Introduction of dry hydrate lime as a building material in Pakistan

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INTRODUCTION OF DRY HYDRATE LIME AS A BUILDING MATERIAL IN PAKISTAN

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SYNOPSIS

Lime is a building material of great antiquity. In the Indo-Pakistan Sub-continent and elsewhere, standard mortar for masonry was either a pure/hydraulic lime or the lime pozzolana mix, till the advent of Portland cement. Since then, it had been relegated to the background, particularly in Pakistan, where its use in mortar and plaster works is absolete inspite of the fact that it still is largely regarded as a building material all over the world.

Cement-edged out lime as it was available in ready to use form, gained initial strength quite rapidly and set in a reasonable time. In contrast, the lime had to be laboreously converted into putty several days before its actual use, needed exhaustive grinding/mixing and thus did no longer appeal to the masons, engineers and the builders.

In order to give lime back its due status, it was essential to produce it in a modified cement like form. The present paper describes the efforts made to produce the finest, reactive and high plasticity lime hydrate powder literally dry for packing in bags to be opened and readily mixed with sand, water and other ingredients at the site of works, just like Portland cement. Hydration conditions and the amount of optimum slaking water have been established for high purity fat lime generally mined in Pakistan. Mortar mixes incorporating produced dry hydrate lime as one of the essential ingredients, have been found to possess adequate compressive strengths, to be safely used in masonry constructions and the plaster works.

INTRODUCTION

Lime has been deployed in construction, to great advantage in one form or the other, from very early times. Its manufacture and use as a cementing and plastering material can possibly be traced as far back as the caveman[1,2] era, the discovery of fire,[3,4] throughout the Moenjo Daro,[5] Egyptian, Roman, Greek and other Mediterranian cultures/civilizations.[6] The lime mortar[7] was amply used in plastering the walls, arches and domes of ancient monuments, indicated by the primitive kilns discovered[6,8] by Archealogists believed to have been used during the sone age for burning lime. Its durability is fairly evidenced by the way, the pyramids built in about 4000 years B.C. in Egypt;[8,9] the Great Wall constructed by the Chinese;[10] Magnificent pre-moghal and Moghal structures; palaces, massive forts, mosques, temples and other historical buildings in the Indo-Pakistan sub-continent,[5,11-14] have withstood the vagaries of time for centuries and are still sound and intact.

Lime is mentioned several times in the old and new Testaments of the Bible.[1,3,6]. Romans under Augustus[6,8,15] built may public works using hydraulic lime as a mortar and also in building the road base of the Appian[6,16] Way; Until the nineteenth century in Europe;[17]; about 1890[18] in the United States and about 1930 in the Indo-Pakistan sub-continent,[5,12,19] when Portland

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cement was developed, the standard mortar for masonry was either a pure or hydraulic lime or the lime-pozzolana mix. As early as 1635, quick lime was being produced in Rhodes Island,[6,20] U.S.A. The oldest brick building at Harvard University's Massachusetts[6,21] Hall, dating back 1730; Independance Hall in Philadephian[22] 1734, and numerous other historical structures were laid in straight pure or fat lime mortar and many are still in surprisingly good state of preservation today.

In the sub-continent, most of the irrigation[5,12,14] works were executed in lime mortar since early times. In about 1850, it was amply used for the construction of the big and small structures relating to the large scales project of Ganga Canal in Northern India. The project was followed by the construction of several barrages, anicuts and dams on a number of rivers. The paramount head works of the Ganga Canal were constructed during 1912-19; while the engineering works in the Mysore State included Vani Vilas Sagar, Krishnaraja Sagar, Hirebhaskar dams and in Bombay State, the Mulshi dam. The practice of construction of irrigation works in lime continued, generally till about the end of the first World War, about which time Portland cement came into some prominance and its use was started in the construction of hydraulic works. However, even for a few years after cement became available, Engineers continued the practice of construction of hydraulic structures in lime. For the construction of Sukkar Barrage[5] in Sind during 1923-33, an artificial hydraulic lime manufactured by burning an intimate mixture of slaked fat lime and clay was used. The magnificient Shalimar Gardens; Badshahi Mosque and the Fort; Empror Jehangir's Tomb; Wazir Khan's Mosque; Chauburji Gardens and many other structures in Lahore are the existing glorious examples of the use of lime in the pre-portland cement era.

In about 1957, on account of acute shortage of cement, attempts[5,23] were made in India to revive the use of lime mortar in place of cement. It was decided then that no cement should be used in permanent or other type single or double storeyed buildings for walls and Plastering on the inside must be done in lime mortar, wherever possible. All gravity dams or proportions of dams less than 100 ft. high should be built in hydraulic lime.

The commercial hydration of lime in the U.S.A. was initiated[6,24] in 1904. Technical progress while non existing in the centuries past; rapidly advanced the industry since then. Although between[25] 1895 and 1910 its predominance as the mortar and plastering material was seriously challanged[6,8,17,25] by Portland cement, yet in view of its rich and venerable heritage in construction, lime is still largely regarded[26] as a building material even in 1985, all over the world particularly in the advanced countries.

NECESSITY

Lime in its natural form, is a carbonate of calcium which is obtained[17,19,27] from deposits of lime stone, marble, chalk or dolomite. When pure, it contains 56% calcium oxide and 44% carbon dioxide. It generally possesses varying amounts of magnesia with the increase of which, high calcium lime stone containing 95% to 99% calcium carbonate, changes to magnesian lime stone (with more than 5% magnesium carbonate) and finally megres into dolomite($CaCO_3$ $MgCO_3$),which in its pure state, contains 54.35% calcium carbonate and 45.65% magnesium carbonate. Impurities such as clay, silica, iron oxide and alumina may be present in small quanities. These impurities react with some of the calcium oxide in the kilns during calcination and produce mineral silicates, aluminates etc. which induce hydraulic properties in the lime. The hydraulic limes set just like cement. In contrast, pure high calcium-content limes, known as fat limes, harden and gain strength very slowly only by the absorption[6,17,28] of carbon dio·le from the air.

The production of lime, energy consumption-wise, is beneficially feasible.[17,18,20,29] The calcination to quick lime requires about 1100 K. Cals. energy/Kg. of lime stone, whereas the cement

production requires 1650 to 2250 K.Cals per Kg. of clinker. The industrially advanced countries with surplus supplies of Portland cement have all along produced and used lime in plasters and mortars to a remarkably great extent. In fact, the mortar/Plaster specified[20,30,32] abroad by various Codes of Practice and Standard Specifications, have lime one of their essential ingredients.

Lime, however, finds itself totally receded in importance and rather relegated to the background in the building industry of Pakistan inspite of its several inherent advantages. It is mostly used,[18,33] in the present day practice, in manufacturing cement, glass, flooring slabs/tiles, paving stone, in white washing, road construction, agriculture and the chemical industries etc. No serious thought/weightage to its use in masonry mortars and plasters is given.

The gigantic development programme, undertaken during the past years in the public sector, the rapid process of industrialization, the diversion of funds by the private entrepreneurs towards the building industry and other projects, have resulted in an acute shortage of cement. The paucity has invariably been responsible, on several occasions, in slowing down pace of the construction works. It becomes more pronounced towards the end of financial year when development works gain momentum.

At the time of independence in 1947, Pakistan had only three manufacturing units[34] producing 4.51 lac tons Portland cement per annum. In the year 1971-72 the production increased to about 30 lac tons. The cement consumption estimates[35] for 1980, amounted to about 42 lac tons as against 34 lac. tons total production, thereby leaving a balance of 8 lac tons which had to be met with throught imports. The shortage remained as such in the following years as well inspite of the integrated plans for the expansion fo cement industry. The production,[34,36] during 1984 of 12 State-owned manufacturing units accentuated to 52 lac tons. It was, however, still deficient to meet with the growing domestic requirements and as a consequent, 11 lac tons cement had to be imported at a huge expense of valuable foreign exchange. This state of affairs has resulted in attracting attention of the engineers, builders and the other concerned quarters to the desirability of developing[5,37] alternate cementing materials from indigenous resources, particularly the lime, as partial or complete substitutes for cement. Such cementing materials have, of necessity, to be lower in cost and also abundantly/readily available to the consumers.

Cement had replaced lime as it was available in ready for use form; its advantages were well realized and the technology of its use greatly developed. The cement mortars/plasters rapidly gain initial strength and set in a reasonable time. In contrast, the lime mortars, owing to their greater consistency and water retentive property, harden with a quite slow pace, just by the physical[6,17,28,38] absorption of carbon dioxide followed by its chemical combination with lime during carbonation under moist conditions. The masons, engineers and the builders, therefore, do not find any appeal in this material. In order to give back lime its due status, it is essential to improve its slow setting property and make it available in the form, as that of cement, so as the initial reluctance could be overcome. The retarded setting/hardening behaviour can be effectively overcome by using lime in conjunction with cement.

