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TRENDS IN THE DESIGN AND DEVELOPMENT OF LIME SHAFT KILNS

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KILN : LIME KILN

C. L. Verma* and N. B. Saxena**

Central Building Research Institute, Roorkee

ABSTRACT

This paper is a general review on the recent trends in the design and development of lime shaft kilns in India and foreign countries. The chemistry and technology of lime burning have been briefly discussed and various tpyes of commercial lime shaft kilns are described.

INTRODUCTION

Lime has been known to mankind since the time of ancient civilizations. It finds extensive applications in building and in numberous chemical and metallurgical industries. The building lime is classified in different grades depending upon its quality and composition. It is largely employed in preparations of mortars, plasters, pozzolanas, limesand bricks, and for the purposes of whitewashing and soil stabliza-tion. The chemical grade lime is of highest purity and is used, by and large, as captive lime in sugar, paper, soda ash, precipitated chalk, carbide, synthetic rubber, glass, aluminimum, magnesium and steel industries.

Before the advent if cement, lime used to be the principal building material in India. Its importance had been overshadowed during the past few decades because of the rapid increase in the manufacturing capacity and the availability of cement. The shortage of cement in the recent years has led to the glorious redemption of the building lime industry. The increased demand for lime and lime burning kilns has substantiated the need to carry out research investigations for improvement in design and performance of existing lime kilns. A major part of building lime is presently being manufactured in vertical shaft kilns of mixed-feed type. A review on the existing general types of shaft kilns has, therefore, been carried out with a view to investigate the effects of various design parameters influencing kiln design and performance.

Manufacture of Quick Lime

Lime is manufactured by burning limestone rocks, having significant percentage of calcium carbonate, at controlled operating conditions and thus driving off carbon dioxide from the parent stone. The impurties present (primarily silica, almunia, iron oxides, sulphide sulphur, etc.) in the stone are non-volatile in nature and remain as contaminants in the lime produced.

Limestones generally contain some magnesium carbonate also and, depending upon the percentages of calcium and magnesium carbonates in the stone, different nomenclatures are used to classify the limestone, but two basic types are of commercial importance, namely calcite and dolomite. The calcitic stone usually contains calcium carbonate exceeding 95 per cent, and the dolomitic stone has the magnesium carbonate content of 35-40 per cent. In the burning operation, both the carbonates are converted to their corresponding oxides. Dolomatik lime is used largerly in the refractories where a high MgO content is essential.

The principal reactions involved in the calcination of calcitic and dolomitic limestones are;

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* Scientist

** Senior Scientific Assistant

$$CaCO_3 \longrightarrow CaO + CO_2 \qquad (1)$$
(calcite)

$$CaCO_3.MgCO_3 \longrightarrow CaO.MgO + 2CO_2 \qquad (2)$$
(dolomite)

The average dissociation tempertture for the above two types of limestones at atmospheric pressure are 900°C and 725°C respectively. Associated with reactions (1) and (2) are other undersirable side reactions; for example, the sulphur dioxide present in the stone or fuel, tends to react with lime and oxygen to form calcium sulphate, which is unstable at high temperatures. So, for the production of sulphur-free lime it is necessary that the lime remains very hot while in contact with the products of combustion. Alumina and silica combine with both CaO and MgO to form various silicates and aluminates at very high temperatures. These compounds are water insoluble, and are generally undersirable in lime since they represent not only a loss of oxide values, but also coat the lime particles with a water-impervious layer and so reduce its reactivity.

The reactivity of quick lime is also influenced by the higher operating temperatures and retention times. It is well known that the temperature has a predominant effect on the rate of dissociation of limestone. With the increase in temperature, the rate increases and consequently the reaction time decreases. However, maintenance of higher temperatures beyound on optimum limit for extended periods of time leads to overburning of lime. The process of overburning causes sintering, with a consequent increase in density, decrease in surface area and, therefore, the loss in reactivity. The optimum temperature for maximum kiln efficiency varies with composition for different stones.

The physical and chemical properties of limestones and the fuels employed in calcining them play an important role in determining the material and heat requirements of the process for a given type of firing system and draft employed in the kiln. Thus the process engineer-design for the manufacture of quick lime involves careful analysis and accurate estimation of raw material properties and optimisation of important variables, which affect the kiln design and the production efficiency. The major parameters to be controlled in the design and operation of a lime burning kiln are temperature, feed particle size, retention times, kiln draft, feed input rate, the physical properties and chemical compositions of raw materials, lime to fuel ratio, and heat losses.

