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Effect of Operational Parameters on Performance of Lime Shaft Kilns

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KILN: LIME SHAFT

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INTRODUCTION

THE behaviour of a lime shaft kiln is characterised by a large number of operational parameters, such as the calcining temperature, operating draft, limestone size and composition, type of fuel, and the limestone and fuel feed rates. In general, the effects of these parameters on the kiln performance in terms of production capacity, product quality and thermal efficiency are inter-related owing to the interaction of one influencing variable with the others. Major developments in the kiln design (1–41) for lime calcination have taken place in some of the industrialised countries, namely USA, Federal Republic of Germany, UK and Japan. The advances in the typical designs of lime shaft kilns are already described in an earlier paper (38). The available literature represents only a small fraction of the enormous work done in this field. The vertical shaft kilns have been designed and developed to achieve peak performance and high thermal efficiencies. However, most of the designs for the improved kilns are covered by international patents.

IMPORTANT PARAMETERS

Temperature

The performance of a lime shaft kiln is predominantly affected by the operating temperature. Pure limestones of calcitic and dolomitic types decompose at temperatures of approximately 900°C and 725°C respectively at atmospheric pressure. In the first part of the series on the 'theory and practice of lime manufacture', Azbe (17) has given the effect of temperature on the calcining time, as reported by several investigators, for a 150 mm limestone. Wide variations in the calcination time corresponding to a given firing temperature were observed. Different calcining times could be obtained by varying the gas velocity, the radiation characteristics, surface orientation of limestone, etc. An increase in temperature enhances the calcination rate by lowering the calcining time and vice versa. The burning of limestone at higher temperature for extended periods of time tends to overburn the product, causing lime shrinkage with consequent reduction in its reactivity.

Draft

The draft employed in a lime kiln also exerts a tremendous influence on the operation and performance of the kiln. The flow of gases through the bed of solids follows the laws of fluid dynamics and Azbe (11' 17) recommended the use of the 'Fannings' equation to estimate the draft loss,

$$\frac{\triangle P}{\rho} = \frac{(4f)\, LV^{x}}{2g_cD} \qquad \ldots (1)$$

where, $\triangle P$ (pressure drop), f (friction factor), ρ (density of gas), L (height of bed), V (gas velocity based on empty cross section), g_c (gravitational constant), and D (diameter of passage). The friction factor, f, is governed by the Reynolds Number (DVP/μ) where μ is the viscosity of the gas.

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According to Balazsovics (18), the gas velocity is directly related to the production capacity of the kiln by the relation. $V \alpha P_s$, where P_s is the cross-sectional capacity t/m^2/day. From the above two relations, $P_s \alpha (\triangle P)^{0.5}$. Thus the production capacity of a kiln can be enhanced by judicious application of a draft system. On the basis Azbe (3,5) investigated the effect of employing mechanical draft systems, namely forced, induced and balanced, on the kiln capacity. He reported that the capacity of an existing kiln could be increased from two to four times by proper application of such draft system, the maximum effect being realised by application of the combined induced and forced drafts in the balanced form.

Type and Size of Limestone

The size, shape, and composition of limestone affect the time of preheating, calcining, and cooling. The physical properties of limestone such as specific heat, thermal conductivity etc., depend to a great extent upon its chemical composition. The passage time in the kiln varies from about 10 hours in modern kilns to as much as 100 hours or even more in some of the older type kilns. To determine the degree of calcination two terms called 'calcination constant' and 'calcining effort' are defined by Azbe (17) He concluded that the heating and calcining times are directly related to the square of stone size. Azbe has also given a graph called 'stone chart' to determine the maximum size of stone for natural and mechanical drafts.

