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"EFFECTS OF ACID SMUT PRODUCTION ON DESIGN OF INDUSTRIAL CHIMNEYS"

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ABSTRACT

Atmospheric, mechanical and chemical kinds of attacks on industrial chimneys constructed of brickwork, concrete and steel are discussed. Acid smut production in chimneys is described. Two of the factors, widely regarded as critical, to avoid acid condensation are identified as thermal insulation and flue gas velocity. The measurements taken by several researchers studying these factors are reviewed. The conslusions of this paper suggests that the 6 mm annular air gap around the steel shell, as specified in the British Standards, may not be the optimal value.

1. INTRODUCTION

The main aim, when designing an industrial chimney, is to produce the draught required to carry air into the combustion chamber and to disperse the exhaust gases into atmosphere. The height of a chimney calculated to meet pollution requirements is normally more than enough to provide sufficient natural draught [1]. The designer must, after that, work out the chimney's cross-sectional area to handle the flow and incur minimum possible costs. New forced and induced draught systems have been introduced to reduce the sizes of chimneys. Although the forced draught fans in the so called pressure furnace systems are used for high capacity units and are in contact with cold and clean air, but they are subject to outward leakage of exhaust gases through the joints of fi box and chimneys structure. In contrast, induced draught fans in the so called suction furnace systems do not have outward leakage. But, the require more power and are subject to fly-ash erosion [2] because they are in contact with the exhaust gases.

Depending on the fuel used and the type of combustion, considerable damage to life and property in the neighbourhood of a chimney can occur as a result of the acidic products of combustion and other harmful materials being deposited. Thus recently there has been a shift in emphasis chimney design procedures. While the draught criteria are still major considerations, greater emphasis is now being placed on reducing pollution by scrubbers and grit arresters using inertial separators and by diluting the flue gases with substantial amounts of excess air to reduce concentrations of sulfur dioxide before releasing combustion products into the atmosphere.

There has also been a recent shift from coal-fired boilers to more efficient oil-fired ones, which are often fitted with steel chimneys. Problems such as acid smut production and the following corrosion have increased however. The main objective of the work described in this paper is, thus, to review and analyze the factors affecting these problems, with a view to defining the conditions, for the optimum design to avoid them.

2. ACID SMUT AND CORROSION

The increasing efficiency in the design of heat transfer devices in combustion systems have resulted in lowering flue gas temperatures. Fuels, including coal, oil and gas, may contain as much as 4% sulfur, which oxidizes during combustion to SO_2. A smaller percentage further oxidizes, in the presence of excess air to SO_3. If the exhaust gases from such combustion processes come into contact with a surface at a temperature between that of the water vapour and the acid dew point (at which point condensation occurs) a film of concentrated sulfuric acid forms. The temperature drop in the chimney can be easily checked by the graphical solutions given in reference books such as the Brightside Chimney Design Manual [3] so that the amount of insulation needed can be calculated. Whilst the sulphuric acid dew point is about 132°C, the maximum corrosion rate in steel chimneys occurs at about 110°C, as shown in Fig. 1 which illutrates the potential corrosion rate of flue gases [4].

Acid dew point, hence acid condensation, depends mostly on the quantity of excess air present, the temperature of flue gases, and the sulphuric content in the fuel. After condensation of the acid, the water evaporates and the sulphuric acid dries solid in particles. These particles are then pealed off and carried out