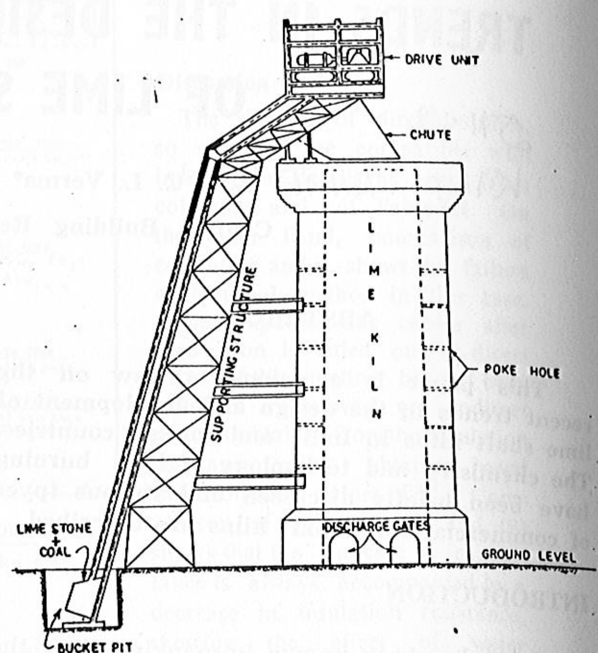

FIG 1 SCHEMATIC DIAGRAM OF A MIXED-FEED LIME KILN

The type and quality of lime produced is considerably influenced by the physical shape and structural design of the kiln, because of their effect on the operating conditions, controls employed for the limestone calcination. The kilns normally used for lime burning are: the vertical shaft, the rotary, and the fluo-solids types. Many variations of these three basis designs have been developed, chiefly in the Federal Republic of Germany, U.S.A., U.K. and Japan. The present review restricts itself to vertical shaft type kilns only because the rotary and the fluo-soilds kilns are still uncommon in India.

Mixed Feed Kilns

Mixed feed lime kilns 1, 5, 6, 11, 12, 20, 21, 25, 26, 34, 35, 37 are widely employed in the European and the oriental countries, but they

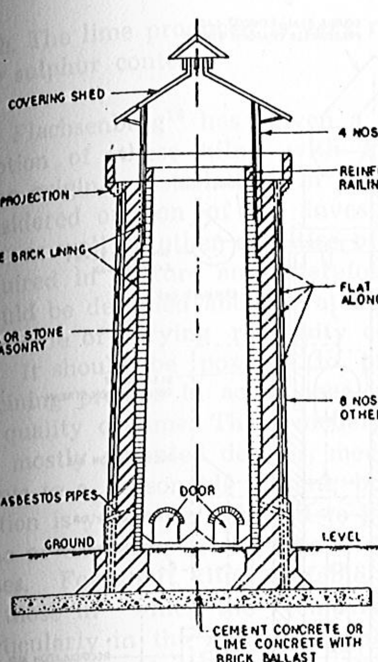

FIG 2 SECTIONAL ELEVATION OF A MASONRY LIME SHAFT KILN

are comparatively less popular in U.S.A. These kilns have good thermal efficiency and give a gas with high carbon dioxide concentration. Thus industries using both lime and gas, such as alkali industry, sugar refining plants and basic magnesia plants depend entirely on such kilns. Small scale production for building lime is also carried out in mixed feed kilns in many developing countries, including India.

A schematic diagram representing a vertical mixed feed lime shaft kiln is given in Figure 1. It is usually a tall cylindrical structure lined inside with refractory and insulating bricks. The fuels employed for burning limestone may be coal, coke, charcoal, cinder, or wood. A uniformly mixed proportion of limestone and fuel is lifted by skip hoist to the top of the kiln and charged into the kiln. The kiln can also be charged with alternate layers of limestone and fuel. The charge travels down through the kiln to a rising stream of combustion products. The lime produced is removed from the bottom of kiln by some suitable means.

Basically, the kiln operates in three zones, namely the perheater, calciner, and cooler. The middle calcining zone operates at elevated temperatures in the range of 900-1200°C for obtaining soft burnt lime, and the upcoming gaseous products from this zone preheat the mixture of limestone and coal. Air for combustion is introduced at the bottom of the kiln and it is preheated while cooling the product lime in the cooling zone near the bottom. There is always some amount of unavoidable crushing of lime during its downward movement into the kiln, and the material collected consists of lime, lumps and powdered lime contaminated with fuel ash and clinkers from coal and coke.