The stone dimensions and shape are important factors in the rate of calcination and in the design of kiln (4). Because of the lower calcining time for the smaller size of limestone, higher capacity increase can be achieved through the use of smaller stone sizes. Azbe, however, claims that the use of small stone in a given kiln with a given draft system will not give as high a capacity as large stone in spite of the fact that small stone calcines rapidly. According to him for any given kiln height, the draft for an equal flow of gas will be four times when stone size is reduced to half. The major advantage in calcination of small stones is the increase of surface area per unit volume of bed. Eigen (23) has considered the burning of small sized limestone in a cross-current shaft kiln and concluded that small sized limestone can be burned in the high coke fired shaft kiln more economically than in the cross-current kiln.

Specific heat data for the limestone, limes and combustion products are reported by Azbe (16) and Murray (32). The integrated values of specific heats for various temperature ranges are given in the form of nomographs. The importance of such data has been highlighted as the errors in available figures and misapplication of data lead to erroneous heat balance and, therefore, contribute to improper kiln design.

Feed Rates and Products withdrawal

During the operation of a lime kiln, the feed input and product output rates are to be regulated and synchronised with the desired capacity and quality of product keeping in view retention times in various zones. Sophisticated kilns have been developed with elaborate arrangements for materials charging and product withdrawal as reported in the earlier paper (38). Azbe (4) has indicated that a kiln with automatic draw to loosen the charge and move the fines will give about 16 per cent higher production over the same kiln, if discharged manually.

Fuel and Firing Systems

The fuel used and its method of burning have been observed to wield significant influence in the operation and performance of a lime shaft kiln. A gas or oil fired kiln for a unit volume obviously produces greater quantity of lime than the solid fuel fired kiln. However, the preference of pulverised coal firing over coke firing has been reported by Eigen (31). High output, low fuel costs, availability of 93 per cent free CaO soft burned lime, and ease of separation of fly ash by screening have been described.

PERFORMANCE INVESTIGATIONS

Azbe (6) conducted a series of experiments to determine the rate of weight loss of calcining limestone with surface to center temperature differential and also the factors essential for maximum kiln capacities. These tests on the kilns proved that production rate depends on the gas rate and this in turn depends on the draft. Azbe (17) reported the experimental data and correlated the convection heat transfer coefficient, h, in Btu/hr. ft² °F by equation 2 whereas Balazovies[8] by equation 3.

$$h = C (V)^{0.7} \quad \quad (2)$$

$$h \alpha (V)^{0.5} \quad \quad (3)$$

where C is constant and equals 1.444

V is the superficial gas velocity based on kiln cross section, ft/sec.

Azbe (11) has discussed the requirements of combustion air and fuels in lime burning and concludes that for obtaining good quality and low cost lime there are certain fundamental requirements which must be satisfied. These are:

(i) Proper fuel combustion and steady supply of heat to the kiln, (ii) Proper heat distribution in the kiln, (iii) Uniform drawing of lime through the different shaft cross-sections, (iv) Complete cooling of lime and recovery of heat, (v) Temperature control of the hot zone by economical means, (vi) Ample draft to obtain a high capacity, (vii) Appropriate arrangements to facilitate operation.

Azbe has also recommended centrally located automatic gas producers of mechanical type for high capacity, and integral gas producers with forced draft system and employing hot zone recirculation of gases for lower capacity kilns. An overall perusal of Azbe's work(2-17) indicates that a generalised model to predict the effect of simultaneous variation in important parameters on kiln performance is yet not developed.

Balazsovics(18) has vividly described the importance of the thermo-chemical processes in line burning kilns. The attainable maximum productivity of a kiln is influenced by the formation and operation of the burning zone of a lime shaft kiln. He has investigated the effect of different factors on the heat transfer and also on the output of the lime shaft kiln and observed that the heat transfer coefficient in the burning zone is proportional to the square root of the superficial velocity of the exhaust gas based on the empty cross section of the kiln. Since the gas velocity is directly related to the cross-sectional capacity, the heat transfer coefficient, h (KCal/m² hr °C), is related to the capacity P_s (t/m²/day) by the correlation:

