POST FIRE INVESTIGATIONS AND REMEDIAL MEASURES FOR RCC CHIMNEY OF CO BOILER

In this post fire investigation report for RCC Chimney of CO Boiler Gopal Krishan, T.P. Sharma, S.B. Gupta and A.K. Jethi, Scientists, C.B.R.I. Roorkee, based on their detailed inspection on site and later various laboratory tests have very ably analysed the causes of the damage. They have also recommended some useful measures that need be taken to avoid such occurrences in future

Editor

ABSTRACT

The R.C.C. Chimney of CO boiler of F.C.C. Unit of an oil refinery was damaged more severely at 20-30 m and 60-70 m Levels due to high temperatures of flue gases assessed to be more than 800°C. The damaged chimney was inspected, photographed at 20-30 m at both the levels and samples of concrete and other materials, besides detailed information on the chimney were collected. Based on the site inspection and other laboratory tests, the probable causes of the damage to the chimney were analysed as combined effect of high temperature and fire, velocity gradient, stack pressurisation due to rise in temperatures.

PREAMBLE

As per the information, the mass flow rate of flue gases entering the chimney was 120 tonnes/hr which was within the design limit of 125 tonnes/hr. The operation of the FCC unit was being first stabilised after the start up with CO gas which was being routed to chimney via by-pass CO duct and thereafter the CO boiler was gradually commissioned first on fuel oil and then gradually diverting the CO gas from the bypass CO duct to CO boiler. The flue gases from regenerator were reported to contain CO 7.4% and oxygen 0.41% besides appreciable amount of N_2 CO_2 and SO_2 which was limited upto 0.11-0.20%. Thus, it can be safely visualised that in the plant CO gas was entering to chimney via the by-pass CO duct at about 700°C and simultaneously flue gases from CO boiler were entering the chimney at about 110°C. Therefore, it would have been possible that ignition of CO gas could have taken place, since ignition temperature of CO is in the range of 630°-650°C. The situation could be further worsened if due to some operational difficulty, CO boiler was malfunctioning and total flue was fed to the chimney by-passing CO boiler. In these circumstances, two situations could have been possible.

(i) If plenty of air was available with feed to the chimney, CO would continuously burn in the chimney and the temperatures inside the chimney could be in the vicinity of 1200°C. A similar case but with more associated hazards might also be possible if unburnt hydrocarbons were passing through the chimney along with the feed.

(ii) When CO gas was partially burning at a lower part of the chimney, the burning might cease due to insufficient amount of oxygen though the temperatures might still be higher than ignition temperature of CO. If due to leakage, some air was induced, it might further start burning of CO. The remaining CO would burn on top as flare as it would be drawing sufficient amount of oxygen from ambient air at top and hence the temperatures would be quite high in upper part of the chimney.

ASSESSMENT OF TEMPERATURES

Temperature Distribution Across the Chimney at Various Levels

Temperature in a vertical surface varies in a direction normal to crossing the isothermal surfaces. The chimney consisted of several layers starting from acid resistant bricks, insulating bricks, air gap, mineral wool and then reinforced cement concrete, all forming heterogeneous layers. In the steady state conditions the rate of heat flow per unit area is constant and is same for all layers. The interface between two adjacent surfaces will be at the same temperature. It will, therefore, be rational to calculate the temperature of intermediate surfaces for the steady state conditions with following assumptions:

1. All the layers in a vertical plane are isothermal.

2. Material properties are uniform for the temperature difference along the entire thickness.

3. As per the design concept, the temperature decreases as the height of chimney increases. However, it is observed that carbon monooxide gas burns inside the chimney and it will be quite safe to assume a uniform temperature along the height of chimney. Hence temperature gradient across the chimney are calculated assuming uniform temperatures of the values 1200°C and 800°C.

As shown in Fig. 1, the quantity of heat q per unit length passing through each layer will be same and constant.

