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An Analysis of a Pre-Calcinator Design for the Kankasanthurai Cement Manufacturing Plant

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Synopsis

The design of a massive precalcinator plant for the Kankasanthurai Cement Factory is described in this paper. The Mechanical Engineering aspects of design such as Heat Transfer, Thermochemical Manipulations, Reaction Kinetics and the Dimensional Aspects are discussed.

1.0 Introduction

The rapid increase in the pace of development in Sri Lanka has brought about a tremendous demand for Portland Cement. It has thus become extremely important to increase the output of cement from the two plants at Puttalam and Kankasanthurai. Broadly, there are two courses of action that could be followed—

(a) To increase the capacity of the plant by adding another kiln,

(b) To increase the throughput of cement material in the present kiln.

The former although feasible cannot be done speedily enough to ease the pressure of demand for cement in the country. This is because adding a new kiln in effect is like building another plant altogether. The latter course of action could help to increase the output of cement from the plant in a short time. Here no changes will have to be made to the kiln itself. The workers investigated this method of increasing the cement output.

The kiln under investigation was giving about 500 MT/day of cement. The workers worked on the basis of increasing this to 700 MT/day. If this increased feed rate was put through the kiln, which was already working to full capacity the fuel rate would have had to be increased which in turn would have reduced the life of the kiln and perhaps would have brought about its complete failure.

In the cement manufacturing process, calcination is the term used for the conversion of calcium carbonate to calcium oxide and carbon dioxide, with the application of heat. Sintering is the term used for the process where the calcium oxide reacts with Alumina and Silica endothermically, to form complex silicate and Aluminate mixtures which is called clinker. Of the heat applied to the kiln about 65% is utilised for calcination and about 35% for sintering. If a good portion of the calcination is done outside the kiln, then with the same heat rate and the dimensions of the kiln it is possible to increase the throughput of material. Thus the workers designed a chamber called the precalcinator to get about 55% to 60% calcination done before the material goes into the kiln.

With the increased raw meal feed, major alterations had to be made in the system such as change in some duct dimensions, air flow rate, vacuum conditions etc. A fan of 2m outside diameter handling 2000 m^3/min at 350°C with 700 mm water gauge vacuum was designed, fabricated, balanced and commissioned to the system. All the fabrication work was done at the K.K.S. Cement factory workshops.

2.0 Design of the Precalcinator

2.1 Notations

Bi – Biot Number ($=h.d/k_r$)

c_{pi} – specific heat at constant pressure of the i^{th} component evaluated at a mean temperature.

c_r – specific heat of the raw meal.

k_p – equilibrium constant for calcination.

m – mass flow rate (ad – additional CO_2 produced; c – clinker; f – fuel; k_{fi} = kiln flue gas; p_i – combustion products per kg. of fuel; r – raw meal inside the precalcinator).

P_{CO_2} – Partial pressure of CO_2

Q – heat input (c – heat for calcination inside the precalcinator; s – sensible heat of the raw meal; ad – additional heat carried away by CO_2 produced inside the precalcinator).

t – temperature (c – calcination; cro-calciner raw material out; en-precalciner entering; 1 – precalciner leaving)

V_f – reaction rate

ΔE – Activation energy for calcination

ΔH^0 – standard reaction heat

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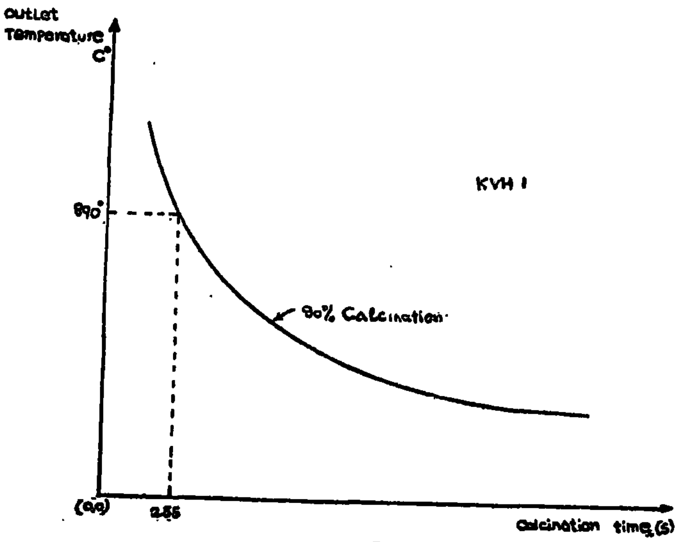