DRY HYDRATE POWDER

Lime can be used[18,20,38,39] in the form of putty or a dry hydrate powder. The production of dry hydrate lime powder, the most concentrated form of hydrate, consists[40] first in the heat treatment of mineral Calcium Carbonate under suitable conditions to expel carbon dioxide leaving quick lime and next in the treatment of the quick lime with a suitable quantity of water required to satisfy its chemical affinity for water. The lime stone is generally stable at normal temperatures but decomposes under a reversible reaction into quick lime and carbon dioxide at temperature ranging[10,40,41] from 900°C to 1300°C.

When exposed[18,20] to water, quick lime exhibits a strong affinity for moisture, absorbing it into its pores. Because of this inherent hygroscopicity, a chain reaction occurs. As the water penetrates into the surface pores, heat of hydration is triggered. This, in turn, exerts great internal expansive force in the lime particle and causes it to fracture, shatter, and then disintegrate completely into countless microparticles, either as crystalline dust or as a colloidal suspension, the difference contingent on the amount of water added. With a lump of quick lime, it visually appears to be a miniature cata-clymic, volcano-like[6,18] eruption with literally explosive violence. Accompanying this reaction is steam, evaporated water from the heat of hydration[2,4,41,42] (15.3 K.cals/gm mole at $25^{\circ}C$), and a hissing noise owing to the turbulence generated. The more rapid the rate of hydration, the greater is the turbulence and temperature rise. The resultant hydrate has an increased volume and is whiter than the quick lime from which it is derived. The assimilated water is chemically combined into one distinct hydroxide molecule.

FACTORS INFLUENCING DRY HYDRATION.

Factors influencing the rate of hydration[17,18,20,43] of the quick lime are its purity, magnsium oxide content, particle size, temperature of the reactants, agitation of the reactants, the shelf life of the quick lime and above all the amount of slaking water.

High chemical purity abets rapid hydration.[18] The impurities clog the pores and partially coat the surface with slag formed by lime fluxing of impurities, rendering it more impervious to the entrance of water. Successive increments of magnesium oxide have a retarding affect on the rate[5,17,18] of reaction. Small sized ground quick lime of 5-10 mm. top size[18,40,43] is appreciably more rapid in slaking than lump or pebble. Still finer dustible particles increase the rate even more. The particle size of dry hydrate reduces quite appreciably if the quick lime, from which it is derived, is pulverized finer. Increasing the temperature of the reactants, particularly of water, accelerates the rate which reaches its peak with steam. With some limes, the rate increases so rapidly that it may double for each $10^{\circ}C$ rise in water temperature, thus simulating an explosion when hot water is used. The agitation increases the rate and dispersion.

The aged, partially slaked or recorbanated quick lime slakes sluggishy and produces the lowest surface area of all methods. On exposure to the atmosphere, the moisture vapours in the air cause the quick-lime to air slake. Accompanying hydration[12,13,15] is absorption[17,18,20] of CO_2 from the atmosphere so that the disintegrated particles of air slaked lime are composed of a mixture of hydroxides, oxides and carbonates. This material is of no commercial significance.[18] In fact, it is an undesirable reaction and simply illustrates that all limes are perishable unless adequately protected.

There is some difference of opinion over the mode of intermixing the reactants i.e. whether water should be added to the lime or vice versa. In majority of cases, the former is preferable,[18,40,43] particularly with relatively slow slaking limes, so as to prevent drowning. If quick lime is added to water then it is paramount that sufficient water is present to avoid localized overheating of the mass that may cause burning. Control of slaking temperature is difficult in manual operation, but maintenance of a temprature slightly below boiling[18] and between about 80 to $90^{\circ}C$ is generally desirable.

AMOUNT OF SLAKING WATER

Difference of opinion exists on the amount of slaking water. A generous excess has been reported[17,18,29,38] to improve dispersion of the hydrate, contributing to the finer particle size. But simultaneously it results in drowning the lime, when the surface becomes hydrated and tends

to be impervious to water penetration to the interior of the particles. Addition of insufficient water causes the greatest temperature rise, incomplete hydration and an irreversible agglomeration of fine hydrate into coarse particles. The greatest temperature[18,39] rise (200-260°C) occurs with the least water which burns the hydrate. The generation of excessively high temperature burns and even dehydrates some of the lime that had initially hydrated. The particles are oxide predominant and considerably coarser, lacking the fine colloidal appearance of a normal dry hydrate.

For complete hydration, one mole of pure high calcium quick lime, has to react with one mole of water, stochiometrically calculated to be 32 percent by weight of the lime. The reaction being exothermic, is accompanied with the evolution[25,40,43] of 15.9 K.Cals heat[24,41,42] which evaporates some of the slaking water as steam. This water if not recouped/reintroduced, results in a situation where lesser than the required quantity of water is available to react with lime without completely satisfying its chemical affinity. In addition to the chemically combined and the steamed out water, it is also invariably present as absorbed free water that envelopes the hydrate particles like a film. This latter moisture can be removed only by heat and by no mechanical means, so in a sense it is not free but rather is bound water. Consequently, if only the theoratical amount of water is added, the lime will be incompletely hydrated and unstable oxides will still be present with the hydroxides. Practically, therefore, an excess over theoratical amount is essential to achieve complete hydration.

The heat generated during slaking can be made use of calculating the amount of water needed for hydration. The quantity of heat required to raise the temperature of one gram mole of water from 30°C ambient temperature to 100°C, works out to be about 10.93 K.Cals. Water equivalent to react with one gram mole of quick lime, accompanied with 15.9 K.Cals. evolved heat comes out to be 1.455 mole by dividing the heat evolved, with the heat needed to evaporate one gram mole of water (Appendix-A). For each gram mole of pure quick non-hydraulic fat lime, therefore, 1.455 gram mole of water are necessary to complete the chemical reaction. Of this quantity of the water (about 47% by weight of lime) about 32% is consumed in the conversion of quick lime into hydrate while the rest goes off as steam.

On the basis of several experiments, Boynton reported[18] the minimum water required for complete hydration of high calcium quick lime to be at least 52% of the lime solids weight of the average commercial product. Variance in this value is contingent on purity and degree of reactivity of the given quick lime. Whiteman and Davis[18,44] regarded the minimum amount of water as 50% over theoratical to allow for evaporation loss. Ramaswamy[40] et. al. reported that a lime having 95% available calcium oxide, normally required 100 gallons of water for one ton of quick lime. Of this quantity, 70 gallons (33%) combine with the quick lime and 30 gallons (14%) evaporate as steam in the process. Benerji and Patwardhan[45,46] reported the total quantity of water to be roughly one-third the volume of unslaked lime.

Commercial dry hydrate products contain 72.74% lime solids (oxides) for high calcium type. Most of the balance[18,20] (23-27%) is chemically combined moisture; the reminder is impurities and a minute amount of free water. Generally hydrate is manufactured[40,43,46] without too much excess water, in the range of one part by weight of quick lime to 0.5 − 0.75 parts water. The least water is required for hydraulic limes since there is only 10-40% free lime present to react with water.

Varying rates of hydration reaction and the divergent physical properties of hydrates are thus directly related[17,18,40] to the derivative quick lime and the amount of slaking water. Therefore, the amount of slaking water and optimum hydration conditions have to be empirically and individually established for every variety of quick lime to produce the finest, reactive and high plasticity hydrate that should be literally dry for packing in bags to be opened and readily mixed with sand, water and

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other ingredients, to any desired consistency, just like Portland cement.

EXPERIMENTAL

Hydration of lime can be carried out in Factory conditions, in the mechanical dry hydrate lime plants, as is the general practice in the advanced countries. It provides with ready-to-use lime. The dry hydrate lime plants have not as yet been introduced in Pakistan. It perhaps is the most significant element in the non-usage of lime as mortar in the construction works. The lime is surely to find its place in the building industry, provided it is made available in the local market just like cement, packed in bags, to be opened and used at the site of work without extra labour/precautions. In the absence of dry hydrating plants, till such times as these are installed, it was necessary to attempt to produce it by manual hydration. All limes can be satisfactoryily hydrated[18,40,43,46] by hand by the direct and careful addition of requisite precalculated quantity of water. To start with, experiments were initiated to evaluate the optimum quantity of water needed to produce dry hydrate powder manually at the site of work alongwith the suitable/easily adoptable hydrating conditions.

DETERMINATION OF OPTIMUM WATER CONTENT TO PRODUCE DRY HYDRATE LIME POWDER.

High purity, sui gas burnt, quick lime with general chemical composition shown in Table-1 was obtained from M/S Wah Stone Industries Ltd., Hasan Abdal and a local manufacturer at Badami Bagh, Lahore. It was broken up into small pieces of minus 10 mm. mesh by hammer/chisel. The broken pieces were spreaded in 10-15 cm. thickness in cylinderical steel vessels, having appropriate lid arrangements to entrap the escaping steam. Generally the cylinderical moulds of 0.015 m³ (½ ft³) capacity, meant for determining the bulk densities of aggregates, were used for this purpose. Thereafter, 30 to 60% water by weight of quick lime, with an increment of 5%, was added into separate reaction vessels by uniform sprinkling and continued hoeing. For each percentage of water, three conditions were adopted. In one case, the added water was allowed to slake the lime by keeping the container fully closed so that the generated steam did not escape but was rather recycled to again react with the lime. In the second case the container was kept open for about 5 minutes, depending upon the progress of the reaction and the amount of the added water, to allow the generated steam to partially escape. The temperature of the reactants was thus prevented to rise above the boilding point, to avoid the burning of the lime particles. While in the third case, the container was kept open throughout, enabling the produced steam to totally escape. In all the cases, the reactants were turned over and over, stirred/mixed periodically with steel rods or showels so as to allow their maximum portions to react with water.