Therefore,

$$q = \frac{2\pi(t_1 - t_2)}{1/\lambda_1 \ln d_2/d_1}$$

or

$$t_1 - t_2 = \frac{q}{2\pi\lambda_1} \ln \frac{d_2}{d_1} \quad .... (1)$$

$$t_2 - t_3 = \frac{q}{2\pi\lambda_2} \ln \frac{d_3}{d_2} \quad .... (2)$$

$$t_3 - t_4 = \frac{q}{2\pi\lambda_3} \ln \frac{d_4}{d_3} \quad .... (3)$$

$$t_4 - t_5 = \frac{q}{2\pi\lambda_4} \ln \frac{d_5}{d_4} \quad .... (4)$$

Where, t_1 and t_5 are inner and outer surface temperatures of stack, t_2, t_3, and t_4 are intermediate surface temperatures and d_1 to d_5 refers to the diameter at the particular height of individual layers and λ_1 to λ_4 are the corresponding thermal conductivity of different insulating materials as shown in Fig. 1

Adding equations (1) to (4)

$$t_1 - t_5 = q/2\pi[(1/\lambda_1) \ln(d_2/d_1)+(1/\lambda_2) \ln(d_3/d_2)+(1/\lambda_3) \ln(d_4/d_3)+(1/\lambda_4) \ln(d_5/d_4)] \quad .... (5)$$

Using equations (1) to (5) and putting the values of diameters at different heights, the temperature gradients across the chimney for flue gas temperature of 1200°C and 800°C, and outer face temperature of 80°C for different heights have been calculated and are shown in Fig. 2 and Fig. 3.

CONDITIONS & ANALYSIS OF MATERIALS COLLECTED

M.S. Flat Hoop Ring

A sample of M.S. flat hoop ring was collected from the debris lying near the chimney but it could not be ascertained whether it was from the 20-30 m level or 60-70 m level. Sample, on visual observation was found to be highly oxidised and twisted.

M.S. Flat hoop ring sample, which was brought from debris of damaged lining, showed the presence of scale. The variation in steel thickness was also very significant as at one end it was quite thin (0.75 mm) compared to its thickness (2.75 mm) at the other end. The probable reason could be attributed to direct exposure of the sample to sulphur dioxide with water vapours. The scale was in several layers. At the thicker end, it seemed to be more adherent and at the thinner end it was badly damaged. All this might be due to combined action of corrosion and high temperature oxidation.

Tensile Strength of Damaged Sample

Tensile strength of a portion of damaged M.S. flat hoop was determined as per IS: 226-1975, Structural Steel (Standard Quality). The sample as shown in Fig.4 was tested on a universal testing machine and results obtained are shown in Fig. 5. The important results are as follows:

Ultimate tensile strength = 1952 kg/cm²

Elongation percent = 12%

If these results are compared with ultimate tensile strength of steel at different temperatures, it could be safely assumed that the sample was exposed to temperatures higher than 600°C. The results tally with temperature effect on concrete by seeing its colour which also indicated temperatures higher than 650°C. Further, fresh M.S. flats had been taken and the samples were exposed to 250°C, 500°C and 800° for five hours each. Results obtained for tensile strength are shown in Fig. 6. Thus it seems that M.S. flat hoop rings have been exposed not only to higher temperatures but also for longer duration.

Assessment of Concrete Temperatures

Although no significant work has been reported in the literature on nature and mechanism of change in bond strength in concrete at higher temperatures, cracking around the reinforcement would have a significant affect on the bond and the reduction in bond strength due to heating could be quite significant. For this reason, the designer is required to satisfy himself that all main reinforcement is secured so that after cracking and spalling, the bond between steel and concrete and bond strength of concrete is sufficient. The spalling of the concrete, exposed reinforcement and of dislodging and disintegration of acid and heat resisting bricks is shown in Fig. 7 and Fig. 8.

If a concrete slab is heated according to ISO : 834-1975 (Fire Resistance Tests) the temperature distribution in a slab will vary with different duration of heating. The temperatures within concrete at different depths for dense concrete are shown in Fig. 9. Concrete when exposed to higher temperature changes its colour to pink at 300°C and to buff at 1000°C. At 1200°C, concrete gets sintered. The colour of the concrete sample obtained from 60-70m level was found to be buff in colour. Therefore, it can be safely inferred that the temperatures in the concrete were about 1000°C.