$$h = K\,(P_s)^{0.5} \quad \cdot\cdot \quad (4)$$

so long as the other factors influencing the heat transfer remain unchanged, 'K' is a constant and for the usual temperature and sizes of stone it can be assumed to be about 12.5. Balazsovics recommends that the above heat transfer coefficient must be multiplied by a factor of 0.75 to account for the surface irregularity of limestones and also for the decrease in available surface for heat transfer. The time period of burning for the practical shape of stone has been given by the equation

$$t_b = \frac{W\rho_s}{\Delta\,\theta_m}\left(\frac{d_p}{6.0 \times 0.75\ h} + \frac{d_p^2}{24\,K}\right) \quad \cdot\cdot \quad (5)$$

where, W (quantity of heat in K cal/kg required for the decomposition of 1 kg limestone), p (bulk density of limestone, kg/m³), $\Delta\theta_m$ (mean temperature difference between exhaust gas and dissociation layer of the stone in °C), d_p (diameter of the stone, m) K (thermal conductivity of stone, K cal/m hr °C).

Balazsovics has further considered the unavoidable overheating of lime resulting in additional heat requirement of about 10 per cent and assuming constant values of $\rho_s = 2700$ kg/m³, $\Delta\theta_m = 170$°C, the equation (5) has been modified to:

$$t_b = 7000\left(\frac{d_p}{4.5\ h} + \frac{d_p^2}{24\,K}\right) \quad \cdot\cdot \quad (6)$$

It is therefore feasible to develop burning times for different types (compositions) of limestones for the range of sizes employed in calcination. Balazsovics has further observed that for large lumps of stone, the thermal conductivity of the stone decisively affects the kiln output, and the mean temperature differential is very important. He has also reported equations relating the behaviour of burning zone with recycling of the exhaust gas and concludes that burning zone with recycling is justified only when an overburning of the lime cannot be avoided by other means.

Major research investigations in Federal Republic of Germany have been carried out by Eigen, mostly on Coke-fired lime shaft kilns(20, 24-26) He observed that the lime output in tonnes per square meter of cross section is directly proportional to the depth of the burning zone and inversely proportional to the true burning time and that the combined coke and gas fired lime shaft kilns give a much higher production rate for such kilns (20). Summarizing the problems of coke-fired lime shaft kilns, Eigen (24) points out that the lime output per square meter of shaft cross-section per day increases with increase in heights of decarbonation and coke combustion zones. High burning efficiency is achieved for small grained limestone with relatively coarse coke free from fines especially if the limestone and coke are closely classified and the effective height is relatively large.

While discussing the technical limits of heat consumption in coke fired lime shaft kiln, Eigen (25) concludes that in the heat calculations for the main thermal system of the kiln the heat of reaction at 20°C should be adopted as a suitable basis for burning and cooling zones, the actual value of the heat of reaction is mainly dependent on the magnitude of the temperature differential between the gas and the material boundary at the junction of the burning zone and the preheating zone. The thermal efficiency of the lime shaft kiln can be increased to 90 per cent simply by reducing this temperature differential to 30°C and he could, therefore, bring down the heat consumption to 774 KCal/kg of burnt lime with 93 per cent free CaO as against the normal heat consumption of the order of 1000 KCal/kg of lime produced. Eigen has recommended a longer preheating zone for bigger size limestone to effectively lower down the temperature differential. He has suggested an optimum size of 150 mm for the limestone in order to achieve high output accompanied with low heat consumption.

Reporting his investigation on the burning of small sized limestone in a coke fired lime shaft kiln, Wuhrer(41) observed that a significantly higher output of reactive lime for small sized stone cannot be realized on account of hard burning due to excessive temperatures. With increasing output of lime the heat transfer coefficient due to radiation is much greater than that of convection, and this tends to overburn the lime adjacent to the coke especially if the stone size is small. For obviating temperature peaks, he considers it more advantageous to burn small sized limestone in shaft kilns with only a part of the requisite heat to be supplied by coke, while the remaining heat may be supplied by installing a gas or oil fired zone after the coke combustion zone. This was also observed to enhance the production capacity per square meter of kiln cross-section.