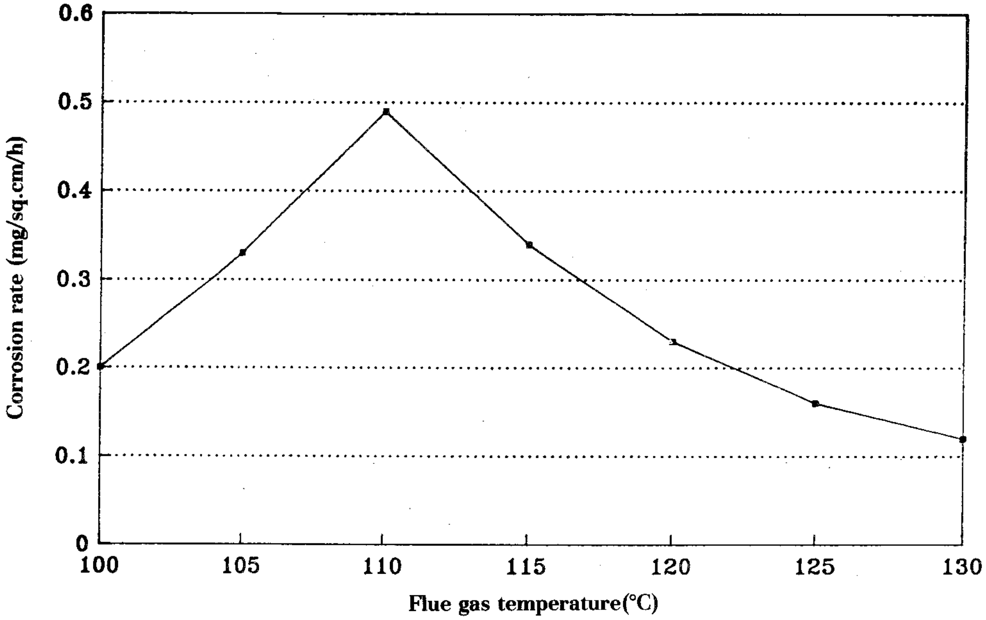

Fig. 1 : Effect of Flue Gas Temperature on Corrosion Rate.

of the chimney in the flue stream, in the form of acid smuts. They may be carried away or fall around the chimney environment. When the acid smut gets moistened, it leaves brown stains, and causes damage to such surfaces as paint-works, vehicle bodies and clothing. The distribution of these solid particles depends on atmospheric conditions such as wind velocity and direction, flue gas velocities, excess temperature over that of the surrounding atmosphere, and chimney height. The later has, recently, been reduced after the use of artificial draught, to reduce cost. Thus, the chances of more deposition of flue dust in the chimney neighbourhood are enhanced.

3. CHARACTERISTICS OF CHIMNEYS

The majority of chimneys in current use are constructed of either brickwork, concrete or steel. Each of these chimneys has its unique features. However, all are subject to three types of attacks; atmospheric (due to wind and humidity) mechanical (due to erosion by grit particles and thermal fatigue) and finally chemical attacks (due to acid production and condensation).

3.1 Brick Chimneys

In this type of chimney, the thermal resistance is high. Accordingly, the temperatures of the flue gases throughout the chimney are also kept high so that they do not fall below the acid dew point within the stack. To protect the main brick structure from these high temperatures, it is common to line the inner surface with a sleeve of refractory bricks. Due also to the high thermal resistance of this refractory brick, a high temperature difference between the inner and outer surfaces of the chimney wall exists and different expansions occur, giving rise to stresses that can lead to cracks in the inner shell. The refractory lining is also susceptible to erosion by grit particles produced within and carried out by the stream of flue gases. However, a low rate of erosion attack upon the brick structure can be obtained by using high density and low porosity bricks.

3.2 Concrete Chimneys

Concrete chimneys are subjected to similar thermal and mechanical attacks, as are brick chimneys. There are two types of these chimneys; monolithic and precast. The surface of the monolithic type often has many minute hair cracks. These cracks extend and become worse when water is drawn into them by capillary action. If this moisture gets as far into the concrete as the reinforcing steel bars, it will cause rust and corrosion. The precast concrete chimneys also suffer from the same type of attack, but in a different way, as they do not have the initial minute cracks. But, the water gets in by the wind when it bends the chimneys at the joints. Consequently, hair cracks appear and the steel reinforcement is attacked by moisture.

3.3 Steel Chimneys

Steel chimneys are usually of riveted plate construction. In this form, they are especially prone to abrasion by grit particles which are common in flue gases. Frequently, rivet heads on the inner walls of the chimneys become completely eroded. Complete erosion of steel chimney shells by grit is particularly rapid due to the relatively thin walls required in the chimneys of this typpe. Although abrasion by grit particles has disappeared with the introduction of oil-fired economic boilers, other serious problems have resulted such as the reduction in chimney life due to the more acid smut production because of the relatively lower temperatures produced.

Bare steel surfaces corrode rapidly when exposed to atmosphere and mechanical properties are consequently deteriorated. Wind loading does not usually cause serious problems to steel chimneys, as small deflections can be accommodated by the elasticity of the steel. However, tall and self-supported steel chimneys may be subjected to wind-excited oscillations. These are produced by Von Karman vortices from each side of chimney. A solution for this problem has been introduced in the form of helical stacks, wound round the upper part of the chimney. Although this is a bit more expensive, the regular formation of vortices is offset and a small damping force is provided.