Fig. 1

2.2 Design Data

For the design, data was obtained from past work(1) In order to get 700 MT/day of clinker the raw meal feed rate should be 1280 MT/day, out of which 77% is Calcium Carbonate. Heat required to produce 1 kg of clinker is 4200 kJ out of which 1176 kJ are used as sensible heat of raw meal and 1554 kJ for dissociation of calcium carbonate at 900°C (ie–2730 kJ for calcination). 1470 kJ is used for sintering. Clinker is produced at a temperature of about 1400°C. The Heat capacity of the raw meal may be taken as 0.84 kJ/kgK.

Net calorific value of the Redwood 1000 fuel oil at constant pressure is 42735 kJ/kg. The ultimate analysis of the fuel (C – 85%, H – 11%, O+N – 2%, S – 0.8% ash 2% and water 1%) shows that the stoichiometric air/fuel ratio is about 13 : 1. One kg of fuel produces 3 kg of CO_2, 1 kg of water and 10 kg of N_2, as flue gases.

The raw meal enters the precalcinator (leaving the 3rd cyclone preheater) at 800°C and leaves it at about 900°C.

2.3 The Calcination Process

2.3.1 Smidth et-al [2]) have reported a detailed study of calcium carbonate dissociation. Appendix (1) gives the variation of partial pressure of Carbon dioxide with the temperature. The calcination reaction may be written as

$$CaCO_3 \longleftrightarrow CaO + CO_2; \ \%H- = 1764 \text{ kJ and}$$
$$k_p = P_{CO2}.$$

It is clearly seen (Appendix 1) that though the calcination starts at 500°C, for effective calcination P_{CO2} must be equal to the precalcinator pressure which is about 100 mm water gauge vacuum. The variation of k_p with the temperature also may be written as (3)

$$\frac{d(\ln kp)}{dt} = -\frac{\Delta H}{R_0T^2} \quad (3.1)$$

The variation of ΔH with the temperature may be evaluated by the Bunsen – Kirchoffs equation (8)

$$\Delta Cp = \frac{d'\Delta H}{dt} \quad (3.2)$$

Equations (3.1) and (3.2) can be used to evaluate the effective calcination temperature within the precalcinator which worked out to be 893°C.

2.3.2 Arhenious reaction rate formulae

$$V_f \propto e^{-\Delta E/RoT} \quad (3.3)$$

and figure (1) shows the corresponding variation of the reaction time with temperature. Equation (3.3) with figure (1) was used to estimate the reaction time as 0.055 seconds for 90% calcination at 950°C. However it was expected to have only 55 – 60% calcination within the precalcinator. Hence the total reaction time is less than 0·05 seconds. The temperature attained by the particle is in the order of adiabatic flame temperature which is nearly 2800°C and the reaction time may be still less. But with a safety margin 0.055 seconds was selected as the design calcination time.

2.4 Heat Transfer Aspects

It has been found[6] that the time taken to transfeheat from the fluid media to the dispersion phase in fluidr ized beds is less than 0.1 seconds. Owing to the disturbance of the boundary layer by the pulsating particle movement, the heat transfer rate is about 2–3 times that of a particle at rest.

Experiments have revealed that the fluidized bed heat transfer depends on numerous factors. Although no satisfactory correlation has been arrived at, it has been established that the boundary layer around the particle plays a significant role in the heat transfer process. For most of the fluidized particles Biot number is less than 0.25, implying that the heat transfer resistance is mainly due to the boundary layer and when once the heat crosses it temperature distribution within the particle is almost instantaneous. Also turbulence inside the precalcinator could increase the heat transfer across the boundary layer. In the present design the entrance Reynolds Number of 25,000, ensures the required turbulence. As the particle size increases, sliding velocity also increases resulting in high heat transfer rates due to boundary layer disturbances.

