

EARNEST A. RICHMOND



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THESIS FOR DEGREE OF M. E.
1908.
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AN ANALYSIS OF
CRITICAL ECONOMIES
IN
PORTLAND CEMENT PRODUCTION
BY
EARNEST A. RICHMOND.

THESIS

Portland cement

Send me a copy of the book "The Book of the Dead"

Yours truly,
J. H. P.

**THESIS FOR DEGREE OF M. E.
1909.**

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BY
EARNEST A. RICHMOND.**

Grand Rapids, Mich.

THESIS

AN ANALYSIS
OF CRITICAL ECONOMIES IN PORTLAND CEMENT PRODUCTION.

The manufacture of portland cement has become a very important industry in the United States, in fact is next to that of iron and steel in the capital invested and value of yearly product. In consideration of this importance it is remarkable that so very little information regarding the process is available. Especially is this true of the data bearing on operating costs. Nearly all of the plants have accurate systems of cost keeping and any change in the cost of an item is immediately noted and its cause sought out. Very little attention is paid however to the relative cost of the various operations and as these costs are carefully guarded it is difficult to tabulate anything like average costs and results.

Portland cement is very exactly defined by the German Cement Manufacturers' Association as follows:—
Portland cement is a hydraulic cementing material with not less than 1.7 parts by weight of lime to 1 part by weight of soluble silica, plus alumina, plus iron oxide; prepared by fine grinding. To this cement shall not be added more than 3% of other material for particular purposes. The maximum magnesia content shall not exceed 4% and the sulfuric anhydride shall not exceed 2 1/2%.

The elements that enter into the composition of portland cement are the most common found on earth, viz, calcium, silicon, aluminum, iron. In the United States limestone, marl, clay, and shale are used and in the middle West a species of chalk rock, and in the East a "cement Rock" having nearly correct proportions of the elements.

In the manufacture of the product there are four important operations:-

- (a) Proportioning the raw materials.
- (b) Mixing and grinding the raw materials.
- (c) Burning mixture to a clinker.
- (d) Grinding clinkers to cement.

The physical properties of the raw materials are so varied that the necessary machinery for grinding can hardly be reduced to a standard, as some of them are very soft, some of them are already finely divided, and again the limestone and cement rock may be very hard and refractory requiring very different treatment.

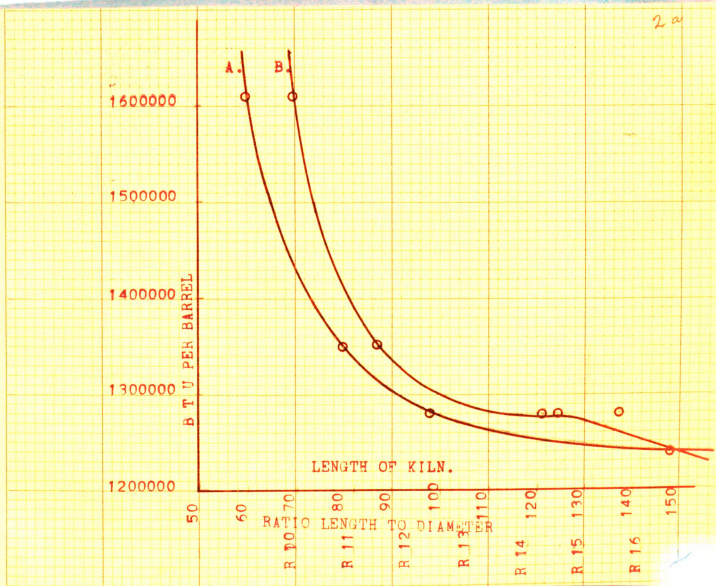
In proportioning the raw materials the formula in most common use is:-

Maximum Calcium = $2.8 \text{ Lime} + 1.1 (\text{Alumina} + \text{Iron Oxide})$.

Free lime is very injurious to cement as it causes it to swell and crack, therefore the proportion of lime approaches this maximum as closely as experience shows to be possible, the nearer the better the cement as long as there is no free lime present.

The burning was formerly done with a vertical kiln similar to those in which lime is burned. These however have nearly all been replaced in the United States by the rotary kiln which is inclined a few degrees out of the horizontal. The vertical kiln required considerable labor

"Informed" cross section



2a

and did not deliver a uniform product. The rotary kiln does deliver a uniform product and requires very little labor, it is not as economical in fuel. The design of these kilns have undergone rapid transformation, especially since Edison obtained good results with a very long kiln. Up to the present time there has been no published comparison of the efficiency of the various designs.

BEST LENGTH AND DIAMETER FOR KILNS.