Performace of chimneys is dependent, in general, on design and operation criteria and lots of other things such as stack head required, allowable friction loss and plant elevation. Some of the operation criteria are: least acid condensation, least smut emission and, finally, least 'downwash' which is sometimes observed when exhaust gases leave the chimney and are caused by wind to swirl down the upper part of the stack on the leeward side. The main factors affecting these criteria are thermal insulation, flue gas properties (velocity, temperature and composition) wind and characteristics of fuel being burned. Two of these factors, namely, the thermal insulation and the flue gas velocity, are discussed in detail below.

4. THERMAL INSULATION

Modern economic boilers are being designed to keep the temperatures of exhaust gases at relatively low values by heat recovery devices placed in the flue gas stream. To counter the problem of smut emission and the subsequent corrosion, it is necessary to retain enough heat in the flue gas during its passage through the chimney, so that at no point does the temperature fall below the dew point. One way of satisfying this condition is by thermally insulating the chimney surface, thus, keeping the temperature of the flue gases throughout the chimney high enough, to prevent condensation of acid on the inner surface of the chimney.

Two methods for thermal insulation of steel chimneys are in common use today. A combination of the two of them is recommended for optimum performance. These methods are:

(a) Cladding the chimney with a high thermal resistance material such as mineral wool, applied to the outside surface of the chimney shell in strips of appropriate thickness, This is then covered with a thin skin (approximately 16 gauge) of bright aluminium sheet. This method is known as material insulation.

(b) Cladding the chimney with bright aluminium sheet as described above but arranging it so that an annular gap exists between that sheet and the steel shell. Current British Standards indicate that this gap should be 6 mm. The air inside that annular gap, which is trapped without leakage over the whole length of the chimney, acts as an insulant. Its effectiveness depends on the heat transfer properties and the physical dimensions of the cavity. These dimensions are critical, as greater air space increases convection heat losses, whilst smaller air space increases conduction heat losses. This method of insulation , known as aluminium clad annular cavity, is generally accepted as one of the simplest, most efficient and durable form of thermal insulation to steel chimneys.

The second method (aluminium clad annular cavity) can be used in installations having flue gas temperatures exceeding 260°C, without the risk of smut emission and corrosion. But with lower flue gas temperatures, it becomes necessary to have a layer of insulating material between the aluminium cladding and the steel flue. This conclusion was drawn [5] after experimenting with aluminium cladding insulation, keeping an air gap of 6 mm, as recommended in the standards. However, there is a strong doubt whether this 6 mm air gap provides the optimal separation for maximum thermal resistance. This is not a surprise judgement since recent findings of the optimal insulation separation for rectangular shapped cavities [6] differs from the British Standards. Also, heat transfer measurments by Etoc and Gills [7] for 6 mm and 20 mm annualar cavity chimneys show that heat losses for the 20 mm air gap are 15 to 20% less than those measured for the 6 mm air gap, irrespective of flow gas velocity. The 20 mm air gap was arbitrarily chosen and there is no suggestion that it represents the optimal separation.

5. FLUE GAS VELOCITY

Flue gas velocity is also a crucial parameter governing the performance of chimneys, specially steel ones. Etoc and Gills [7] also showed that the overall thermal resistance of a chimney decreases with an increase in flue gas velocity, as shown in Fig. 2. They also showed that the gas outlet temperature increase with higher mass flow, as appears in Fig. 3.

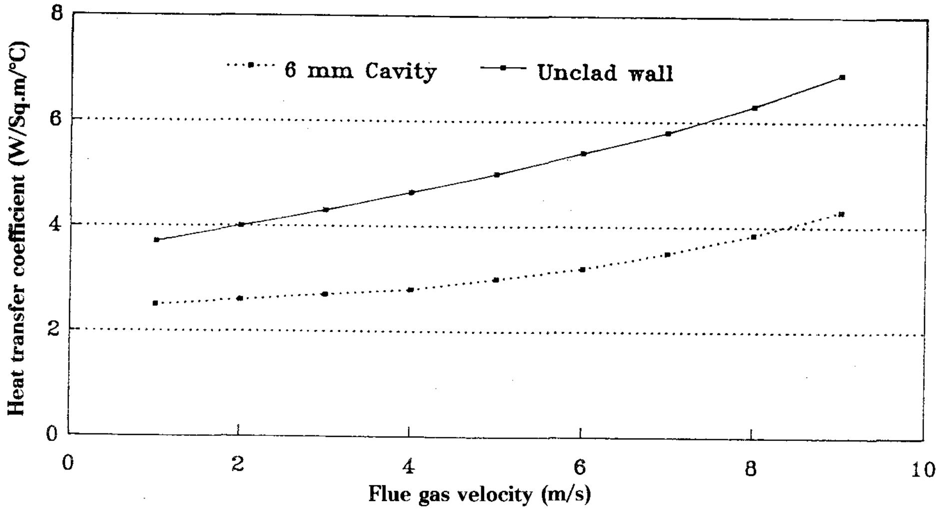

Fig. 2 : Effect of Flue Gas Velocity on Heat Transfer Coefficient.