With the above mentioned analysis it can be easily inferred that the time of material retention within the precalcinator should be 0.15 seconds. Since the particle retention witnin the present design was kept at 1 second, so tnat there was a safety margin of about 7 to ensure the complete envisaged amount of calcination, within the precalcinator.

2.5 A Model for Combustion

There are two main designs for the precalcinator and the thermochemical calculations can be made accordingly. They are

(i) combustion air for the precalcinator fuel taken through the kiln itself (A–T) system.

(ii) Air for the precalcinator fuel taken through a separate passage (A–S system).

The former method was used for the present design.

2.5.1 The fuel consumption in the precalcinator was evaluated using a model with the following assumptions.

(a) The fuel is burnt on the particle itself, thus exposing it to a temperature of the order of adiabatic flame temperature.

(b) The heat of combustion of the fuel is transformed to the combustion products and can be calculated as

$$Qc = m_c . q_c . \qquad (3.4)$$

$$Qs = m_r . C_r . (t_{cro} - t_{cri}) \qquad (3.5)$$

$$Qkf = \Sigma m_{kf.} C_P^{kf} (t_{kfo} - t_{kfi}) \qquad (3.6)$$

$$Qod = md. \; Cp \; (t_{kfc} - t_c) \qquad (3.7)$$

(c) The mass flow rate of the fuel may be calculated as $Qc + Qs + Qkf + Qad =$

$$m_f \left[\Sigma m_{pi} C_{pi}^{p} (t_{en} - t_c) + \Delta H_B + \Sigma m_{Ri} C_{cpi}^{R} (t_o - t_{en}) \right] \qquad (3.8)$$

Witn this model he estimated fuel consumption was 1MT/hr. (ie. 24 MT/day).