GRADATION ANALYSIS

After 24 hours, the resultant products were once again mixed thoroughly. A representative part of each category was subjected to gradation analysis after oven drying (Table-2) while another was put to wet sieve[31,47,49,50] analysis by placing 100 gram sample over a 25 mesh (600 um) B.S. Sieve. The specimen over the upper sieve was washed with a stream of water from a water tap attached with a rubber tubing for half an hour. Thereafter, the freaction retained on each sieve was even dried and weighed. Results are given in Table-2.

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*Private entrepreneurs M/S Wah Stone[48] Industries Ltd.,; encouraged from the experiments described herein and elsewhere, have come forth and are endeavouring to establish a commercial dry hydrate lime plant at Hasan Abdal.

CHEMICAL ANALYSIS

The end product in each case was also analysed for its available calcium hydroxide content using the ASTM available lime index method; the iodine titratin method and the combined water determination method.

a) "Available Lime Index".

The available lime[51] index designates those constituents that enter into the reaction under the conditions of the Rapid Sugar Method. The sample is slaked and dispersed with water. The lime is solubilized by reaction with sugar to form Ca-sucrate which is then determined by titration against standard acid using phenol-phthalein as the indicator.

Hydrated lime was weighed (0.5 g) into an Erlenmeyer flask containing about 50 ml. distilled water. The flask was shaken/swirreled vigorously. Into it 50 ml. neutralized sugar solution was added and the flask again swirreled after stoppering, for 5 min. Then 4 to 5 drops of phenolph-thalein were added and the contents rapidly titrated against standard hydrochloric acid (0.1782 N). At the first complete dis-appearance of pink colour, end point was noted. Calcium hydroxide content (Table-3) was then calculated as follows:

$$\text{Available } Ca(OH_2)\% = V \times 0.66/W$$

where V = ml. of standard HCl (0.1782 N)

W = Grams of sample (0.5)
0.66 = grams of $Ca(OH_2)$ equivalent to one ml.
of standard acid x 100 or
one ml. of standard HCl = 1.32% $Ca(OH_2)$ when
exactly 0.500 g of sample was used.

b) Rapid method for the determination of $Ca(OH_2)$ in the presence of $CaCO_3$ using standard iodine solution.

The dry hydrate lime specimen was sieved through No. 36 B.S. (425 um) sieve and the percentage retained recorded.[45,52] Fraction passing No. 36 sieve was weighed (1 gram) and transferred to a 250 ml. beaker. About 50 ml. distilled water was added and the contents boiled for a few minutes and then cooled. An excess known volume of standard iodine solution (1 ml. of iodine solution as equivalent to 0.0132 g. of $Ca(OH_2)$ when prepared by mixing 90 grms. of potassium iodide with 45.27 gms. of iodine and diluting to one litre) was added to the lime and stirred for 5 to 10 min. so as to ensure that the reaction is complete. This was indicated by the persistant red colour of the iodine. The excess of iodine left over, after the reaction, was titrated with standard thio sulphate solution (44.24 gm. $Na_2S_2O_3$ in one litre; 2 ml. of this solution = 1 ml. iodine) using starch solution as an indicator. From the above readings, the volume of iodine solution that had reacted with lime was determined. Since the percentage of lime passing 36 B.S. Sieve was known, the percentage purity of lime in the original sample was calculated (Table-3):

a) Percentage purity of Calcium. $= \dfrac{V_b - V_r}{2} \times \dfrac{0.0132 \times 100}{W}$

b) Percentage purity on the basis of original sample. $= \dfrac{PCa(OH_2) \times \% \text{ passing B.S.36 sieve.}}{\text{Wt. of original sample taken (50 gm).}}$

where V_b = Vol. of thiosulphate solution for 25 ml. of iodine solution in the blank titration.

V_r = Vol. of thiosulphate solution for 25 ml. of iodine solution used in the actual reaction.

W = Weight of No. 36 B.S. Sieve passing sample (1 gram).

C) Combined Water Determination Method.

The combined water determination method consisted of igniting at $600^{\circ}C$ the oven dried samples above the dissociation temperature[24][42] of the calcium hydroxide ($580^{\circ}C$). The results are given in Table-3 & 4.

PREPARATION AND TESTING OF MORTARS WITH PRODUCED DRY HYDRATE LIME.

25 Cement-Lime-Sand and one lime-sand mixes (by volume) were selected for finding out their crushing strength at 3, 7, 14, 28 days, 3 and 6 months. The cement used in these experiments was ordinary Portland cement from Zeal Pak conforming to British Standard 12:1978. The sand was ordinary Ravi sand of fineness modulus of 0.85 duly washed and dried before use. The requisite quantities of the ingredients i.e. slaked lime, cement and sand were taken in a mixing bowl. The materials were thoroughly mixed by a trowel in the dry state. The mixing water was thereafter slowly and evenly added by constantly working the resultant mortar with the trowel. The quantity of water was pre-determined in a way as to yield a mortar of 105% ± 2% flow/consistency when tested in accordance with the specified[47][49][53] methods.

The thoroughly mixed/homogenized mortar was then cast in sufficient numbers of 25 cm. gang cube moulds, made of non-corrodable material and tightly fitted with base plates. The moulds were lightly tamped/jerked over the concrete floor to remove the entrapped air bubbles. After finishing the top surface, the cubes were kept as such within the moulds for 24 hours or slightly more by covering with wet gunny bags. Whereafter, these were demoulded and were put over a conorete platform. The cubes containing cement-lime-sand mixes were kept covered by constantly wet gunny bags till their testing. The cubes containing lime-sand mixes were cured in the air, throughout.

The cubes at the appropriate testing age were removed from the curing platform, kept for drying for 2 to 4 hours prior to their crushing in the Hounsefield Tensometer. The cement-sand mortars of different mix proportions were also prepared, cured under water. The results of compressive strength of a selected 1:2:9 Cement-Lime-Sand (by volume) mix at different slaking conditions/ water contents are given in Table-5 while those of different cement-lime-sand; lime-sand and cement-sand mixes in Table-6.

RESULTS AND DISCUSSION.

The criteria for assessing the optimum quantity of the slaking water and other hydrating conditions for producing dry hydrate powder of adequate properties was the lowest value of the finencess modulus on the basis of gradation analysis; the permissible quantities of the fractions retained over appropriate sieves during wet sieve analysis; the maximum amount of available calcium hydroxide content and finally the compressive strength of the mortar cubes prepared, cured and tested under identical conditions, in all the cases.

i)   Gradation analysis and fineness modulus.

The cementing material has to be appreciably fine to be able to provide more surface area for the chemical reaction to proceed during the initial hardening period. As a general principle, it ought to have the same fineness as that of ordinary Portland cement with a surface area of at least 2250 cm^2 per gram and not retained by more than 10% by weight, on No. 170 (90 um) B.S.Sieve.

The slaked lime powder was found generally in an appreciable state of fineness. Sieving is not an easy operation with fluffy materials particularly through finer meshes as most of the material remains clustered together but to be easily broken down just by pressing between the fingers. The sieve analysis results of dry hydrate lime powders at different slaking conditions/water contents are given in Table-2. The fractions passing British Standard Sieve No. 100 and 170 & 90)   and the fineness modulus (F.M.) are plotted in Figure-1.

It may be seen that with the increase of slaking water content from 30%, with respect to the weight of the quick lime onward, the amount of minus 150 um mesh goes on increasing significantly upto 50% water content whereafter the curve assumes a somewhat parallel to X-axis shape indicating that water content beyond 50% produces only infinitesimal increase in the minus 150 um fraction. This pattern of increase in the fineness of the resultant dry hydrate powder with the increase in the slaking water content was almost identical for all the slaking conditions adopted. The finest powder, however, was produced when the container was kept open for one hour (condition C) closely followed by the condition when container was kept open for 5 minutes (condition b). The fraction passing 90 um mesh and the fineness modulus also indicated an identical behaviour. The slaking condition (C) when the reaction vessel was kept open for one hour after the addition of water and thereafter covered with the lid to make it air tight, at 50 to 55% slaking water, produces a predominantly finer dry hydrate powder closly followed by condition (b) when the container was kept for 5 minutes as compared to the condition (a) when the container was kept closed throughout.

ii)   Wet Sieve Analysis.

The results of wet sieve analysis performed in persuance of the prescribed method, are given [31,47,49,50] in Table-2 and reproduced in Fig. 2. It may be seen that the amounts retained on the 600 um and 75 um sieves go on decreasing with the increase in the slaking water content and attains a somewhat constant value at 50% water content and beyond. Comparison of the results of three adopted slaking conditions, interalia indicates that least amounts of retained fractions were recorded under condition (C) when the container was kept open for one hour closely followed by condition (b). In case of condition (a) maximum retained amounts on the two sieves were recorded.