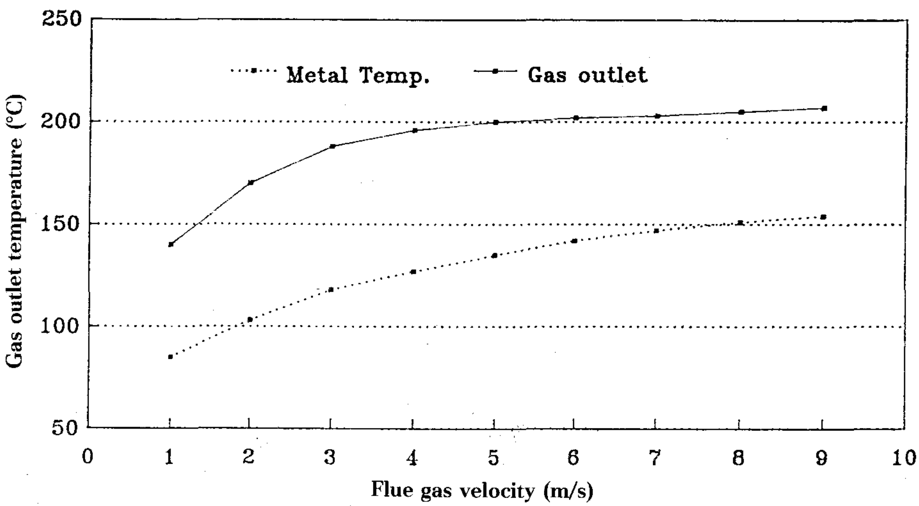

Fig. 3 : Effect of Flue Gas Velocity on Gas Outlet Temperature.

Work by Beaumont et al. [8] has yielded results, as given in Fig. 4, from which the required overall thermal resistance of a chimney of given dimensions can be determined, in order to avoid acid condensation, for any assumed minimum flue gas entry velocity. They also derived a relation giving the flue gas condensation at any point in the chimney, to avoid acid condensation at the top. This relation is:

$$t - t_a = \frac{(t_d - t_a).r}{r - r_l} \exp \frac{\pi.D.(H-z)}{M.c.r}$$

where

t	=	Flue gas temperature at any point in the chimney (°C)
t_a	=	Ambient temperature (°C)
t_d	=	Dew point temperature, including a safety margin (°C)
r	=	Overall thermal resistance (flue gas to air) m^2 °C/W
r_l	=	Thermal resistance, offered by the flow of flue gas, to the inside of the chimney (m^2 °C/W)
D	=	Diameter of chimney (m)
H	=	Height of chimney (m)
z	=	An arbitrary distance measured up the chimney (m)
M	=	Mass rate of flue gases flow up the chimney (Kg/s)
c	=	Mean specific heat of flue gases (J/Kg °C)