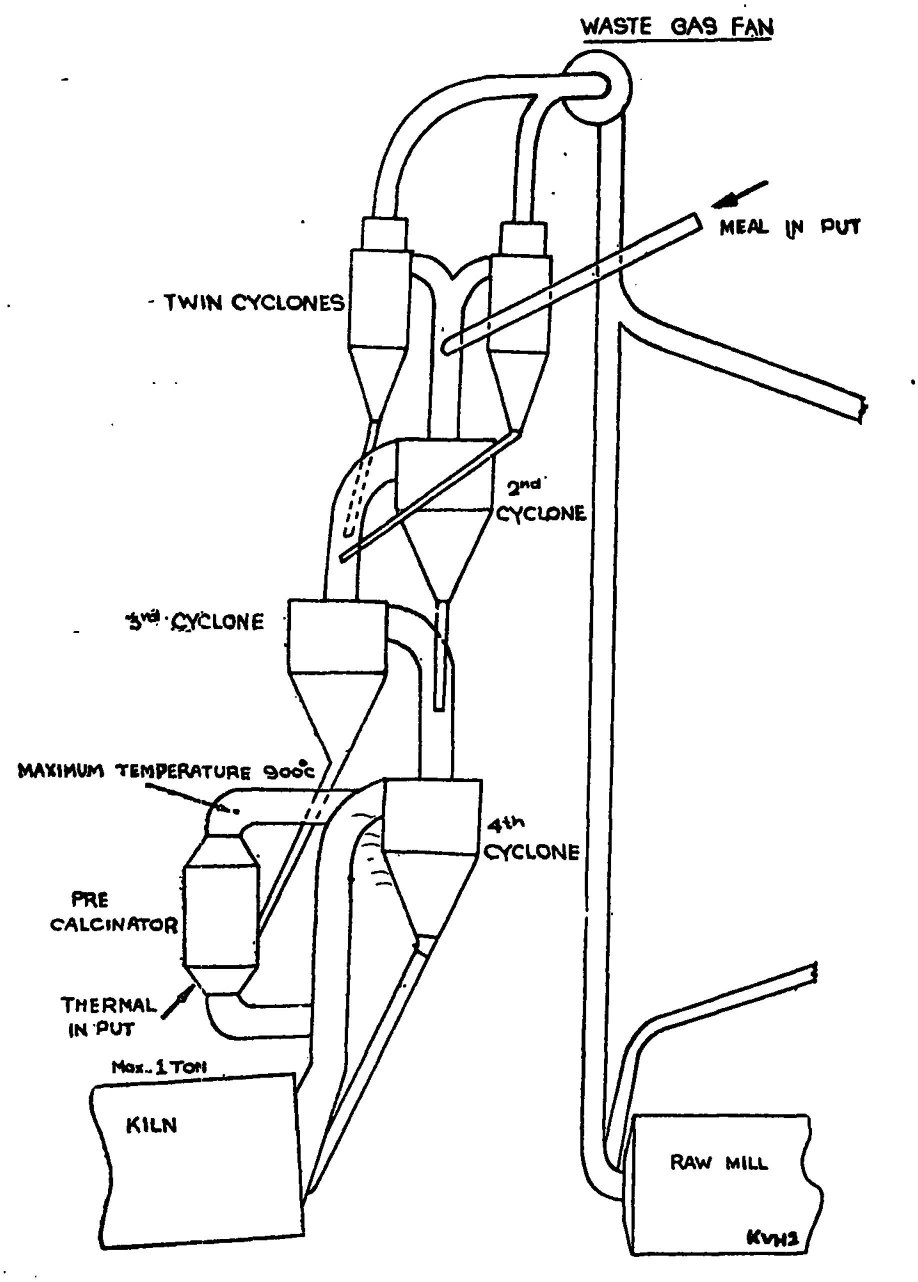

Fig. 2

2.6 Selection of Dimensions

2.6.1 The precalcinator dimensions were decided by taking to account the recommended speed of fluid flow and the calculated calcination time. Reference[4] gives a suitable velocity of flow within the precalcinator as 5 m/s and Indian Experts have adduced a value of 7 m/s. At the beginning, the workers decided on 7 m/s, for a safe design for a clinker output of 800 MT/day. Theoretical calculations showed that this would require an exhaust waste gas fan capacity of 2400 m^3/min at 350°C, and a motor power around 400 h.p. For a retention time of 1 second in the calcinator, the height required was 7m. The diameter required for this flow rate and velocity was 3.56 m. After realization of a new constraint, that is, the available waste gas fan motor power was only 346 h.p. and not 400 h.p., a new series of design calculations had to be done to accommodate the 346 h.p. fan motor. (It would have taken a long time to purchase a suitable motor from a foreign country).

Calculation for a motor of 346 h.p. showed that the fan capacity was 2,000 m^3/min at 350°C and the corresponding clinker output was 700 MT/day. At this moment fabrication of the precalcinator had started and the workers had to maintain the previously decided diameter of 3.56 m. After a stringent check it was found that this diameter does not violate the fluidization velocity requirements with the altered flow rates, and it was decided to proceed with the same diameter thus making the flow velocity about 5.5 m/s, which was proved to give trouble-free operation.

2.6.2 Fig (3) shows the main design. Raw meal enters the precalcinator through an inclined chute fitted with a gravity operated door, which feed the raw material spasmodically. The meal first meets the fuel and then the hot air stream which contains air for combustion. Violent combusion occurs concurrent with the turbulence which facilitates the heat transfer.

3.0 Remarks

The design of the K.K.S. cement mill precalcinator was done with the idea of coping with the soaring demand for cement. No time was available for supporting work to obtain the necessary data, but the findings of past workers had to be adhered to. The team involved completed the design basing their work on a firm theoretical foundation. The present precalcinator is now being instrumented, and the workers are optimistic that their work will help future workers in understanding the design format unequivocally. Calculations for the present precalcinator are available with the Department of Mechanical Engineering, University of Moratuwa, or with the R & D Division of the K.K.S. cement factory.

4.0 Acknowledgements

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Appendix 1

The variation of partial pressure of CO_2 with temperature.

