. Cement kilns are an attractive way of disposing of hazardous materials, because of the temperatures in the kiln, which are much higher than in other combustion systems (e.g. incinerators),the alkaline conditions in the kiln, afforded by the high-calcium raw mix, which can absorb acidic combustion products. The ability of the clinker to absorb heavy metals into its structure.Whole tires are commonly introduced in the kiln, by rolling them into the upper end of a preheater kiln, or by dropping them through a slot midway along a long wet kiln. In either case, the high gas temperatures (1000–1200 °C) cause almost instantaneous, complete and smokeless combustion of the tire. Alternatively, tires are chopped into 5–10 mm chips, in which form they can be injected into a precalciner combustion chamber. The steel and zinc in the tires become chemically incorporated into the clinker. Other wastes have included solvents and clinical wastes. A very high level of monitoring of both the fuel and its combustion products is necessary to maintain safe operation.Fig1.2 shows preview of air preheater structure. In that we can see peak level shall be maintained in higher altitudes. For maximum kiln efficiency, high quality conventional fuels are the best choice. When using waste materials, in order to avoid prohibited emissions (e.g. of dioxins) it is necessary to control the kiln system in a manner that is non-optimal for efficiency and output, and coarse combustibles such as tires can cause major product quality problems.

Fig.1.2. Preview of air preheater Structure:

Fig1.3 shows 4 stage air preheater in that stages wise the amount of exhaust gas is entering from the kiln where as in 5 stages we find temperature profile in a dry kiln which shall be shown in Fig 1.4 shows five stage air preheater

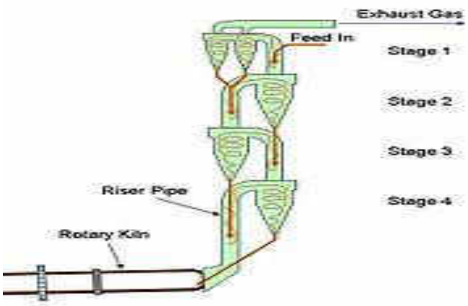

Fig.1.3. Four-stage air preheater

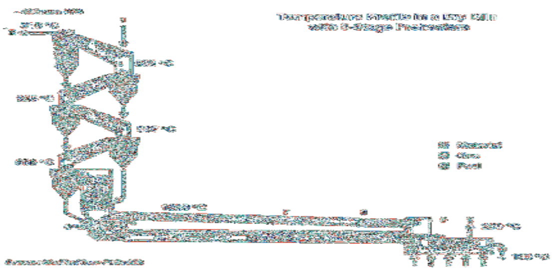

Fig.1.4. Five-stage air preheater

The number of cyclones stages used in practice varies from 1 to 6. Energy, in the form of fan-power, is required to draw the gases through the string of cyclones, and at a string of 6 cyclones, the cost of the added fan-power needed for an extra cyclone exceeds the efficiency advantage gained. It is normal to use the warm exhaust gas to dry the raw materials in the raw mill, and if the raw materials are wet, hot gas from a less efficient preheater is desirable. For this reason, the most commonly encountered suspension preheater have 4 cyclones. The hot feed that leaves the base of the preheater string is typically 20% calcite, so the kiln has less subsequent processing to do, and can therefore achieve a higher specific output. Typical large systems installed in the early 1970s had cyclones 6 m in diameter, a rotary kiln of 5 x 75 m, making 2500 tonnes per day, using about 0.11-0.12 tonnes of coal fuel for every tonne of clinker produced. A penalty paid for the efficiency of suspension preheater is their tendency to block up.

Preheaters with integrated calciner have three different types of cyclones. The topmost stage has one or more meal-collection cyclones (C-type). The intermediate preheater stages consist of system cyclones (B-type). The lowest stage, which is connected to the calciner, is a calciner cyclone (A-type).

Fig.1.5. shows multi stage dip pipe. Where rock structure involving in sucking of heat. Each cyclone stage basically performs the following two functions It heats up the raw meal in the gas stream It separates, the raw meal and discharges it via the meal In every cyclone’s head there is placed a multi-element dip pipe, as shown in the following picture. The interior of every cyclone is also provided with a refractory lining.