Lining Property

Chimneys are built up of metallic parts, refractories, ordinary bricks and RCC. The factors which affect the strength and durability of these are:

i. High temperature

ii. Variations of temperature

iii. Chemical affect of oxides, sulphur compounds and slags.

iv. Explosions/high pressure generation.

v. Erosion by moving solids with flue gases and sudden high velocity due to temperature rise.

Since all these factors are some way or other related with temperature (partly in case of IV and V) therefore, it is very important that inner lining of chimney should be capable of

i. bearing thermal shocks

ii. withstand continuous high temperature

iii. able to withstand erosion and resistant to acidic nature of flue gases.

iv. further, the chimney lining should be supplemented with insulating brick lining and if chimney has to cope with gases at high temperature it should be supplemented with air gap and other insulating materials of low conductivity to provide temperature protection to its structural component i.e. RCC or metal structure.

A well-designed structure should still perform satisfactorily if heated more quickly or to a higher temperature than the anticipated exposure. It is a part of basic philosophy to accept and anticipate the effect of local damage that might occur in the early stage and to make provision for this with the use of suitably anchored reinforcement or reinforcement outside it.

Possible Causes of Lining Failure

The lining provided in the chimney consisted of acid resistant bricks, insulating bricks with combination of air gap and mineral wool. It has already been concluded that the temperature inside the chimney might have shot up beyond 800°C. Acid resistant bricks are generally poor to resist such high thermal shocks. As per IS: 4998-1975 (Criteria for Design of Reinforced Concrete Chimneys, Part I, Design Criteria) acid resistant bricks should be used in chimneys where the flue gas temperature is below 150°C. In this case, the design temperature itself inside the chimney is 242°C and at times the temperature has reached values more than 800°C.

The low P_H values of concrete and powdery deposits on the exposed surface indicate the highly acidic nature of the flue gas. This combined, with the high temperature has primarily caused the failure of acid resistant brick lining.

The rise in temperature leads to three distinct phenomena which could attribute to the failure of the chimney.

Thermal shock

A steep temperatures gradient may cause spalling of the refractory. The refractory also expands with rising temperature. The high expansion rate of acid resistant bricks due to thermal gradient makes it unsuitable for higher temperature. Also, this type of brick lining is unsuitable for fluctuation in temperature.

Velocity gradient

The velocity fluctuations inside the chimney is quite an important factor especially at high temperatures and at minimum diameter. This coupled with thermal shock may cause failure of the lining. The velocity at different internal diameters of the chimney for different flue gas temperatures of 250°C, 800°C and 1200°C have been plotted in. It is quite clear from Fig. 10, that velocity of flue gases at 1200°C at top is 57.0 m/sec which is about 3 times more than the velocity of flue gases at the same height but at 250°C. This rapid rise in flue gas velocity may be quite hazardous to the lining of chimney and could have caused erosion resulting in failure of lining.

Stack pressurization Due to Rise in Temperatures

In a chimney the draught is realised/achieved as a result of the heat of combustion of the fuels which results in a column of hot gases within the stack which weigh less than weight of an equal column of cold air outside the chimney. The driving force is the difference between the two.

If the height of the chimney is h, the mean temperature of the gases and air are t_m and t_a respectively, then if p be the density of the air at O° and 'the coefficient of expansion for unit cross-sectional area of the stack.:

Weight of air at $t_a = \dfrac{h}{1 + \alpha t_n}$

Weight of air at $t_m = \dfrac{h}{1 + \alpha t_m}$

Driving force $= h[(l/(l+\alpha t_a) - (l/(l+\alpha t_m)]$ ... (6)

It may be observed by equation (6) that as the mean flue gas temperature is increased the driving force is also increased. Therefore, when CO is passed through boiler and part of it burns in the chimney than chimney is more pressurized.