Table I

Temp.°C	*Press: Hg mm*	*Temp.°C*	*Press: Hg mm*
500	0.073	800	167
550	0.41	850	372
600	1.84	894	760
650	6.90	900	793
700	22.2	950	1577
750	63.2		

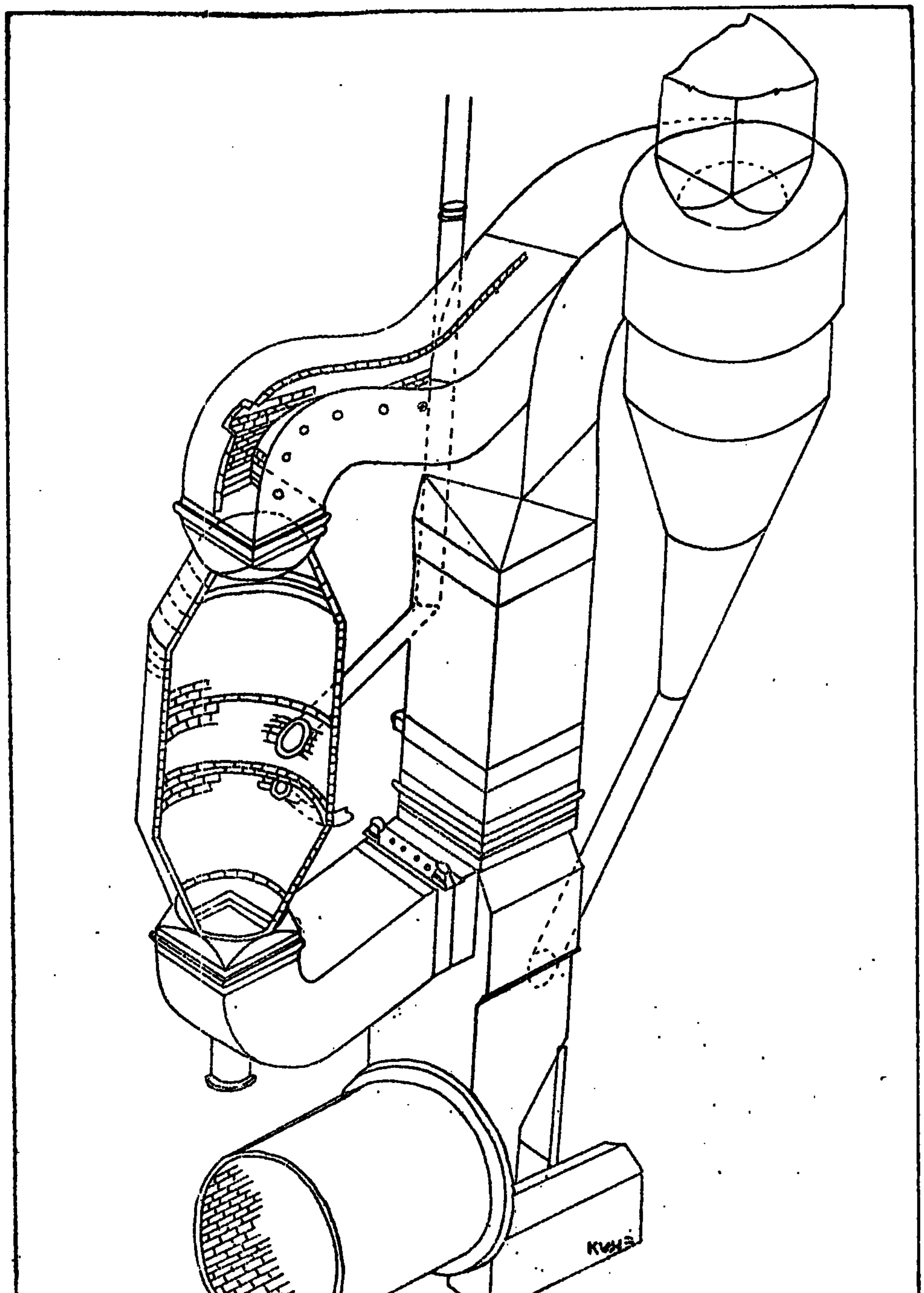

Fig. 3