Shaft kilns are constructed in masonry as well as steel structures lined inside with refactory bricks. In India, building lime is, by and large, produced in small capacity masonry kilns. The sectional view of a masonry shift kiln is shown in Figure 2. The steel structures are normally designed for higher capacities and are generally equipped with mechanical draft system. The recent developments in such kilns are normally concerned with the charging and drawing methods. Figure 3 represents a steel shtft (mixed feed) lime kiln. The existing mix-

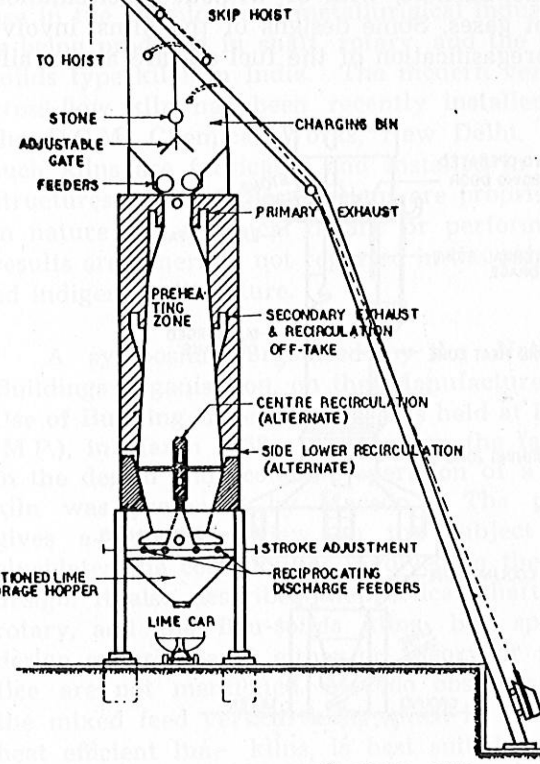

FIG. 3 GENERAL DETAILS OF AZBE'S MIXED-FEED (STEEL SHELL) LIME KILN

ed feed kilns are suitable for burning large size stone, say 75-150 mm, but by incorporating temperature control and proper draft application, burning of small stone is also feasible.

Oil or Gas Fired Kilns

Oil or gas-fired vertical shaft kilns 2-4, 7, 13, 14, 19 22-24, 28-31 are also, in general, cylindrical structures with suitable arrangements for burning the limestone, which is charged into the kiln from top, with oil or gas. Some suitable fuel oil, normally the furnace oil, is employed for firing the kiln. Combustion of the oil can be effected either in the external combustion chambers or within the kiln body itself but the heat consumption per kg of lime has been reported to be comparatively less in the latter case.[19] The producer gas, natural gas, etc. may be used as the gaseous fuel. Uniform distribution and flow of combustion gasses along with air are essential prerequisites for the efficient performance of these kilns. The kiln design also specifies suitable burners, depending on the choice of the fuel. Typical kiln designs have been developed with centre and/or side burners, with or without recirculation of hot gases. Some designs of the kilns, involving pregasification of the fuel oil, are also available. Most of such designs are either patented or of proprietory nature. Some of the reported kiln dsigns are shown in Figure 4 and 5. The main advantages of these kilns over the mixed feed kilns are higher capacity, better quality and non-contamination of the product lime with fuel ash.

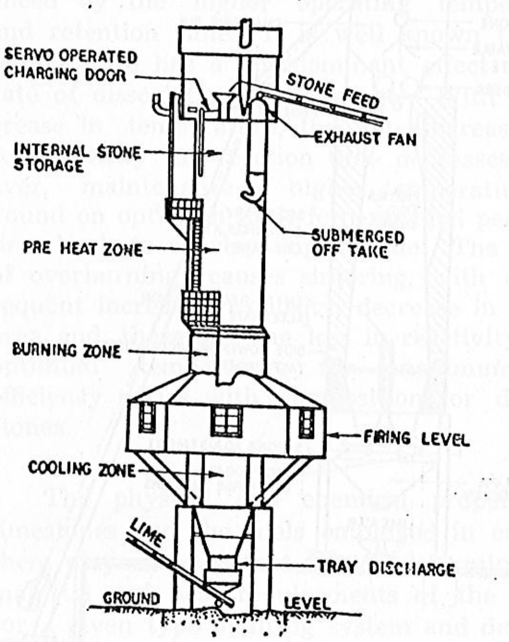

FIG. 4. GENERAL VIEW OF AN OIL FIRED KILN INSTALLTION.