CONCLUSIONS

Thus it can be safely concluded that the lining with acid resisting brick is used when the flue gases are highly acidic and are at temperature below 150°C. Since this type of lining can not be used at higher temperatures or where temperature fluctuations are more, it is suggested that lining with fire bricks having high alumina content may be used. The mortar used for setting these bricks shall also be suitable to resist high temperatures. This type of lining, with high strength will not only be able to bear thermal shocks but will also give necessary protection to the shell from abrasion. The brick lining may be as per IS: 8-1967 (Specification for High Duty Fire Clay Refractories).

- The outer lining around fire brick should be insulating bricks preferably to resist quite high temperatures. The bricks shall conform to IS:2042-1963.

- The bonding between fire brick and insulating brick should be interlocked after 3 or 4 layers of bricks, so that there is proper interlocking of two brick linings and lining remains intact.

- A temperature monitoring system for inner surface of concrete should be provided for about every 10 m of height. The system should be such designed to give an alarm at a preset temperature.

- In situation where high temperature is a problem, it is advisable to use limestone aggregate in preference to quartzitic and granitic aggregates because of its better insulation property, lower modulus of elasticity and lower coefficient of thermal expansion.

- It is further suggested that a bypass chimney should be provided with induced draught and capable of withstanding high temperatures so that in case of malfunctioning of CO boiler, the gases may be burnt in the standby chimney without causing further damage to main chimney.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Director, Central Building Research Institute, Roorkee for his permission for publication of the paper in The Fire Engineer. They are also thankful to Miss Deepti Gupta for word processing the manuscript.

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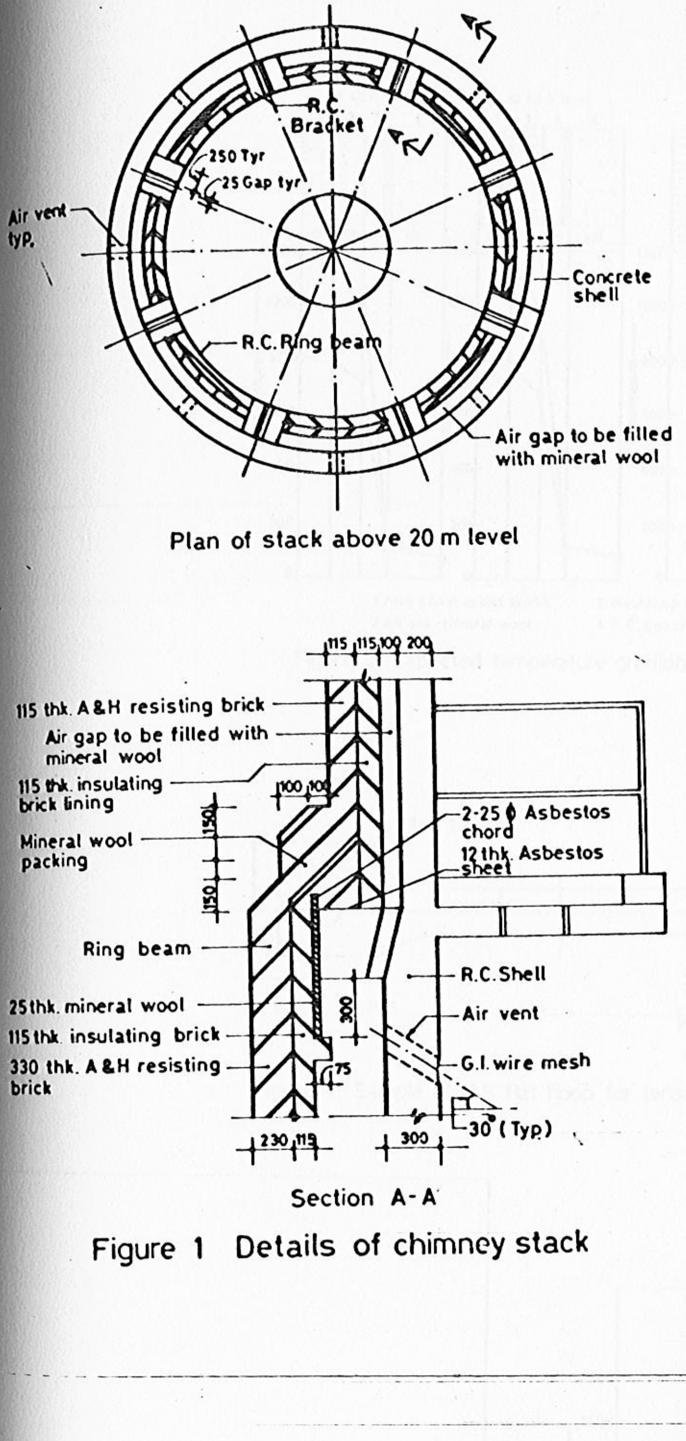