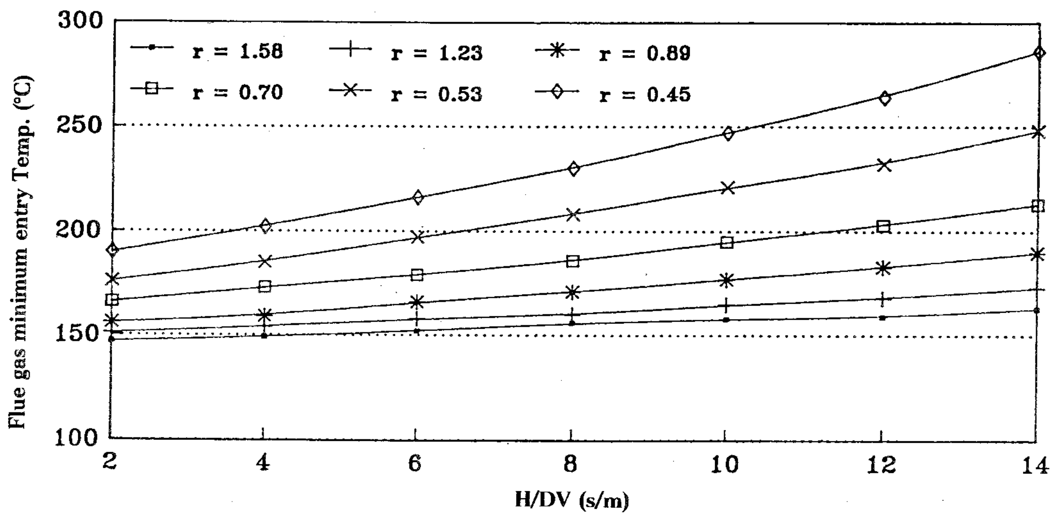

Fig. 4 : Effect of Heat Transfer Coefficient and Flue Gas Temperature on Acid Condensation.

This relation is especially useful in finding the minimum chimney inlet temperature compatible with no acid condensation (when z=0). In general, the flue gas velocity depends on the gas flow rate and the cross-sectional area of the chimney. It is a variable quantity, and the turn-down ratio is the governing factor for that amount of variation. The turn-down ratio is defined as the ratio of the mass of the steam produced per unit time by the boiler, when on maximum load, to that produced per unit time, when on minimum load. To reduce the problem of turn-down, the modern trend is to employ one flue for each boiler. Recent designs have accommodated that and have allowed several flues to be incorporated in one chimney. Finally, Fig. 5 illustrates the variation in average temperature of a particular chimney due to the change on boiler conditions over a period of 24 hours.

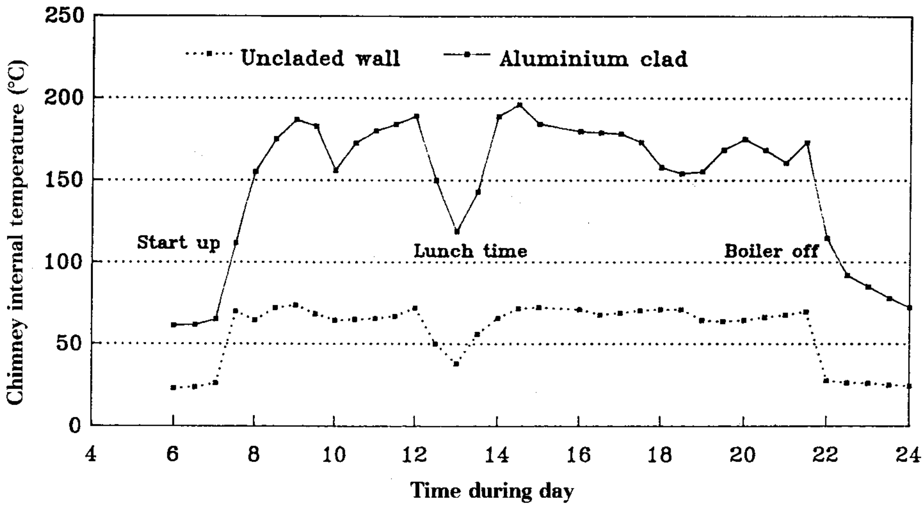

Fig. 5 : Effect of Cladding on Chimney Internal Temperature.

6. SUMMARY AND CONCLUSIONS

The following points can be concluded from this preliminary study on the factors affecting the acid smut production in industrial chimneys and the design considerations for the prevention of its formation:

(a) The majority of chimneys, in current use, are either brickwork, concrete or steel chimneys. Each of these chimneys has unique features. However, all are subjected to three different types of attacks; atmospheric, mechanical and chemical.

(b) Some of the operation criteria upon which the performance of industrial chimneys are judged are: least acid condensation, least smut emission and least 'downwash'. The factors affecting these operation criteria are: flue gas properties, thermal insulation, wind and characteristics of fuel being burned.

(c) The effect of flue gas velocity is crucial on performance of chimneys, especially the steel ones. Increasing the velocity decreases the overall thermal resistance of the chimney and increases the gas outlet temperature to atmosphere.

(d) The required overall thermal resistance and the flue gas temperature at any point in a chimney of given dimensions can be determined, in order to avoid acid condensation on the surface of the inside wall of the chimney.

(e) Aluminum clad annular cavities can be used in installations of steel chimneys having flue gas temperatures exceeding 260°C. With lower temperatures, it is necessary to have a layer of insulating material between the aluminium cladding and the steel flue. An annular air gap of 6 mm is recommended in the British standards. However, there is a strong doubt whether this gap is providing te optimal separation for maximum thermal resistance. Current research is progressing, to investigate this point.

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