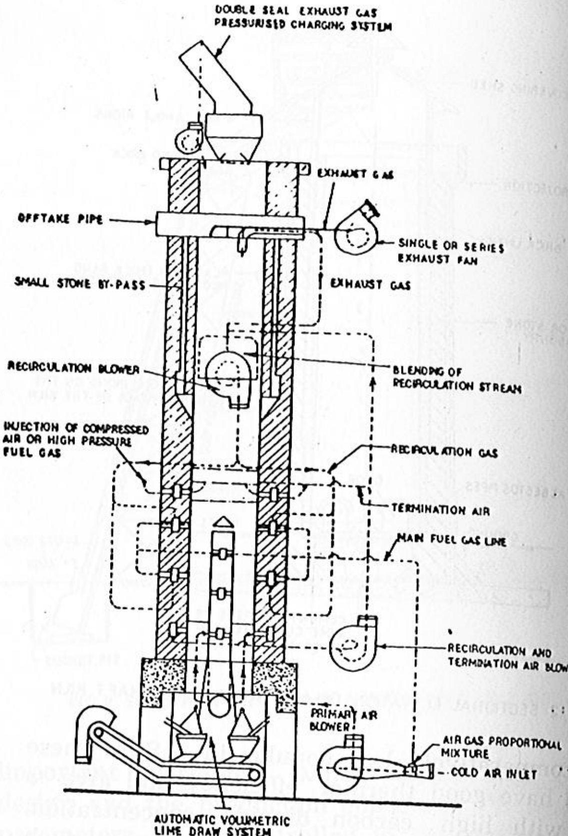

FIG. 5 AZBE'S NATURAL GAS FIRED KILN

Recent Design Developments

Some of the ultramodern oil and gas-fired shaft type kilns, such as the cross-flows[18], double-inclined [9,13,33] paralled-flow regenerative shaft kilns[13, 15, 17, 18, 33, 34], and the annular shaft kilns[8–10, 13, 39] have been recently developed. Such kilns have been successfully installed and operated in the Federal Republic of Germany, U.S.A., Japan, and some other countries. These kilns have been observed to be highly economic with nominal capacities, generally in the range of 100-600 tpd, but the initial investment on these kilns is quite high. The lime produced is very reactive and of low sulphur content.

Flachsenberg[13] has given a detailed description of these kilns with illustrations of some original installations in Germany. In the considered opinion of the investigator, active lime as well as other qualities of lime shall be required in future and, therefore, lime kilns should be designed and operated in such a way that lime of varying reactivity can be produced. It should be possible to programme the calcining process in accordance with the desired quality of lime. These modern kilns, which are mostly patented designs, meet this requirements to a reasonable extent, but more information is yet to be obtained to properly fix the time of exposure of the feed in the inlividual zones. For shaft kilns, suitable designs would be those in which the temperature profiles, particularly in the zone of terminal calcining, can be adjusted and held constant.

Miscellaneous Shaft Kilns

Apart from the generalised types of shaft kilns discussed earlier, severtl other designs [6, 15, 16, 27, 29, 30] are also developed by making minor modifications in kiln shape and structure, location of fuel injection system, etc. Some developments of the lime shaft kilns have been reviewed by Azbe,[6] Gribbin,[15] and Shaw[36] The 'Ultimous' kiln was invented by Azbe.[7] The details of this positively controlled gas-fired kiln are given in the paper. Pelletized mixed coal stone feed is usefully fired in a lime shaft kiln.[16] Kilns have also been developed which lend themselves to convenient firing both with oil and gas.[27,30] A new design of oil-fired lime shaft kiln based on the 'categas' system of oil gasification has also been reported.[29] This kiln is basically a conventional gas-fired design with catagas units fitted at the bottom of the burning zone. The UCM's vertical lime kiln is another design. It is a gas-fired square cross section kiln with additional lime storage zone at the top and the exhaust gas off take pipe at the bottom of this zone.