Figure 1 Details of chimney stack

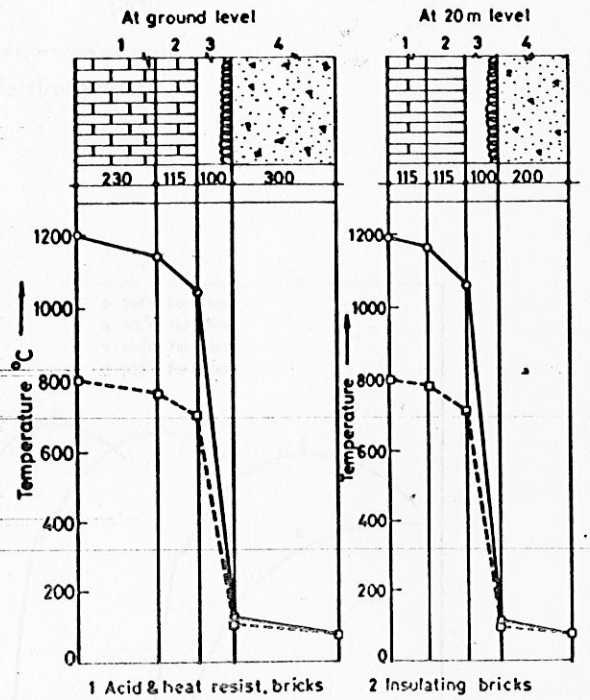


Figure 2 Expected temperature gradient

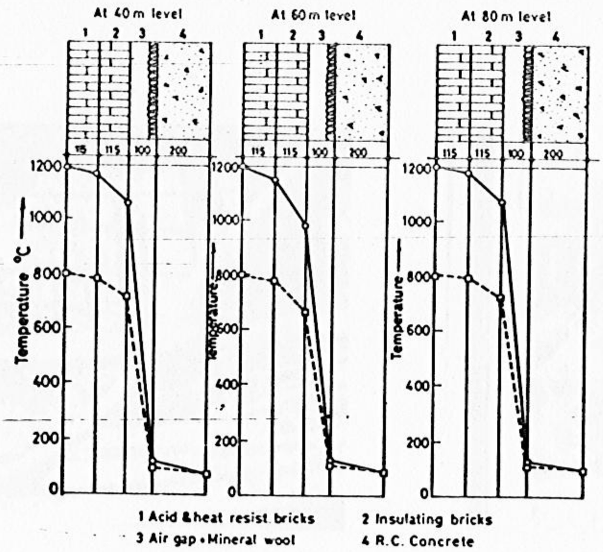


Figure 3 Expected temperature gradient

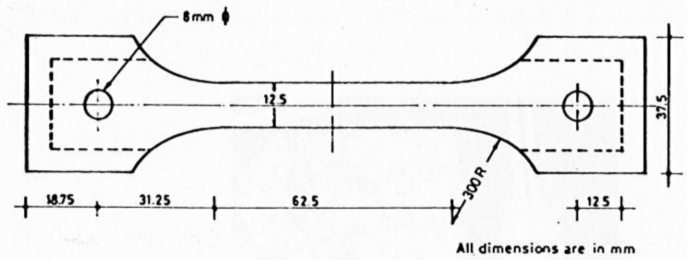