The Indian Standard Specifications[50,54] prescribe for hydrated lime maximum fineness residue on sieving through No. 52 (300 um) B.S.Sieve as 5% and through No. 72 (212 um) B.S. Sieve as 10%. The British Standard prescribes maximum fineness residue as 5 percent on 212 um sieve and 10 percent on 75 um sieve, during wet sieve analysis. The American[31,33,55,56] Standard Specifications prescribe that the commercial dry hydrate lime should pass 600 um mesh sieve while it should not be retained by more than 10% on 75 um mesh sieve. All plus 600 um material, largely core and impurities should be removed. The predominant percentage of commercial hydrate should be in the 1 − 2.5 U ± 10 − 25% range.

Examining the experimental results with these fixed parameters, it may be seen that the fractions retained on 600 um sieve were much more than the prescribed. At 35% water content, the residue amounted to 10 percent on 600 um and 11 percent on 75 um sieves. At 50 percent water the residues, respectively, were 648 percent showing further nominal decrease with the increase of

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slaking water. On the basis of the prescribed limits for 600 um mesh, the laboratory produced dry hydrate powder could well be rejected but the provisions of the specifications call for the removal of all plus 600 um material even in the commercially produced dry hydrate lime.

Examining from this angle, it may be seen from the results of dry sieve analysis (Table-2), that in almost all the cases sufficient residues were left on No. 25 B.S.Sieve (600 um). The cumulative amounts retained on this sieve under slaking condition (C) for all slaking water contents are summarized below:

Slaking Water Content (%) (Condition-C).	Cumulative (%) retained on No. 25 (600 um) B.S.Sieve
30	25.0
35	20.1
40	15.1
45	12.0
50	8.32
55	8.0
60	8.3

The cumulative residues on 600 um sieve amount from about eight to 25 percent. The minimum value was obtained at the water contents from 50 to 60 percent. Deducting the plus 600 um (during dry sieving) material, from the amounts retained on this sieve during wet analysis, the retained amounts fall well within the prescribed limits. Thus at about 50 to 55 percent slaking water content, dry hydrate lime of appropriate fineness may be achieved under the slaking conditions C&B.

iii)   Calcium Hydroxide Content.

The results of calcium hydroxide content of the produced dry hydrate lime powder at different slaking water contents/conditions are given in Table-3 and also plotted in Fig.1. Three different procedures for evaluating the calcium hydroxide content comprising available lime index, Iodine titration and combined water determination methods were adopted to have a concordant opinion. There was a difference in the observations recorded by the three methods but in overall attitude the results obtained with one method generally corresponded to the other methods. Therefore the average values of all the three methods were made the basis for evaluation. The calcium hydroxide content has been found to be appreciating with the increase in the slaking water content and attained maximum value at 60 percent water. The values at 55 & 50 percent are quite close to the values at 60 percent. The quantity of water beyond 60 percent did not result in increasing the calcium hydroxide content. It rather resulted in wetting the powder and changing it from dry state to a semi-wet state. Below 50 percent water, there was a sharp decrease in the amount of calcium hydroxide.

In contrast to the results of gradation, fineness modulus and wet sieve analyses, the condition (a), when the steam was entrapped and not allowed to escape, produced maximum calcium hydroxide at all the tested water contents. The rate of increase was quite small beyond 50 percent water. The condition (b) & (C) when the containers were kept open for 5 to 60 minutes and then closed overnight gave lesser calcium hydroxides than condition (a). This is explainable, in view of the fact, that the total entrapment of steam under condition (a) made maximum water available for the chemical reaction to proceed thereby producing maximum hydroxide. Under conditions (b) & (c)

some of the water had escaped as steam and thus lesser water than condition (a) was available for the chemical reaction.

As per standard[31,33,47,50,55] specifications prescribed in various countries the available calcium hydroxide content of commercially produced dry hydrate lime should not be less than 70%. The prusal of the results reported in Table-3, would reveal that the available calcium hydroxide varied under condition (a) from 61.84% to 70.29%; under condition (b) from 59.79% to 71.26%; and under condition (C) from 55.54% to 69.98% for slaking water contents of 35% to 60% with respect to the weight of quick lime. At 50% to 60% water contents, the figures of available calcium hydroxide were:

Slaking Water Content (%)	Available calcium hydroxide (%) under slaking condition.		
	a	b	c
50	69.37	68.13	65.66
55	69.49	69.37	67.88
60	70.29	71.26	69.98

The available calcium hydroxide content at a cursory glance at 50 & 55 percent, under condition (C) appears to be some-what less than the specified value of 70 percent. However, this values falls within prescribed limits if due account for un-burnt lime stone present in the quick lime to an extent of about 10 percent is given by calculating the results on the "available for reaction" quick lime minus un-burnt lime stone. The provision of standard[50,55] specifications for the removal of plus No. 600 um mesh material supports this interpretation. Further standard specifications are solely meant for commercial dry hydrate limes produced under controlled factory conditions, to yield comparably better stuff/out put than the laboratory conditions subject to several atmospheric/environmental variables. Even then dry lime of about 66% to 70% calcium hydroxide content has been produced at 50 percent slaking water content which is in close proximity to the specified minimum 70% value for commercial produced products.

iv) **Compressive Strength.**

The final criterion for the assessment of suitable slaking condition/water content was the testing of compressive strength with the produced dry hydrate lime powders. For this purpose 1:2:9 Cement:Lime:Sand mix by volume was chosen. Cubes were cast under standard preparation conditions and cured under constantly wet gunny bags till the time test. The results are given in Table-5 and plotted in Fig. 1. It may be seen that no appreciable variation in the results was observed with the changing slaking conditions and the increase or decrease of the slaking water content and vice versa. This was because of the fact that invariably, in all the cases, the hydrated lime after having been allowed to mature over-night was sieved through 170 mesh (90 um) B.S.Sieve for its subsequent use in the mortar making. Since only that fraction of the quick lime was sievable that had been converted into hydrate form, hence the changing conditions and water contents produced no pronounced effects on the reactivity of the end sieved product.

On the basis of the fineness modulii of the produced dry hydrate powders; the fractions passing through 600 um and 75 um sieves during wet sieve analysis; the amounts of available calcium hydroxides and the compressive strengths of the mortar cubes; it may be interpretted that of the various water contents tested, the 35 percent water when the resultant steam was allowed to escape, did not result in a uniform powder. Most of the material remained un-attacked. The situation, however, improved when the steam was entrapped within the matrix by covering the amount of the reaction vessel/container. The reaction of the quick lime with water, is highly exothermic. The heat produced, if entrapped totally and not allowed to escape in the initial stages, can result in the

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bursting of the container and also in serious accidents. It would be of interest to note that the totally entrapped steam produced with one kilogram quick lime in a 0.015 m³ (½ ft³) measure, practically induced circular motion to the covering steel disc weighing about 1 Kg. The temperatures of the reactants also exceeded the boiling point. The same was the position with 40 & 45 percent water. The 50 to 60 percent water, when the containers were kept open for 60 minutes, after the addition of the water, produced the best results with appreciably lesser quantity of unreacted residue and the lowest values of fineness modulus. Generally, wet hydrates produced at higher water contents, yielded finer particles than dry hydrates from the same quick lime.

Keeping in view the quantities of hydroxides, the fineness and above all the sievability of the resultant powders, the 50 to 55 percent water with respect to the weight of the quick lime, when the container was kept open for about one hour, has been found to be the most suitable to produce economical and readily sievable dry hydrate powder of desirable qualities, involving no risks of bursting of the reaction vessel due to developed steam temperature/pressure.

CRUSHING STRENGTH OF VARIOUS MORTAR/PLASTER MIXES.

The study of basic stresses from British Standard[57] Code of Practice for load bearing walls, would reveal that basic stress requirements of brick work for a wall made of first[58] class bricks; having an average compressive strength of more than 2000 PSi (14 MN/m²) and water absorption less than 10 percent; with different mortars may be derived as:

Description of mortar.	Mix by volume. C : L : S	Hardening time (days)	PSI. MN/m²	Basic stress for units with crushing strength of		
				1500 10.5	2100 14.7	3000 21.0
	1 : 0 : 3	7		150 1.05	180 1.26	240 1.65
Cement.	1 : 0 : 6	14		140 0.95	157 1.10	190 1.3
	1 : 0 : 8	14		120 0.85	137 0.96	170 1.15
	1 : 1 : 6	14		140 0.95	157 1.10	190 1.30
Cement and Lime	1 : 2 : 9	14		120 0.85	137 0.96	170 1.15
	1 : 3 : 12	14		100 0.70	113 0.79	140 0.95
Lime, Hydraulic.	0 : 1 : 2	14		100 0.70	113 0.79	140 0.95
Lime, non Hydraulic.	0 : 1 : 3	28		80 0.55	88 0.62	100 0.70

The mortars of crushing strength of 88 PSi. (0.62MN/m²) to 180 PSi. (1.26 MN/m²) are suitable for use with first class local bricks. The American[26'31'33] Standard Specifications have prescribed mortar strengths, at the age of 28 days, suitable for masonry construction and plaster works ranging from 2500 PSI. (17.5 MN/m²) to 75 PSi. (0.5 MN/m²). The experimental results in respect of 25 Cement-Lime-Sand; one lime-sand and four cement-sand mixes are reported in Table-6. In accordance with the prevailing practice, the usual field mixes for masonry and plaster works comprise 1:5 to 6 cement-sand by volume. The dry hydrate lime mortars equivalent in strength properties to 1:5 and 1:6 cement sand mixes are presented in Fig.3 and Table-7.