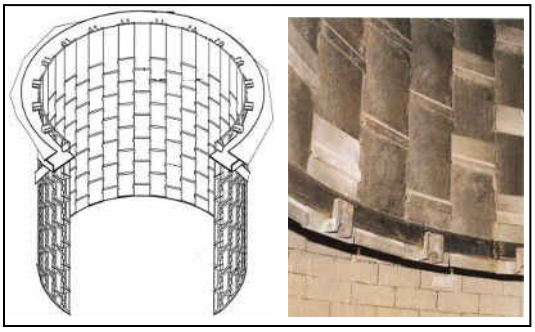

Fig 1.5: Multi-element dip pipe

The hot meal flap valves Fig.1.6. Installed in the meal chutes, and with refractory lining has been specially developed for use in the lower cyclone stages. They prevent the gas from flowing through these chutes and “bypassing” the proper routes. Fig1.6 shows hot meal flap. Hot meal flap valves are discharge devices for a varying mass flow of material with simultaneous shutting-off of the counter flowing hot gas. The exposed cross-section, which remains when the flap blade is closed, corresponds approximately to the filling level at nominal power of the plant. With increased mass flow of material the flap blade opens. Then the flap blade closes again by means of the external sliding weight up to the internal stop. The smooth-running roller bearings of the flap blade do not fail even with possible deformation owing to the effect of heat on the housing.

Items in the drawing:

1. Housing with refractory lining
2. Cover for mounting and
   Dismounting of the flap blade
3. Flap blade
   - Shaft
4. Levers
   - Sliding weights
5. Roller bearings
6. Inspection port
7. Safety guard

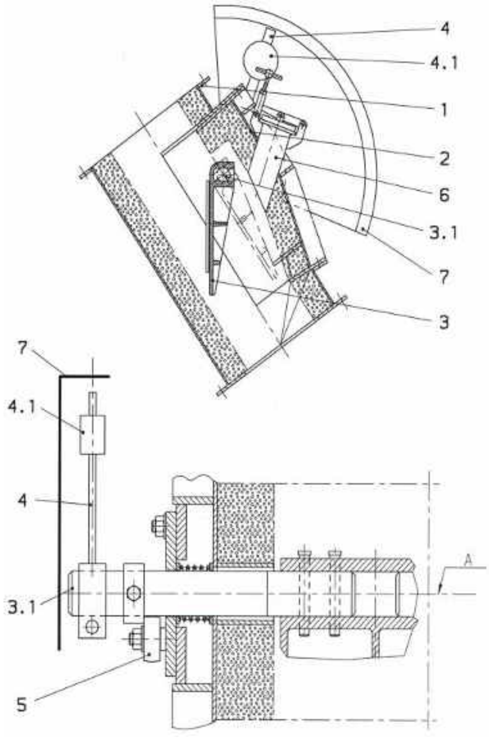

FIG.1.6. Hot Meal Flap Valva

Tertiary Air Duct:
The function of the tertiary air duct in the kiln line is to supply the calciner with additional combustion air. This additional combustion air is hot exit air from the kiln hood or from the cooler. The tertiary air duct AS Fig.1.7 shows TA-duct AS-LC with extraction from kiln hood is routed above the rotary kiln from the kiln hood to the calciner and supplies the required combustion air to the calciner burners.
Items in the drawing:
2.1 Main duct
2.2 Supports
2.3 Kiln hood extraction duct
2.4 Expansion joint
2.5 Throttle device
2.6 Tensioning ropes
2.7 Support at kiln hood
2.8 Sealing to kiln hood
2.9 Sealing towards DOPOL