Figure 4 Sample of M.S. flat hoop for tensile strength test

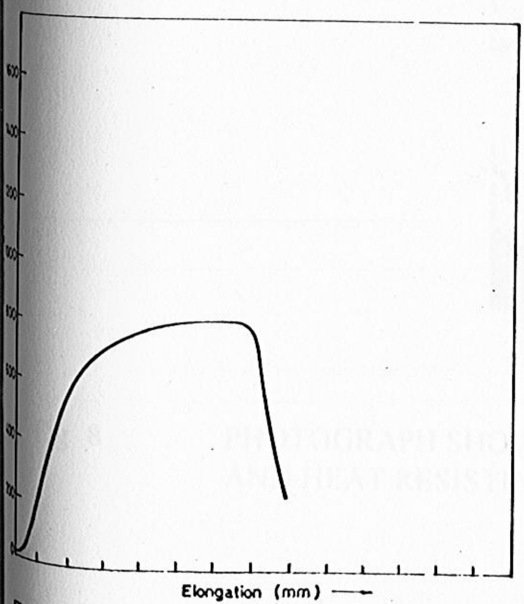


Figure 5 Tensile strength of mild steel flat hoop

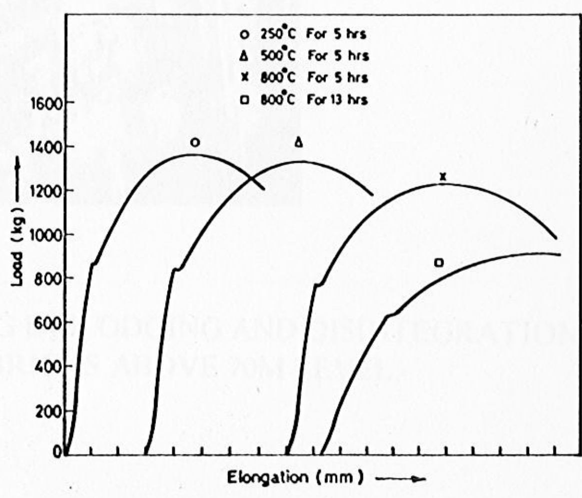
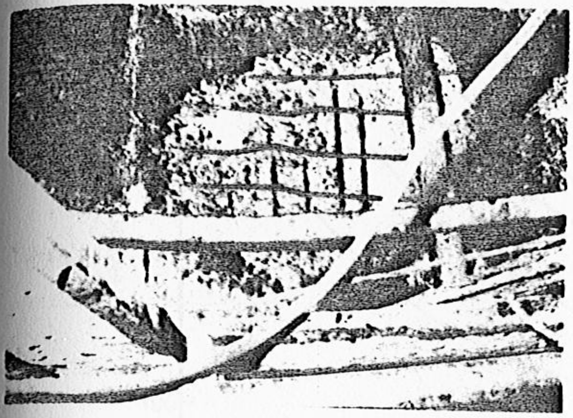