The Cement-Lime-Sand mortars of the ratios of 1:1:7, 1:1:6, 1:2:6, 1:3:7 and 1:3:6 possess appreciably higher compressive strengths ranging from 388 to 520 PSi. (2.72 to 3.64 MN/m²) 28 days than 1:5 Cement-Sand mix with an average value of 320 PSi. (2.24 MN/m²). The 1:2:8, 1:2:9, 1:3:8, 1:3:9, 1:6:8, 1:7:12 and 1:9:12 cement-lime-sand mixes possess compressive strengths within the range 200 to 267 PSi. (1.40 to 1.87 MN/m²) which, though is slightly less yet is significantly closer and almost in the vicinity of the strength of 1:6 Cement-Sand mix, at all curing period. Compressive Strengths of such magnitudes are not normally required for mortars to match with the local bricks of even the first class category. According to the British[57'59'60'64] Standard Code of Practice, the basic compressive stress of 157 PSi. (1.10 MN/m²) at 14 days is permissible for 1:6 Cement-Sand masonry; 100 to 113 PSi. (0.70 to 0.79 MN/m² and 80 to 88 PSi. (0.55 to 0.62 (MN/m²) for 1:2 and 1:3 lime mortars respectively with 1500 to 2100 PSi. (10.5 and 14.7 MN/m²) for 1:2:9 Cement-Lime-Sand mix are 120 and 137 PSi. (0.85 and 0.96 MN/m²). These strengths for walls of 12 ft. height and of 8 to 12 slenderness ratios (effective height/thickness) give the safe permissible stresses (with reduction factors of 0.95 for slenderness ratio 8 and 0.84 for slenderness ratio 12) of 130 to 115 PSi. (0.91 to 0.81 MN/m²) for 1:2:9 mix; 107 to 95 PSi. (0.75 to 0.67 MN/m²) for 1:2 mix and 84 to 74 PSi. (0.59 to 0.53 MN/m²) for 1:3 lime-sand mix for 13½" wall (340 mm.).

cement-lime mortars are valuable for other reasons as well; e.g. improved resistance of brick work to cracking and less risk of efflorescence on the bricks. Cracking of brick work in practice is rarely due to directly applied loads; usually it is a result of differential movements between the mortar and the bricks and may also pass through the bricks themselves. With a weak mortar, however, the mortar can "give"[18] a little to take up differential movements, and so cracking is often avoided; should movements be so great that cracking still occurs, it will tend to be distributed throughout the brick work in the joints rather than through the bricks. As a general rule it is therefore[59'61] advantageous not to use a mortar stronger than is just necessary to give the optimum brick work strength.

The actual load on masonry of a 14 x 12 x 12 ft. (4.25 x 3.65 x 3.65 m) average sized room of single and double storey building with 9" (225 mm) walls comes out to be about 15 to 30 PSi. (0.105 to 0.21 MN/m²) while for a class room of size 15 x 30 ft. (4.56 x 9.12 m) with 12 ft. (3.65 m) high 9" (225 mm) thick walls, the superimposed load is about 20 PSi. (0.4/mm²) only. It is obvious that 1:2:9 cement-hydrate lime-sand mortar with compressive strengths of 153 and 230 PSi. (1.07 and 1.61 N/mm²) at the age of 14 and 28 days and of 1:2 lime-sand mortar with compressive strengths of 70 and 95 PSi. (0.49 and 0.68 N/mm²) at the age of 14 and 28 days respectively are strong enough to bear the superimposed loads.

In view of the foregoing discussion, strengths of 1:1:6, 1:1:7 and 1:2:9 cement-lime-sand mixes and 1:2 lime-sand mix are well within the prescribed vicinity of the specified ones, by all the standard specifications, including the British as well as American. The strengths given by these mixes are computable and comparable with the strength of the generally used 1:6 cement-sand mortar mix. The 1:1:7; 1:1:6 and 1:2:9 cement-lime-sand mixes by volume, may therefore, be

respectively adopted at situations where 1:5 and 1:6 cement: sand mortars are being used at present.

PROCEDURE TO THE ADOPTED TO MANUALLY PRODUCE DRY HYDRATE LIME IN THE FIELD.

All limes can be satisfactorily hydrated, but the entire bulk does not hydrate readily. A properly burnt lime begins to hydrate very quickly. On the other hand, the case is different with an over-burnt or dead burnt lime. In manual hydration, the quantity of water to use for slaking a given weight of lime varies from lime to lime. After the water requirement has been determined, the quick lime obtained from the kiln, be broken to small pieces of about 10 mm. mesh or even less. It may then be spread evenely on a clean cemented floor of a walled concrete tank/platform to a thickness of about 10 to 15 cm. A tank of 60 x 100 x 25 to 30 cm. (2 x 3 x 3/4 to 1 ft.) dimensions with cubic contents of 0.15 m³ to 0.18 m³ (4.5 to 6 ft³) will conveniently suffice for 40 Kg. of quick lime to yield about 0.1 m³ (3.5 ft.³) of dry hydrate. The pre-determined mixing water, which normally has been found to be about 50 – 55% (by weight) of lime, in case of sui gas burnt fat local limes, be taken in water cans/resecans and sprinkled evenly over the entire layer of lime by continuously turning over the lime with a shovel. When all the water has been sprinkled, the material be mixed thoroughly and collected into the shape of a heap. After about ½ to 1 hour of water addition, the tank or platform be covered with a concrete slab, steel plate or suitable wooden plank. The lime at this stage is hot and also contains some free calcium-oxide and moisture. It may therefore, be kept as such for overnight to complete the reaction, mature and cool.

The dry hydrated lime produced in this manner is mostly in finely divided form to be used as such. The un-hydrated or incompletely hydrated fractions are likely to cause popping, pitting and/or general expansion. The defects may be minimised by allowing a thorough distribution of water during spraying and also by sieving the resultant powder through 100 mesh (150 um). B.S. Sieve. The sieved lime may then be either used atonce or if it is in excess than the requirement, be preserved in sealed polythene or water proof paper bags.

COST ANALYSIS.

The cost analysis has also been worked out and attached herewith in Table-7. It may be seen that lime-sand mortars are cheaper than the cement-lime-sand mortars which in turn are cheaper than the cement-sand mortars. The material cost of 1:5 and 1:6 cement-sand mixes, as per current market rates comes out to be Rs. 1260/- and Rs. 1097/- respectively, per 100 Cft. of ready mortar. The costs for 1:2:9, 1:1:7 and 1:1:6 Cement-Lime-Sand mixes work out to be Rs. 1032/-, Rs.1125/- and Rs. 1250/- respectively per 100 Cft. Thus 1:1:7 cement-lime-sand mortar would be about 4 percent cheaper than 1:5 cement-sand mortar and 1:2:9 cement-lime-sand mortar about 6 percent cheaper than 1:6 cement-sand mortar. The cost of 1:2 lime – sand mortar is about Rs. 795/- per 100 Cft. of mortar, giving about 28% saving over 1:6 cement-sand mortar.

Besides reducing cost, lime mortars/plasters have the added advantage of being less susceptible to shrinkage than the cement plaster; provide better plasticity and workability; possess high water retentivity and therefore, require less water curing, possess high sand carrying capacity; are more flexible under stress, show less efforescene; give light coloured finishes, as has been confirmed by observing experimental walls constructed and plastered with cement-lime-sand and lime-sand masonry.

The use of 1:2 dry hydrate lime-sand mortar (by volume) would therefore, be economically beneficial particularly in Block Schemes e.g. rural/basic health centers; primary and middle schools in public sector and the single/double storeyed residential buildings, being constructed in the

private sector.

CONCLUSION

The gigantic development programme undertaken every year, the ever increasing shortage of Portland cement, the only binding agent in vogue; call for the revival of the use of lime in the modern dry hydrate concept.

Lime mined in Pakistan is generally of high purity. It can be satisfactorily hydrated manually to produce dry hydrate powder ready for use possessing adequate crushing strengths, when used as such or in conjunction with the cement.

The dry hydrate lime promises a great future as its introduction would not only supplement the demand of cement but also aid in reviving the use of one times most essential, but now forgotten, cementing material in the building industry of Pakistan. On an average, it would be a more profitable product to manufacture than quick lime as about 125 tonnes of dry hydrate would be made from 100 tonnes of quick lime. The dry hydrate would also generally have a higher sales price.