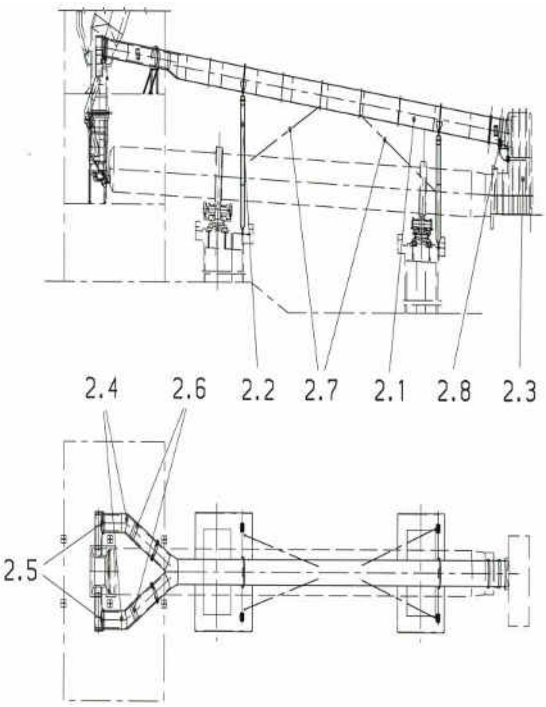

Fig .1.7. TA-duct **AS-LC**

II. THERMAL ENERGY SAVING OPPORTUNITIES

The Preheater system is one of the major areas for potential reduction in thermal energy consumption in the plant. The main aim of the PH system is to recover maximum heat from the kiln exhaust gases and to reduce overall thermal energy consumption. In Preheater System, the overall system is counter current, whereas stage wise is a co-current heat exchange system
Maximum heat transfer between the kiln feed & calciner exit hot gases and the inlet feed material takes place in the riser ducts. In the Preheater cyclones, the separation of feed material and hot air takes place. The feed material is then fed to the lower cyclone and the hot air moves to the higher elevation cyclone. s Almost 80% of the entire heat transferred from the hot gases to raw meal is in riser ducts. To ensure maximum heat recovery in the riser ducts, the feed pipe from the higher stage should be lowered as much as possible.
This increases the heat transfer between the hot gases and feed material in each stage, before they are separated in the cyclone. This will result in lowering of exit gas temperatures from the PH system. The optimum point of feed inlet to the riser duct is at 1.0 m height from the cyclone top.
The lowering of feed pipes as shown in the Figure in the identified cyclones of Preheater would result in a reduction of at least 5 – 100C reduction in Preheater gas exit temperature. Most of the Cement plants modified the dispersion box height and reduction in their Preheater exit temperature is observed. Thermal energy savings: 2 - 5 k Cal/kg clinker reduction in the thermal energy consumption of the plant. For a conventional burner Primary Air supplied for combustion of

Coal is 15 to 20% for total theoretical air required for combustion (i.e high primary air to theoretical air ratio).

Replacement of Kiln Inlet Pneumatic Seal with Graphite Seal: Circular bearing race is mounted on kiln and adjusted to compensate any pre existing eccentricity Graphite plates are mounted on a specific support which is bolted on the fume box Graphite plates are held in contact with circular bearing with help of 2 metal wires and adjustable counter weights Graphite plates overlap on each other to enhance overall leak tightness

III. TEST SETUP

The setup arranged for the description of setup with both types of preheater such as 4 stage as well as 5 stage preheater. In which there shall be 4-stage which is shown in Fig 4.1.and 5-stage shall be shown in Fig 4.2. Preheater analysis shall be done through the kiln steam outlet which shall be passed to preheater

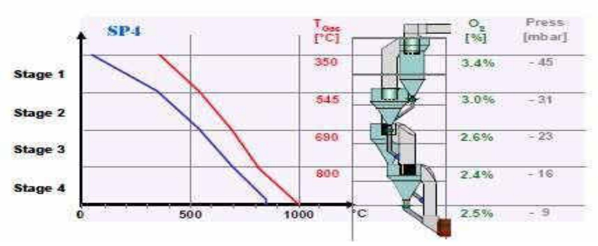

Fig.4.1.Typicalsetupof4stagePreheater

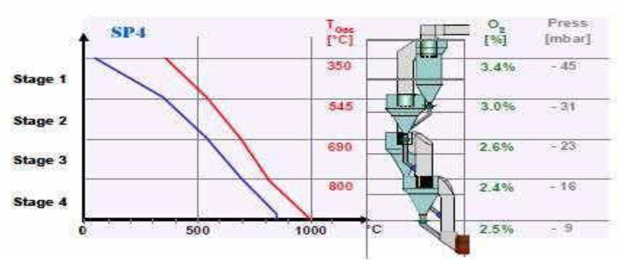

Fig.4.2. Typical Setup Of 5 Stages Preheater

As such there is a transfer of hot flu gas from kiln to preheater. In Fig.4.3 the figure showing preheater as well as total working of a cement plant

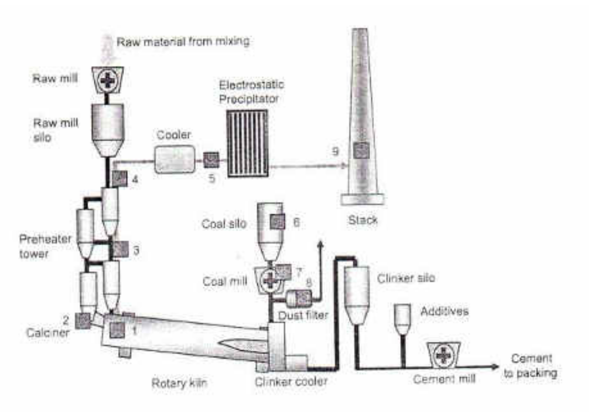

Fig.4.3. Preheater and total working of cement plant

Preheater shall be connected to kiln as the heat exchange takes place with stages of preheater taken place. The kiln inlet (Fig.4.4) connects the tilted rotary kiln to the calciner or to the gas duct of the preheater.