Edison's kiln was 150 feet long and had a diameter of 9 feet. It developed a capacity of 750 Barrels in 24 hours with a fuel consumption of 85 pounds of coal per barrel. The 6' x 60' kiln has a capacity of 240 barrels per day and a fuel consumption of 110 pounds of coal per barrel.

The following table gives the length, diameter, fuel consumption, and heat units per barrel on various kilns:-

Size.	Capacity	Fuel	B. T. Us.
	bbls. 24 hrs.	consumption.	per bbl.
150x9	750	85lbs. coal	1240000
125x 8	751	9.25 gal. oil	1280000
100x 7	400	87.5 lbs. coal	1280000
80 x 7	300	92.5 " "	1350000
60 x 6	240	110 " "	1610000

Diagram "A" is a curve plotted from the heat units per barrel and the length of the kilns. The first increase in length gave very marked decrease in fuel consumption but the amount drops off very rapidly after we pass the 100' mark.

CAPACITY BARRELS IN 24 HRS.

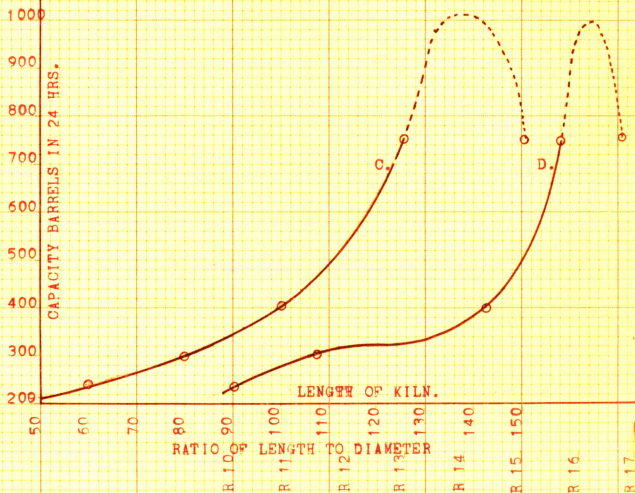
50
60
70
80
90
100
110
120
130
140
150

209
290
390
490
590
690
740
790
840
890
940
990
1000

LENGTH OF KILN.

RATIO OF LENGTH TO DIAMETER

R 10
R 11
R 12
R 13
R 14
R 15
R 16
R 17





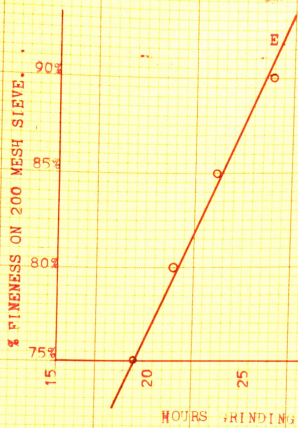
The heat lost by radiation is so very great that the diameter of the kiln is also very important. Diagram "B" is a curve of the heat units and the ratio of the length to the diameter of the kiln.

The fuel used was coal pulverized to 92% through a 100 mesh sieve. with the exception of the 125' x 8' kiln which used residuum oil from a refinery in the Middle West. This oil contains many impurities and does not burn quite as efficiently as pulverized coal. Allowing for this we have very smooth curves for "A" and "B".

A very important element in the study of the rotary kiln is its capacity. Diagram "C" has been prepared to show that the capacity increased with the length up to a certain point. The 125 foot kiln has the same capacity as the 150 foot although the fuel consumption in the latter is slightly lower. As the curve has a very great slope as it approaches 125' and comes back to the same capacity at 150' it must follow a path something like that shown by the dotted portion. The 225' kiln 751 barrels as an average and has a maximum record of 1100 barrels per 24 hours. This would indicate that the greatest capacity would be obtained by a kiln having a length somewhere between 125' and 150' long.

Diagram "D" is the same capacity records plotted according to the ratio of the length to the diameter and determines that a ratio between 15.6 and 16.7 should be correct for maximum capacity.

In consideration of these diagrams the ideal kiln seems to be one that has a length of 130' - 140' and a diameter of 8' 4". This kiln should have a capacity of about 1000 barrels and a fuel consumption of 86 lbs. of coal per barrel.







THE EFFECTS OF FINE GRINDING.

In an analysis of the effects of fine grinding of raw material in preparation for burning there are many things to be taken into consideration and some of them have a very critical bearing on operation. The nearer the raw material in its natural state satisfies the formula for correct proportions the coarser it may be fed into the kiln. In the process of burning it is first necessary to drive off the volatile carbon, oxygen, sulfur, etc. Next each group of elements that form a molecule of cement compound should be associated together and fused into ainder. In a perfect cement rock this grouping is already in existence but in an artificial mixture this grouping has to be performed mechanically by fine grinding and thorough mixing. It is obvious that much depends upon the position of the elements when they should unite and the closer they are brought together the less work (heat) is necessary to perfect the process.