Parson (33) has pointed out the following advantages of the vertical shaft kiln; simplicity of construction and operation, higher thermal and volumetric efficiencies, minimum deoripitation of solid products, and minimum erosion of refractory linings due to slight movement of particles relative to each other. He points out that the gas kilns popular in America have never matched the efficiency of the mixed feed kilns used in Europe. According to Parson it is impossible to produce perfect quality of lime, that is, 100 per cent core free and uniformly soft burned lime, in a shaft kiln. He further remarks that all the defects of the vertical kiln namely, irregularity of operation, unburnt core and overburnt surface, deterioration of refractories, etc., can be blamed on one common characteristic, that is, channeling with the result that some parts of the shaft kiln run at a higher temperature than others.

The process engineering problems of lime shaft kilns have been elucidated by Jeschar (30). He observes that though considerable improvements could in fact be achieved in some plants but it is not possible to predict the behaviour of a particular kiln in all respects. He has obtained certain design equations for the kiln under idealised conditions of operation, such as, the equations for the estimation of effective heat transfer coefficient in bulk materials, and the kiln heights in the preheating and calcining zones. For a complete understanding of a lime shaft kiln it is not only necessary to know the heat transfer characteristics, and the course of reaction, but also the loss of pressure caused by the flow of gases through the kiln because this affects the productivity as well as the costs for maintaining the necessary draft for the flow of gases.

The manufacture of good quality lime under most economic conditions has been highlighted by Flachsenberg (28). He has presented a comparison between the shaft and the rotary kilns, and suggested the guidelines for the selection. For an output of less than 400 tonnes per day, the rotary kiln has been ruled out because of high first cost and fuel costs. Low energy consumption is another factor favouring the selection of a shaft kiln. Flachsenberg has also numerated the limitations of the shaft kiln according to whom its lack of flexibility with regard to the type of fuel, the sizing of the limestone, and the controlled production of various grades of lime with specific degrees of burning is a drawback.

GENERAL DEVELOPMENTS

For obtaining an efficient operation of a lime kiln the role of instrumentation and control has been emphasized by Azbe (12) especially for modern kilns incorporating complex design features. Hot zone recirculation of gases has been suggested for temperature control. Separate draft controls are described for kiln fan motor and producer fan motor in a gas fired kiln. The significance of measurement and control engineering in lime burning have been discussed by Ruch (3 He has numerated several variables which should be measured by direct or indirect means to execute the process for an optimal operation.

Bessing and Schafer(19) have described the importance of industrial electronic computers for the fixation and calculation of quantities of fuel and air for combustion, which are dependent upon several factors in a lime shaft kiln. Three types of influencing variables are categorised and they must be introduced into the computation process. Rapid methods of analysis for raw materials are employed in the lime plant and the results are fed into the computer. Centralised computer control for lime kilns is in operational practice in Federal Republic of Germany since 1962.

CONCLUSIONS AND RECOMMENDATIONS

Survey of available literature, reveals that though some of the most sophisticated lime shaft kilns have been developed to obtain high productivity, lime quality and thermal efficiency of kiln, yet the design of a suitable kiln for a new situation using the basic principles involved in lime burning still remains uncertain owing to the complexities of the process and operational behaviour of a lime shaft kiln. Some serious efforts to develop the fundamental or empirical design correlations to establish the basic design criteria have been made by some foreign investigators for typical kiln designs, especially for gas or oil firing systems. Most of the lime in India, is produced in the vertical shaft kilns as revealed by a recent survey conducted for the building and chemical limes. The building lime, by and large, is being produced in the mixed-feed kilns. It is, therefore, necessary to analyse the performance of these kilns and develop suitable design and performance correlations for efficient utilisation of these low cost kilns in developing countries. From a knowledge of these correlations, it would be possible to make some minor modifications in the design and draft system of the existing lime kilns for optimal operation. Some experimental investigations on the existing mixed feed kilns should be carried out to develop the desired correlations.

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