The interior of the inlet is provided with a refractory lining. Coming from the rotary kiln, exhaust gas flows through the kiln inlet to the preheater (blue arrow). The raw meal enters the inlet via the meal chutes and passes through the kiln inlet downward to the rotary kiln (red arrows).

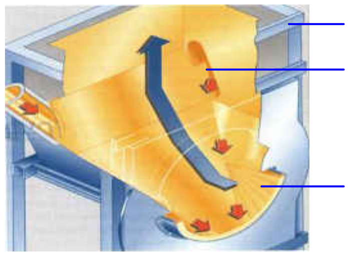

Fig 4.4. Kiln inlet

IV. HEAT OPTIMUM DESIGN ANALYSIS OF REHEATER AND KILN

Here we will know about concentration and efficiency of stages done in Preheater. The inlet and outlet temperatures, pressure, density shall be known.

Spray Cooling Of Gas:

Amount of Water spray for cooling gas can be calculated as mentioned below:

Water t/h = $Q.\rho.S.\Delta T/[(100-Tw)+539)]$

Where Q = gas flow m^3/h

ρ = gas density Kg/m^3

ΔT = gas cooling, ^0C

S = specific heat of gas

Tw = water temperature

Kiln Burner Optimum Design:Range of Kiln Burner Primary air momentum:(With 6 to 8% primary Air): 1250 to 1780 % m/s. Optimum Kiln Burner Primary air momentum:

1400 to 1600 % m/s Lower Primary Air Momentum causes Longer Flame & high kiln shell temp in burning zone area, high kiln back end temp, too long burning zone & lower burning zone temp. Kiln optimum design shall be applicable for both primary as well as tertiary air. Mode of transfer shall be taken place by the means of hot masses or the transport from from port to port.Burner Solid fuel load in transport duct:

5 -7 kg/m^3 air Peat / brown coal, coal

3-5 kg/m^3 air

(Feed of solid fuel (kg/s) divided by the transport air flow in duct (m^3/s)

Transport velocity of solid fuels in the transport duct:

>25 m/s acceptable

Volume flow of transport air (m^3/s) at burner tip temperature divided by the area of the solid fuel injection channel at the burner tip.

Kiln Exhaust Gas (Coal) Results:

Assume a typical bituminous coal with ultimate analysis (as dried basis)

Table 5.1. Coal Analysis

MATERIAL	COMPOUND AMOUNT
C	80%
H	5%
S	1

O	5
N	0
ASH	8
NET kcal/kg	7400

With indirect firing and specific fuel consumption of clinker. Then coal consumption is 0.127 kg/kg clinker and combustion gases produced are

C 0.80 X 127 ---> 101.6g X 22.4/12 = 190 L CO_2 = 271 g O_2

H 0.05 X 127 ---> 6.35g X 22.4/2 = 71 L CO_2 = 51

S 0.01 X 127 ---> 1.27g X 22.4/32 = 0.9 L CO_2 = 1

Then added O_2 required for combustion = 323g – 6.35g = 317g = 222 L Or 0.222 NM^3

Then equivalent N_2 from air = 222 L X 79/21= 835 L

Or 0.835 NM^3 CO_2 from calculation of raw meal to yield 1kg clinker (assuming kiln feed

LOI of 35) ((1000/0.65)-1000) = 539 g = 274 L or 0.274 NM^3

Then total CO_2 in exhaust gas = 274L+190L= 0.464 NM^3

H_2O from Kiln feed (assuming 1.65 Kiln feed: clinker factor and 0.5% H_2O)1kg X1.65 X 0.005 = 8.25g = 10L or 0.01 NM^3

Then exhaust gas with no excess air is:

CO_2 0.463 NM_3 = 33.5%

H_2O 0.081 = 5.9

SO_2 0.001 = 0.1 (1000ppm)

N_2 0.835 = 60.5

Estimation of net **exhaust gas volume, NM^3/kg clinker @ 0% excess O_2**

= (kcal/kg X 0.00129) + 0.284

Estimation of gross exhaust gas volume, NM^3/kg clinker with *n% O_2 = Net NM^3/kg X (1+n/(21-n))*

Upper limits and lower limits of Gas velocities at different areas in Preheater, Kiln and cooler are given below:

Table.5.2.Upper Limits

PART	VELOCITY
Through Cooler grate	5
HOOD	6
UNDER COOL BULL NOSE	15
BURNING ZONE(14500C)	9.5
Feed end transition(10000C)	13
RISER	24
PREHEATER GAS DUCTS	18