COST OF FINE GRINDING.

To establish the exact amount of grinding to reach a desired fineness will require a definite material to work upon. In an effort to determine the amount of work necessary to reduce hard limestone to various degrees of fineness a quantity of it was placed in a test tube mill and at the end of 19 hours 75% would pass 200 mesh sieve, at 21 hours 80%, at 23 hours 85%, and at 26 hours 90%.

Diagram "E" is a curve illustrating these results and show that the time will vary nearly with the fineness within the limits given.



A tube mill being delivered a hard limestone mixture of the same class, all of which passed a 20 mesh sieve and 45% through a 100 mesh sieve, gave the following capacities:- 87% through 100 mesh, 30 barrels per hour; 92% fine, 16 barrels; 99% fine, 5 barrels. The average for a Griffin mill on the same material was 87% fine, 9 barrels; 92% fine, 4 barrels; 94% fine, 2 barrels. These capacities are shown by diagrams "F" and "G".

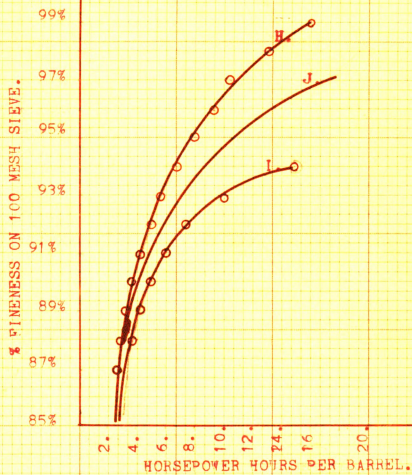
All of these diagrams indicate that for each degree of fineness obtained a definite amount of grinding must be done. The tube mill required about 80 HP. to operate it and the Griffin mill about 30 horsepower. From "F" and "G" the following table has been prepared which shows the horsepower hours per barrel for each and the average.

%Fine	Capacity		Horsepower hours		Average HP.Hours.
	Tube Mill	Griffin Mill	Tube Mill	Griffin Mill	
99	5		16		26.3
98	6		13		21.0
97	7.6		10.5		17.0
96	8.6		9.3		13.3
95	10.3		7.8		10.6
94	12.0	2	6.7	15	8.7
93	14.0	3	5.7	10	7.8
92	16.0	4	5.0	7.5	6.2
91	18.3	5	4.4	6.0	5.2
90	21.6	6	3.7	5.0	4.3
89	24.4	7	3.3	4.3	3.8
88	27.2	8	2.9	3.75	3.3
87	30.0	9	2.7	3.3	3.0

Diagrams "H" and "I" are plotted from the horsepower hours for the tube mill and for the Griffin mill.

"J" is an average curve and shows that the horsepower hours will increase very fast for reductions finer than 92%.

6a



FUEL SAVED BY FINE GRINDING.

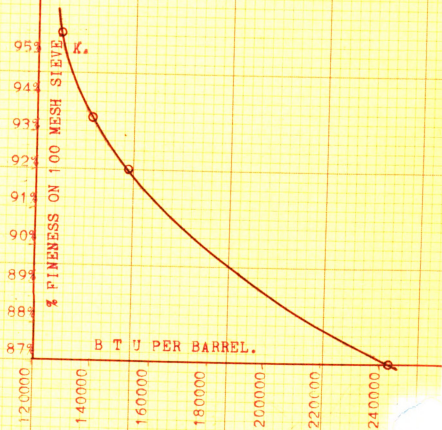
IT has already been shown that less fuel will be required for burning fine particles than for coarse ones. This fact is well known but there is no published record of just what saving is effected. The remarkable fuel consumption of three kilns operating on a mixture of dry marl and clay is very good proof of this. The marl when separated from the insoluble matter, mostly silica, will all pass 200 mesh sieve. The yearly average of these kilns (60' x 6') was 65 pounds of coal per barrel. The alumina-iron ratio was very high and does influence this low record very materially but does not account for the fact that this fuel consumption is at least 35% lower than it would be on the average milled raw rock.

Again, a raw material averaging 72% on 200 mesh sieve and 85% on 100 mesh required a temperature of 2936 degrees Fahrenheit to properly burn. The same material when reground would average 98% on 200 mesh sieve and required a temperature of but 2687 degrees, or 246 lower to do the same work.

Taking 400 pounds of clinker to the barrel and its specific heat to be .25 it would represent a saving of 100,000 B. T. U. per barrel in the heat supplied the clinker. The efficiency of the rotary kiln is about 27.5% hence the actual saving in heat units is about 364,000 B. T. U. A general average of the heat units required per barrel is about 1,360,000 B. T. U., hence a saving of 26.8% in fuel can be made by regrinding this material.