Development of Lime Kilns in India

Building lime is being produced in India largely in the small scale and cottage industries. Several types of lime burning kilns have been in vogue since the ancient times, namely the stack or heap kilns and the intermittent kilns of batch type. These kilns, being primitive, are highly inefficient and produce lime of unpredictable quality. Such kilns, commonly termed as country kilns, are constructed in various shapes and sizes, i.e., rectangular, cylindrical, concial etc. The improved vertical shaft kiln, constructed in masnory and based on intermediate technology, is rather a recent development in the country and its use is presently being advocating by the Central Building Research Institute, Roorkee, and the Khadi and Village Industries Commission, Bombay, for the manufacture of building lime at smaller capacitiies of production. The other types of shaft kilns or the rotary kilns are yet to be used in the country to achieve much larger capacities of building lime production, say exceeding 26 tpd. These vertical shaft kilns, in general, operate on natural draft, and higher production capacities can be achieved by the study and application of suitable mechanical draft systems on the existing kilns.

A recent survey indicated that the lime for use in the chemical and metallurigical industries is being produced in shaft, rotary, and the fluo-solids type kilns in India. The modern vertical cross-flow kiln has been recently installed by the D.C.M. Chemical Works, New Delhi. All such kilns are fabricated and installed in steel structures. Most of these designs are proprietory in nature and technical details or performance results are generally not reported in the published indigenous literature.

A symposium, organised by the National Buildings Organisation, on the 'Manufacture and Use of Building Lime in India' was held at Rewa (M P.), in March 1958. A paper on the factors in the design and economic operation of a lime kiln was presented by Macedo.[25] The paper gives a general review on the subject and elucidates the complexities involved in the klin design. It also describes the vertical shaft, the rotary, and the flou-soilds kilns, but specific design criteria based either on theory or practice are not mentioned. Macedo observes that the mixed feed vertical klin, which is a highly heat efficient lime kilns, is best suited to the Indian conditions and recommends its further development to suit the local conditions economising on cement and steel.

In another paper, Govinda Krishnayya[14] persents salient features on the design of oil-fired lime shaft kilns. The operational advantages of oil firing over solid-fuel firing are outlined and he concludes that, for the manufacture of lime as a building material in comparatively small size shaft kilns, the oil firing system is neither practical nor economical. Only for huge output kilns, oil firing can be justified. However the authors believe that, for the production of better building grade and chemical lime, development of oil-fired kilns be encouraged, but it may not be an economically viable proposition under the present oil crisis.

Sharma and Rai[35] conducted a study of the lime industry at Dehradun, U.P. The country batch type and vertical semi-continous type (conical shape) kilns were investigated for their general design featurs. They concluded that the design of those kilns and their burning methods do not embody any heat exchange principle. It is now well established that the country kilns popularly knows as 'Bhattas', existing in the country, are of primitive nature and highly inefficient in operation. The important drawbacks of such kilns are given below:

i) Low thermal efficiency with resultant fuel wastage.

ii) Poor quality product — high percentage of underburnt and overburnt lime.

iii) Poor draft, leading to inadequate production capacities.

iv) Unpredictable kiln behaviour with no operational difficulties.

After a careful analysis of the existing practices of lime burning, Macedo[26] observes that most of the building lime produced in the country comes from the small and cottage scale sectors, where the cost of lime is higher and the quality of the product is uncertain. It is therefore clear that enough scope exist for improvement in the mixed feed vertical shaft kiln design and operation.

Efficient methods of calcination in lime kilns are discussed by Dave[11] with a brief description of the problem of heat dissipation from one source to the other. Dave and Masood[12] also published a survey report on the existing lime kilns in India. They have reported the construction and operational features of some typical kilns, such as the country batch type, Vindhyan kiln, Rajasthan kiln, and fire-bricks lined kiln. In their report, they concluded that most of the lime kilns in operation in India are following the age-old uneconomic practices and need considerable improvements for efficient operation. Dave and Masood further observed that the lime burning is characterised by a large number of operating variables, and optimum performance is achieved by trial and error methods. Authors believe that this degree of uncertainty in optimum klin performance can be eliminated to a considerable extent if the analysis of design and operation of lime kilns for optimum performance is undertaken to investigate and correlate the effect of numerous parameters which affect the thermal efficiency and product quality.

Adhia[1] has reported a nomograph to determine the performance of a lime kiln for use in the chemical industry, where lime and gas both are used, such as the alkali and sugar industries. The nomograph is basically a presentation of material balances in a lime klin. It take into consideration excess air upto a maximum of 5 per cent, whereas the excess air, to an exent of 20 per cent, is not uncommon for such kilns, when operated with mechanical draft systems. Adhia has not made any attempt to predict important kiln design characteristics such as the thermal efficiency and the product quality.