The work described herein has aroused a great deal of interest. Private entrepreneurs M/S Wah Stone Industries Ltd. encouraged from the results described in this paper and elsewhere, have come forward to establish an industry for the commercial production of dry hydrate lime powder.

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TABLE-1

CHEMICAL ANALYSIS OF QUICK LIME AND HYDRATED LIME WITH OPTIMALLY DETERMINED SLAKING WATER CONTENT/CONDITION.

Constituent.	Quick Lime %	Dry hydrate lime produced with 50% slaking water content (%).
Loss on ignition.	9.7	25.843
Silicon dioxide (SiO_2).	.9	0.8
Mixed oxides (R_2O_3).	0.4	0.32
Calcium oxide (Cao).	84.68	69.37
Magnesium oxide (Mgo).	1.70	1.36
Sulphuric anhydrite (SO_3).	2.57	2.06

TABLE-2

SIEVE ANALYSES (STANDARD DRY & WET) OF DRY HYDRATE LIME POWDERS AT DIFFERENT SLAKING CONDITIONS/WATER CONTENTS

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Slaking water by Wt. of quick lime (%)	Slaking Method/ Condition.	Amount retained (%) when sieved as such on B.S. Sieve Nos.							Amount passing (%) on B.S. Sieve Nos.	Amount retained (%) when sieved through a stream of water on B.S. Sieve Nos.			
		7	14	25	52	100	170	F.E.	100	170	25 (600um)	200	(75 um)
30	a	15.0	6.5	2.0	6.5	8.5	4.8	1.29	60.5	55.7	15.0		20.0
	b	14.0	8.0	3.0	7.0	4.6	3.9	1.30	62.5	58.6	12.0		15.0
	c	15.0	10.0	5.0	2.0	3.8	2.7	1.38	63.0	60.3	13.0		13.0
35	a	12.0	5.0	1.5	6.3	4.8	8.8	1.02	68.8	60.0	13.0		18.0
	b	11.1	4.02	3.1	5.3	4.67	1.5	0.962	70.50	69.0	10.0		14.0
	c	8.6	8.0	3.5	4.0	3.5	11.5	0.97	72.60	65.0	10.0		11.0
40	a	10.0	4.5	2.0	6.0	4.5	10,2	0.91	72.8	62.6	12.0		14.5
	b	9.0	3.7	3.0	4.5	4.5	6.5	0.823	75.0	68.5	10.0		10.0
	c	8.3	3.8	3.0	4.0	4.3	6.1	0.78	76.5	70.4	8.0		10.0
45	a	10.5	2.5	1.5	4.0	4.5	6.5	0.80	75.6	69.1	10.0		10.0
	b	10.0	3.0	1.0	3.2	4.0	6.0	0.754	78.5	72.5	7.5		9.0
	c	10.0	1.0	1.0	3.2	3.8	4.0	0.672	80.2	76.2	6.0		8.2

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Slaking water by Wt. of quick lime (%)	Slaking Method/ Condition.	Amount retained (%) when sieved as such on B.S. Sieve Nos.							Amount passing (%) on B.S. Sieve Nos.		Amount retained (%) when sieved through a stream of water on B.S. Sieve Nos.		
		7	14	25	52	100	170	F.E.	100	170	25 (600um)	200	(75 um)
50	a	7.2	0.86	2.3	6.0	3.5	4.0	0.62	80.0	76.0	8.0		9.64
	b	6.8	0.43	1.48	4.21	2.87	3.2	0.52	84.12	80.92	6.5		9.0
	c	6.5	0.50	1.32	4.3	2.68	4.0	0.50	84.57	80.57	6.0		8.0
55	a	7.0	1.0	3.0	5.6	1.5	2.7	0.61	81.5	78.8	6.0		9.0
	b	6.5	0.5	1.5	4.5	2.5	4.5	0.51	85.0	80.5	6.0		6.33
	c	6.5	0.5	1.0	3.8	2.6	3.5	0.48	85.5	82.0	5.5		6.0
60	a	7.0	0.8	2.0	6.0	2.0	1.5	0.612	81.0	79.5	6.0		8.5
	b	7.0	0.5	1.0	4.5	1.5	3.5	0.51	85.0	81.5	5.5		7.0
	c	6.8	0.5	1.0	3.5	1.8	3.0	0.478	85.0	82.0	5.5		5.5

a = Totally closed.

b = 5 Min. open, rest closed.

c = 60 min. open, rest closed.

TABLE-3

ACTIVE CALCIUM HYDROXIDE CONTENT OF DRY HYDRATE LIME PRODUCED AT DIFFERENT SLAKING CONDITIONS/WATER CONTENTS

Slaking water by wt. of quick lime (%)	Slaking method/ Conditions	Calcium hydroxide content (%)			
		Combined water detr. method.	Iodine titration method.	Available lime index method.	Average.
30	a	58.26	55.85	53.65	55.92
	b	55.78	54.03	52.70	54.17
	c	45.97	45.14	46.85	45.97
35	a	63.88	62.10	59.55	61.84
	b	62.85	60.52	56.00	59.79
	c	57.06	55.34	54.23	55.54
40	a	65.18	54.98	63.80	64.65
	b	64.80	64.56	61.25	63.54
	c	61.17	56.34	59.82	59.11
45	a	68.98	67.12	67.03	67.71
	b	68.06	66.87	64.87	66.61
	c	65.45	63.15	62.74	63.78
50	a	70.72	69.21	68.21	69.37
	b	69.06	68.85	66.94	68.13
	c	66.32	65.82	64.85	65.66
55	a	69.81	68.95	69.70	69.49
	b	69.50	69.13	69.48	69.37
	c	67.06	67.62	68.97	67.88
60	a	71.28	69.69	69.93	70.29
	b	73.91	70.11	69.76	71.26
	c	71.86	69.25	68.83	69.98

a = Totally closed.

b = 5 min. open rest closed.

c = 60 min. open rest closed.

TABLE-4

FREE AND COMBINED WATER CONTENTS OF DRY HYDRATE LIME AT DIFFERENT HYDRATING CONDITIONS/WATER CONTENTS

Slaking water by wt. of quick lime (%)	Slaking Conditions.	Water content (%)	
		Free at 110°C	Combined at 600°C (after oven drying).
30	a	0.50	14.175
	b	0.25	13.572
	c	0.10	11.185
35	a	0.75	15.543
	b	0.28	15.292
	c	0.15	13.883
40	a	1.5	15.859
	b	1.1	15.766
	c	0.15	14.883
45	a	4.6	16.784
	b	2.9	16.564
	c	1.1	15.925
50	a	6.636	17.207
	b	3.246	16.803
	c	1.250	16.136
55	a	12.85	16.985
	b	7.35	16.910
	c	4.70	16.316
60	a	18.55	17.343
	b	16.00	17.983
	c	10.375	17.484

a = Totally closed.

b = 5 min. open, rest closed.

c = 60 min. open, rest closed.

TABLE-5

CRUSHING STRENGTH OF 1:2:9 (BY VOLUME) CEMENT-LIME-SAND MORTAR UNDER DIFFERENT HYDRATING CONDITIONS/WATER CONTENTS

Slaking water by Wt. of quick lime (%)	Slaking method/ Condition	Crushing Strength at the age of (days)							
		3		7		14		28	
		PSi	MN/m³	PSI	MN/m³	PSi	MN/m²	PSI	MN/m²
30	a	45	0.315	108	0.756	115	0.805	243	1.701
	b	60	0.42	144	1.008	160	1.12	233	1.631
	c	55	0.385	146	1.022	155	1.085	235	1.645
35	a	53	0.371	102	0.714	120	0.84	215	1.505
	b	82	0.574	117	0.819	153	1.232	230	1.61
	c	58	0.406	133	0.931	176	1.071	250	1.75
40	a	50	0.35	98	0.686	130	0.91	200	1.4
	b	53	0.371	99	0.693	128	0.896	215	1.505
	c	60	0.42	125	0.875	140	0.98	230	1.61
45	a	45	0.315	125	0.875	170	1.19	220	1.54
	b	55	0.385	130	0.91	165	1.153	208	1.456
	c	65	0.455	135	0.945	150	1.05	240	1.68
50	a	60	0.42	120	0.84	160	1.12	225	1.575
	b	65	0.455	140	0.98	170	1.19	240	1.68
	c	70	0.49	140	0.98	165	1.155	335	1.645
55	a	80	0.56	143	1.001	165	1.155	206	1.442
	b	80	0.56	150	1.05	185	1.295	250	1.75
	c	75	0.525	108	0.756	200	1.4	268	1.876
60	a	55	0.385	106	0.743	140	0.98	202	1.414
	b	60	0.42	171	1.197	160	1.12	242	1.694
	c	58	0.406	117	0.810	155	1.086	250	1.75

a = Totally closed.

b = 5 Minutes open, rest closed.

c = 60 Minutes open, rest closed.

i) Curing Condition: 1 Day in mould, then under wet gunny bags till the time of test.

ii) Consistency/flow = 105% + 2%

iii) Minus 170 No. B.S. Sieve (90 um) fraction lime powder was used in each case.