Table.5.3.Lower Limits

PART	VELOCITY
Tertiary duct	25
Pulverized Coal conveying	20

Table.8.4.Technical Data

Number of cyclone		4	5	6
Exhaust gas				
- temperature	°C	370	315	280
- volume	Nm³/kg clinker	1.372	1.353	1.345
- dust relative to clinker	%	8	6.5	5
- pressure loss	mbar	33	38	45
Fuel consumption	kcal/kg clinker	740	718	705
Cooler efficiency	%	74.6	73.1	72.1
Clinker temperature	°C	100	100	100
Cooling air	Nm³/kg clinker	1.7	1.7	1.7
Cooler vent air				
- volume	Nm³/kg clinker	0.84	0.87	0.88
- temperature	°C	295	305	312
Electrical power consumption				
- for exhaust gas fan	kWh/t clinker	5.6	5.7	6.1
- for total kiln plant	kWh/t clinker	15.1	15.2	15.7
Permitted RM moisture				
- exhaust gas only (with coal mil	%	7.6	5.6	4.3
- exhaust gas only	%	8.5	6.5	5.3
- exhaust gas with exhaust air	%	11	9.5	8.7

DATE		13-03-016	14-03-2016
Time		10.30-1.30	10.30-11.30
Clinker production	t/d	3658	3658
Coal mill	On/off	Off	Off
Preheater exhaust			
Gas before CT			
Temperature	^{0}C	327	333
Static pressure	Mbar	-47.8	-47.8
Actual gas flow	M^3/H	553.318	555.557
Standard gas flow	Nm^3/h	221.357	217.503
Composition			
O_2	%dry	1.96	1.90
CO_2	%dry	36.78	37.44
CO	%dry	0.03	0.07
NO	Ppm	823	-

Table.8.3.Analysis of Path Line from Time to Time

Calculations observed for the Preheater as well as Kiln. The amount of heat transfer is shown with the different variations as shown in the graph. Day wise calculations are recorded for the continuous analysis. Heat transfer spreadsheet calculation a)Conduction b)Convection c)Radiation

The main results of the pre heater measurements are

Total excess or waste heat available is 203.7 kcal / kg clinker

Only a low amount of pre heater exhaust gas is used for the coal mill.

Excess heat available in Preheater is 108.6 kcal / kg clinker

The main results of the kiln measurements are Total flame momentum flux is 1725 % m/s. The amount of heat released to preheater has been re generated through nodes which are available near to the preheater. Analysis of heat transfer has done by the amount of heat distribute to preheater from kiln and preheater to kiln. The analysis done through conduction, convection, radiation are through the pre module .

CONCLUSIONS

The extreme values and the figures are taken in the cement plant and thus the calculations are done with the part point of the formulas taken from the industry as well.

Greater demands for throughput and efficient use of heat in the kiln have placed greater demands on kiln induced-draft fans. These fans have been designed with ever-increasing volume and static pressure requirements, as well as higher process gas requirements. The result has been larger fan rotors operating at very high tip speeds.

Build-up on pre heater ID fans is definitely temperature and impact velocity related, which would support theories about lower-melting-point alkaline forming a sticky compound.

Sulphur may be ruled out as a cause of build-up on preheater fans since no sulphur was found in the fuel in the lab test, though build-up still occurred.

Formation of FeCl subscript 3 resulting from a chlorine reaction with the rotor's steel may also be ruled out. Build-up occurred even with stainless steel and other protective (non-iron) coatings on the rotor.

The recommended temperature of gas entering the kiln ID fan is 482 ºF (250 ºC). This temperature may be achieved with water sprays in the down comer from the preheater tower. The presence of moisture in itself may minimize build-up.

The fan rotor should be designed for the smoothest possible flow lines. The backward-curved and airfoil rotor designs are best for this purpose.

Fans should be selected to achieve minimum gas/dust particle velocity at the inlet of the fan rotor. Minimum velocity means minimum impact on the fan rotor. Consider using double inlet fans instead of single inlet fan, Larger-diameter and lower rpm fans and a peripheral speed at the rotor inlet opening limited to 15,000 fpm and an inlet velocity not to exceed 7,500 fpm.

Oversized shafting should be used to reduce sensitivity to imbalance. The design critical speed (including effects of bearing oil-film stiffness) should be at least 1.25 times the operating speed of the fan including the weight of 1-in.-thick (2.54 cm) build-up on all leading surfaces (pressure side) of the fan rotor blades.

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