Conclusions

From a persual of the available literature, it is evident that the lime kiln design at present is largely based on the thumb rules deduced from the operational behaviour of such kilns. The trial and error procedures are still employed in India after commissioning the kiln to obtain desired capacity and product quality from the mixed feed shaft kilns for building lime. The available Indian standards [20,21] on mixed feed lime shaft kilns also reflect similar thumb rules. Process design correlations, based on theoretical or detailed performance analysis, have not been obtained thus far. The proper design criteria for fixing kiln dimension for the three zones need to be established from theoretical considerations for feeds of different characteristics for the optimal design of mixed feed kilns.

LITERRATURE CITED

1. Adhia, J. D., Rock Products, **55** (12), 115 Dec. 1952).
2. Anon., Cement and Lime Manufacture, 35(6), 93 (Nov. 1962).
3. Anson, D. H. and Kimberley, I. E., Cement Lime and Gravel, **41** (4), 150 (Apr. 1966).
4. Azbe, V. J., Rock Products, **44** (4), 46 (Apr. 1941).
5. Azbe, V. J., Rock Products, **51** (Nos 2 & 5), p. 106 & 94 (1948).
6. Azbe, V. J., Rock Products, **63** (3), 122 (Mar. 1960).
7. Azbe, V. J., Rock Products, **70** (7), 74 (July 1967).
8. Beckenbach, K., Zement Kalk Gips, **23** (5), 206 (May 1970).
9. Beckenbach, K., Rock Products, **74** (7), 68 (July 1971).
10. Beckenbach, K., Zement Kalk Gips, **27** (4), 182 (Apr. 1974).
11. Dave, N. G., Indian Chemical Journal, p. 1 (Oct. 1971).
12. Dave, N. G. and Masood, I., Paper presented, Seminar on Lime: Manufacture and Uses, New Delhi, p. 98 (1972).
13. Flachsenberg, P., Rock Products, **73** (7), 75 (July 1970).
14. Govindakrishnayya, P., Paper presented, Symposium on Manufacturt & Use of Building Lime in India held at Rewa, p 47 (Mar. 1958).
15. Gribbin, W., Rock Products, **73** (12), 68 (Dec. 1970).
16. Hedges, C. R., Pit & Quarry, **57** (11), 139 (May 1965).
17. Hoffer, H., Zement Kalk Gips, **23** (6), 277 (June 1970).
18. Hoffer, H. et.al., Zement Kalk Gips, **18** (8), 395 (Aug. 1965).
19. Hoffman, F., Zement Kalk Gips, **16** (6), 227 (June 1963).
20. I.S.I., Indian Standards No. 1861 (1961).
21. I.S.I., Indian Standards No 1849 (1967).
22. Kimberley, I. F., et.al., Cement and Lime Manufacture **39** (6), 106 (Nov. 1966).
23. Kohn, G., Zement Kalk Gips, **27** (10), 513 (Oct. 1974).
24. Lacy, G. R., Rock Products, **52** (G), 120 (June 1949).
25. Macedo, N., Paper presented, Symposium on Manufacture and Use of Building Lime in India held at Rewa, p. 47 (Mar. 1958).
26. Macedo, N., Paper presented, Seminar on Building Limes New Delhi (1967).
27. Meyer, H., Zement Kalk Gips, **27** (8), 380 (Aug. 1974).
28. Middlemas, J. W., Cement Lime & Gravel, **39** (5), 151 (May 1964).
29. Middlemas, J. W., Zement Kalk Gips, **17** (6), 263 (June 1964).
30. Minderman, H., Zement Kalk Gips, **16** (10), 443 (Oct. 1963).
31. Rittman, R., Zement Kalk Gips, **23** (5), 206 (May 1970).
32. Roberts, J. E., Chemical Engineering Progress, **59** (10), 88 (Oct. 1963).
33. Schmid, A. and Hofer, H., Cement Lime and Gravel, **42** (Nos. 6 & 7), p. 183 & 220 (1967).
34. Schwarzkopf, F., Rock Products, **75** (7), 85 (July 1972).
35. Sharma, C. S. and Rai, M., C.B.R.I. Roorkee Report (Sept. 1966).
36. Shaw, K., Cement Lime and Gravel, **47** (10), 226 (Oct. 1972).
37. Uppal H. L. and Singh, M., Paper presented, Conference on Research & Industry, C.S.I.R., New Delhi (Dec. 1965).
38. Weinhold, H., Zement Kalk Gips, **18** (8), 404 (Aug. 1965).
39. Yamaguchi, H., Rock Products, **77** (71) 68 (July 1974).

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