TABLE-6

COMPRESSIVE STRENGTH OF MORTARS PREPARED WITH HYDRATED LIME AS THE CEMENTING MATERIALS

Mortar mix (by Volume) Cement-Lime-Sand			Compressive Strength (Average) age of (days)									
			3		7		14		28		90	
			PSi	MN/m²	PSi	MN/m²	PSi	MN/m²	PSi	MN/m²	PSi	MN/m²
1	= ¼	= 3	850	5.59	942	6.594	1467	10.27	1633	11.43	1933	13.53
1	= 1	= 6	120	0.84	192	1.344	300	2.10	407	2.85	483	3.38
1	= 1	= 7	94	0.66	120	0.84	220	1.54	388	2.72	445	3.12
1	= 1	= 8	63	0.44	98	0.69	152	0.064	208	1.46	272	1.902
1	= 1	= 9	50	0.35	90	0.63	125	0.875	150	1.05	193	1.351
1	= 1	=10	43	0.301	65	0.455	72	0.504	85	0.595	115	0.805
1	= 2	= 6	286	2.002	397	2.779	412	0.884	470	3.29	537	6.759
1	= 2	= 8	68	0.478	130	0.91	165	1.155	242	1.694	287	2.009
1	= 2	= 9	52	0.364	117	0.819	153	1.071	230	1.61	377	1.939
1	= 2	= 10	50	0.35	100	0.7	150	1.05	198	1.386	267	1.869
1	= 2	= 12	45	0.315	93	0.651	150	1.05	175	1.255	—	—
1	= 3	= 6	400	2.8	437	2.989	510	3.57	550	3.85	793	5.551
1	= 3	= 7	253	1.771	350	2.45	370	2.59	480	3.36	610	4.27
1	= 3	= 8	143	1.001	187	1.309	210	1.47	267	1.859	307	3.149
1	= 3	= 9	103	0.721	137	0.959	197	1.379	250	1.75	290	2.03
1	= 3	= 10	72	0.504	125	0.875	180	1.26	190	1.33	280	1.96
1	= 3	= 12	40	0.28	80	0.56	110	0.77	123	0.861	193	1.351
1	= 3	= 14	38	0.256	80	0.56	107	0.749	115	0.805	125	0.875
1	= 3	= 16	35	0.245	55	0.385	77	0.539	97	0.679	107	0.749
1	= 6	= 8	125	0.875	172	1.204	220	1.54	252	1.764	273	1.911
1	= 6	= 12	87	0.609	127	0.889	153	1.071	167	1.169	220	1.54
1	= 7	= 12	102	0.714	130	0.91	157	1.099	200	1.4	255	1.785
1	= 9	= 12	110	0.77	143	1.001	187	1.309	210	1.47	258	1.806
1	= 9	= 14	83	0.581	140	0.98	148	1.036	170	1.19	213	1.491
1	= 9	= 16	67	0.469	82	0.574	107	0.749	130	0.91	132	0.924
0	= 1	= 2	15	0.175	45	0.315	70	0.490	95	0.655	—	—
1	= 0	= 3	510	3.57	790	5.53	1050	7.35	1250	8.75	—	—
1	= 0	= 4	165	1.155	320	2.24	485	3.395	540	3.78	—	—
1	= 0	= 5	105	0.735	210	1.47	290	2.03	320	2.24	—	—
1	= 0	= 6	75	0.525	120	0.84	185	1.295	260	1.82	—	—

i) Curing Conditions: (a) For cement:Lime:Sand Mixes 1 day in mould, then under wet gunny bags till the time of test.
(b) For Lime:Sand Mixes in the air throughout.

ii) Consistency/flow: 105% + 2%

iii) Minus 170 No. B.S. Sieve (90 um) fraction lime powder was used in each case.

TABLE-7

COST OF MORTARS (MATERIALS COST ONLY)

Sl. No.	Mix Volume Cement:Lime:Sand	Dry* Vol. (Cft.)	Cement. Cft.	Cement. Cost	Hydrate Lime Cft.	Hydrate Lime Cost	Sand. Cft.	Sand. Cost	TOTAL COST (RS) % Cft.	TOTAL COST (RS) m³	REMARKS.
1.	1:1:6	125	15.62	905.96	15.62	249.92	93.75	93.75	1249.63	35.40	Cement: Rs.72.50 per 1.25 Cft.
2.	1:1:7	125	13.88	805.04	13.88	222.08	97.22	97.22	1124.34	31.05	(0.036 m³)
3.	1:1:8	125	12.50	725.00	12.50	200.00	100.00	100.00	1025.00	29.05	Hydrate Lime: Rs.16/-
4.	1:1:9	125	11.36	658.88	11.36	181.76	102.27	102.27	942 .91	26.70	per Cft.(0.02832 m³)
5.	1:1:10	125	10.42	604.36	10.42	166.72	104.16	106.16	875.24	24.80	Sand: Rs. 100/- per 100 Cft.
6.	1:2:6	125	13.88	805.04	27.77	444.32	83.33	83.33	1332.69	37.75	
7.	1:2:8	125	11.36	658.88	22.72	363.52	90.90	90.90	1113.30	31.55	
8.	1:2:9	125	10.42	604.36	20.84	333.44	93.74	93.74	1031.54	29.25	
9.	1:2:10	125	9.61	557.38	19.23	307.68	96.16	96.16	961.22	27.25	
10.	1:3:6	125	12.50	725.00	37.50	600.00	75.00	75.00	1400.00	39.65	
11.	1:3:7	125	11.36	658.88	34.09	545.44	79.55	79.55	1283.87	36.40	Cement:Lime:Sand Mortar.
12.	1:3:8	125	10.42	604.36	31.25	500.00	83.33	83.33	1187.69	33.70	
13.	1:3:9	125	9.61	557.38	28.85	461.60	86.54	86.54	1105.52	31.30	
14.	1:3:10	125	8.93	517.94	26.78	428.48	89.29	89.29	1035.71	9 .35	
15.	1:6:8	125	8.33	483.14	50.00	800.00	66.67	66.67	1349.81	38.25	
16.	1:7:12	125	6.25	362.50	43.75	700.00	75.00	75.00	1137.50	32.25	
17.	1:9:12	125	5.68	329.44	51.14	818.24	68.18	68.18	1215.86	34.45	
18.	0:1:2	132	—	—	44.00	704.00	88.00	88.00	792.00	22.45	Lime:Sand:Mortar.
19.	1:0:3	120	30.00	1740.00	—	—	90.00	90.00	1830.00	51.85	
20.	1:0:4	120	24.00	1392.00	—	—	96.00	96.00	1488.00	42.15	Cement-Sand Mortar.
21.	1:0:5	120	20.00	1160.00	—	—	100.00	100.00	1260.00	35.70	
22.	1:0:6	120	17.14	994.12	—	—	102.86	102.86	1096.98	31.07	

* Per 100 Cft. of wet mortar ready for use.

COST OF PREPARATION OF HYDRATE LIME

Cost of 40 Kg. of Quick Lime.   Rs. 35/-

40 Kg. CaO on hydration yields 90% $Ca(OH)_2$ and 10% Kunkar (unsievable part).

40 Kg. CaO yields 36 Kg. (79.2 Lbs.) of $Ca(OH)_2$

Density of $Ca(OH)_2$ tested.   = 35 Lbs./Cft.

40 Kg. CaO yields. $= \dfrac{79.2}{35} = 2.26$ Cft.

Rate per Cft. of hydrate lime.   = 35/2.26 = Rs. 15/50

Labour Charges.   = -/50

Rate of lime per Cft.   = Rs. 16/-
per m³.   = Rs. 565/-.

APPENDIX 'A'

AMOUNT OF WATER NEEDED TO HYDRATE QUICK LIME

(Calculated on the basis of total heat energy evolved, during the process).

1) Latent heat of vaporisation of steam i.e. g. cals. required to convert 1 g   = 537
of water from liquid into vapour without change of temperature (Ref. Phys. &
Chem. Constants by kaye G.W.C. & Laby T.H.; 10th ed. Longman, London
pp 76).

2) Specific heat of water i.e.; g. cals required to raise the temp. of 1 g.   = 1
of water through $1^{\circ}C$ from Lab. Temp. to $100^{\circ}C$, b.p. of water.

3) For raising temp. from $30^{\circ}C$ ambient temp. to $100^{\circ}C$; specific heat required   = 70
for 1 g. of water $(1 \times (100-30)$.

4) Total heat required to convert 1 g. water into steam from $30^{\circ}C$ (specific   = 607
heat+latent heat; 1 + 3); cals/g.

5) Total heat required to convert 1 g. mole water into steam from $30^{\circ}C$ = 10926
(Sr. No. 4 X 18) (Cal/g. mol).

6) Heat evolved in converting 1 g. mole of quick lime into its dry hydrate;   = 15900
cal per g. mole. (Ref. Chem. Inds. & Process; N. Shrieve, 1956/pp
215 & pp 35).