Figure 6 Tensile strength of M.S. flats kept at various temperatures



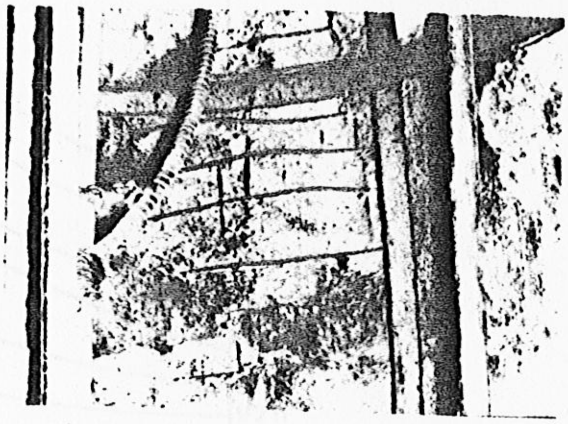
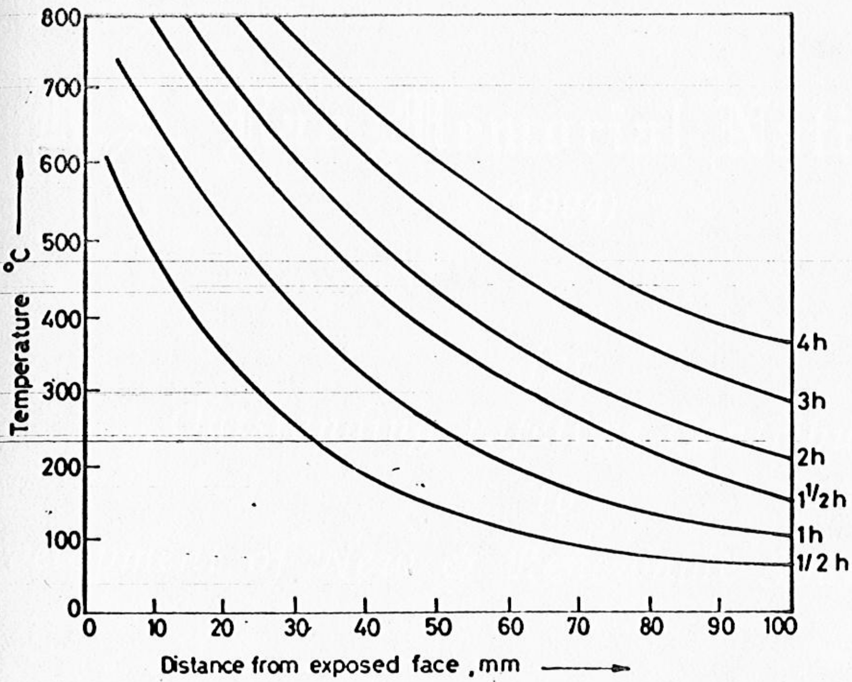


Fig. 7. PHOTOGRAPH SHOWING EXPOSED REINFORCEMENT AT 60-7 M LEVEL

Fig 8 PHOTOGRAPH SHOWING DISLODGING AND DISINTEGRATION OF ACID AND HEAT RESISTING BRICKS ABOVE 70M LEVEL.



(A) Dense concrete, ie concrete of density 2300 kg/m³

Figure 9 Temperature distribution in a concrete slab

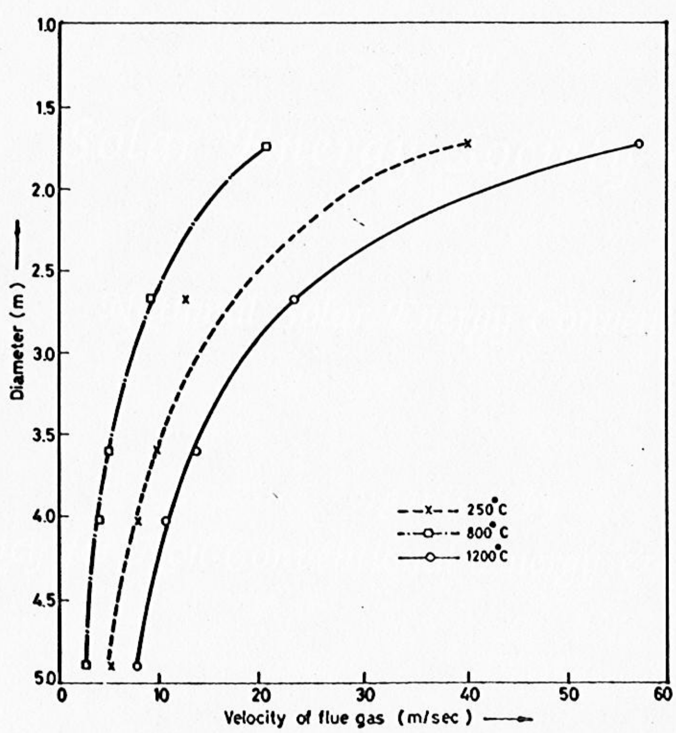


Figure 10 Variation of flue gas velocity at different temperatures with internal diameters of chimney