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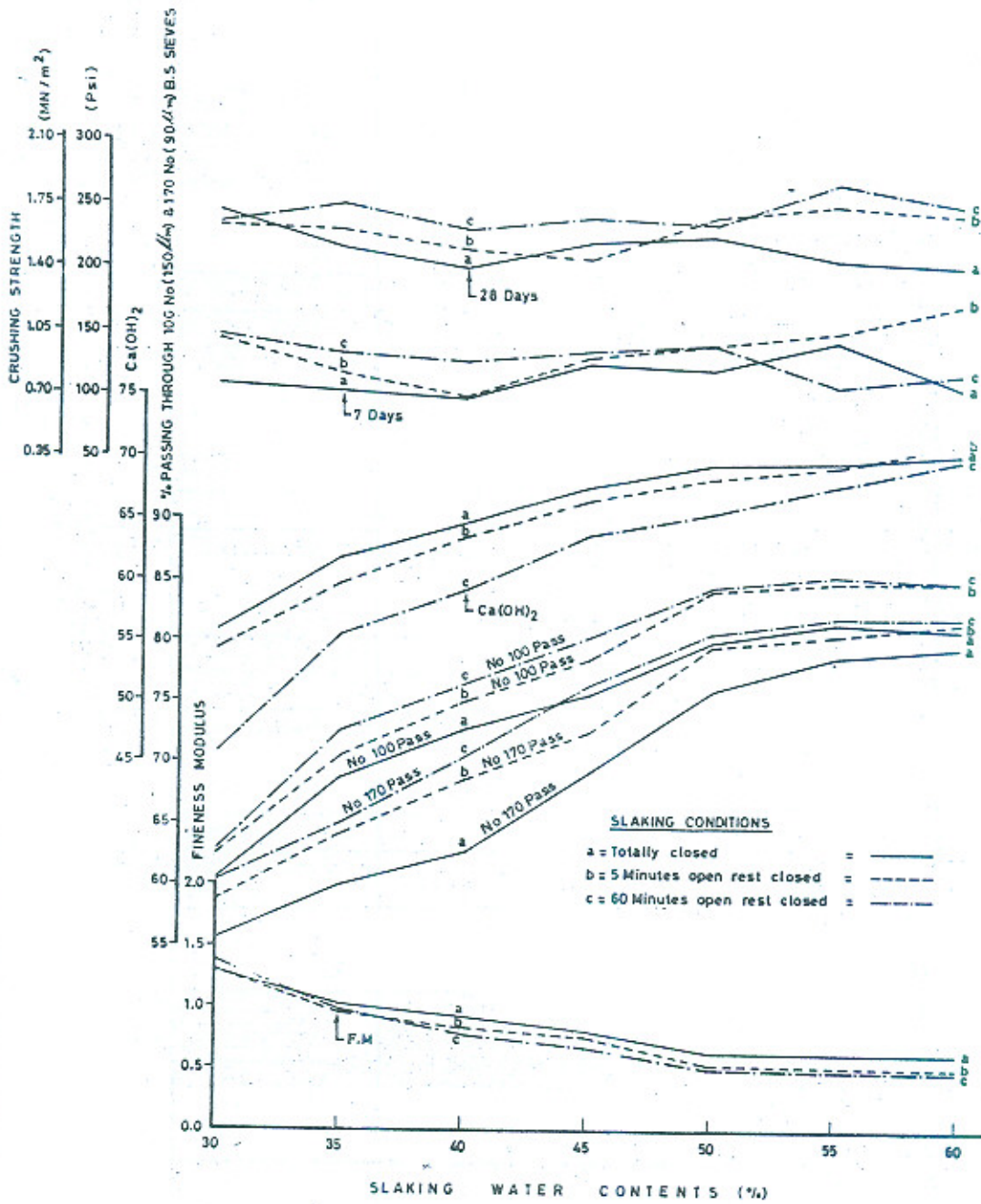MUHAMMAD IQBAL, ALI MUHAMMAD,
K.L. KHAWAJA

7) g. moles of water needed to react with 1 g mole of quick lime, when 15,900   = 1.455
cal/g. mol are evolved (Sr. No. 6 ÷ 5).

<div align="center">OR</div>

CaO (g mol) : Water (g mol)

1   : 1.455

8) Amount of water in g. requied for 1 g. mole (56 g) of CaO (Sr. 7 X mol   = 26.19
wt. of water).

9) Water requirement; Sr. No. 8 X 100/56 (%).   = 46.768

10) Hydration reaction of quick lime:

$CaO + H_2O \quad Ca(OH)_2$; steam ΔH

56   18   74

11) Water required for the reaction with the quick lime: Mol wt. of Water X 100/-   = 32.143
mol wt. of CaO (18 X 100/56); %.

12) Water which evaporates as steam (Sr. No. 9 — Sr. No. 11).   = 14.625

ABSTRACT

a) Total water required for hydrating
quick lime (pure).   OR SAY   = 46.768%
= 47%

b) Water required to react with
pure quick lime.   OR SAY   = 32.143%
= 32%

c) Water that evaporates as steam.   OR SAY   = 14.625%
= 15%

EVALUATION OF OPTIMUM SLAKING WATER CONTENT /
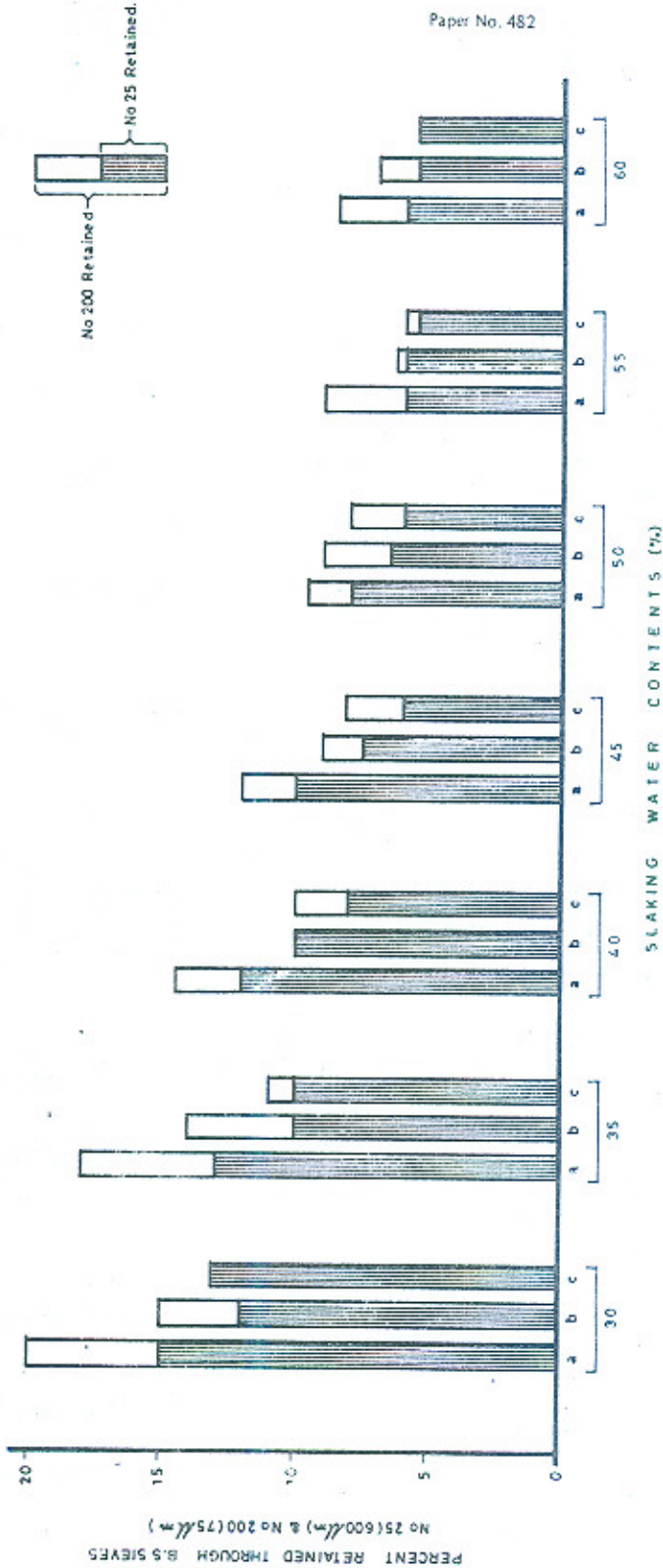# CONDITION FOR PRODUCING DRY HYDRATE LIME.

FIG:1

SLAKING CONDITIONS

a = Totally closed
b = 5 Minutes open rest closed
c = 60 Minutes open rest closed

WET SIEVE ANALYSIS OF PRODUCED DRY HYDRATE LIME

FIG: 2

Slaking Conditions.

a = Totally closed
b = 5 Minutes open, rest closed.
c = 60 Minutes open, rest closed.

No 200 Retained.

No 25 Retained.

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SLAKING WATER CONTENTS (%)

PERCENT RETAINED THROUGH B.S SIEVES
No 25 (600 µm) & No 200 (75 µm)

CEMENT : DRY HYDRATE ` LIME : SAND & CEMENT : SAND MIXES

OF EQUIVALENT COMPRESSIVE STRENGTHS.

FIG: 3

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