Observations of the fuel consumption of 125' x 8' kiln gave for 95.5% through a 100 mesh sieve 1280000 B. T. U while 1390000 B. T. U. were required for 93 1/3% fine, and 2420000 B. T. U. for 87% fine.

1/2.



The material and other conditions were the same throughout. The figures were taken from the daily record of the mill and each is an average value, the whole extending over a period of several months.

Diagram "K" is plotted from these records. Reading direct from the diagram we can get the heat units saved for each increased per cent of fineness and by using the value of 14,6000 B. T. U. per pound of coal, its coal value can be obtained. This value divided by the efficiency of the kiln gives the actual saving of coal effected.

Pulverized coal costs delivered to the kiln about \$7.00 per ton and on this basis the money value of the saving for each degree of fineness can be obtained.

%Fine	B. T. U.	Difference	Coal	Actual	Saving.
			Value.	Coal	
87	2420000				
88	2130000	290000	19.9	72.5	\$.252
89	1930000	200000	13.7	50.0	.175
90	1770000	160000	10.9	40.0	.140
91	1630000	140000	9.6	35.0	.122
92	1520000	110000	7.5	27.4	.096
93	1420000	100000	6.8	24.7	.086
94	1350000	70000	4.8	17.4	.061
95	1290000	60000	4.1	14.9	.052
96	1260000	30000	2.1	7.7	.027
97	1230000				

The cost per horsepower hour will average about \$.015 and this figure can be used in computing the cost per barrel for each increased percent of fineness. The cost of maintenance will also increase per barrel as the output is restricted and should be considered. In the case of the tube mill this charge will be about \$1155 per year or \$.13 per mill hour. From "F" can be obtained the capacities



per hour for each percent of fineness. Dividing the maintenance charge per hour by the capacity, the maintenance charge per barrel for the various fineness of product is obtained from which the charge for each percent of increased fineness can be determined. All of these steps have been combined in the following table:-

- A - % Fineness through 100 mesh sieve.
 B - Horsepower hours per barrel.
 C - Power cost per barrel.
 D - Maintenance and depreciation cost per barrel.
 E - Total cost of grinding per barrel.
 F - Increased cost of grinding per % Fineness.
 G - Saving in fuel per each increased % Fineness.

A	B	C	D	E	F	G
87	3.0	.045	.0040	.0490		
88	3.3	.050	.0055	.0555	.0065	.252
89	3.8	.058	.0065	.0645	.0090	.175
90	4.3	.064	.0070	.0710	.0065	.140
91	5.2	.078	.0075	.0855	.0135	.122
92	6.2	.093	.0081	.1011	.0156	.096.
93	7.8	.117	.0108	.1278	.0267	.086
94	8.7	.130	.0130	.1430	.0162	.061
95	10.6	.159	.0151	.1741	.0311	.052
96	13.3	.200	.0180	.2180	.0439	.027
97	17.0	.255	.0226	.2776	.0596	
98	21.0	.315	.0240	.3390	.0614	
99	26.3	.394	.0260	.4200	.0910	

Diagrams "L" and "M" show the relative increased cost of each percent of fine grinding and the corresponding decrease in the cost in fuel. They meet at a point of fineness of about 96% and as the curves meet at a very wide angle it is apparent that for the conditions considered this is the most economical point to which fine grinding can be carried.

Curves "A" and "B" show that very little saving in fuel consumption need be looked for by increasing the length of the kilns more than 150 feet or by a length to diameter ratio of more than 17. Mechanical difficulties also become very hard to overcome. Increasing the length and also the length to diameter ratio increases the capacity very rapidly up to a length of 125' and a ratio of 15.7, but between this a point where length is 150' and ratio is 17 there seems to be no increase in capacity and very little reduction in fuel consumption. Should the 125' kiln record be an exceeding good one and the 150' a poor one the curves might pass between them and still have greatly increased values for greater ratios and longer kilns. By special appliances it is possible to keep the 125' kilns open and free from rings of material but it more than probable that these difficulties keep down the capacities of the longer kilns. Hence a kiln 135' long and 8' 4" should meet all conditions imposed on it better than any other and should have a capacity of about 1000 barrels per day and a fuel consumption of less than 86 pounds of coal per barrel.

The data on fine grinding are averages of long periods on hard limestone, clay, or shale and should be conclusive for this material. For other raw material it may be necessary to make slight changes which can be determined by observation of the special case and corrections made by similar process of calculation. The first cost of fuel will vary between very wide limits as will its heating value and will effect the cost of burning and power cost but increasing or decreasing together as they will, the results will be compensating to a degree. The curves for fine grinding all show that the greatest reduction of particles for power applied take place between certain limits and would indicate that much can be expected by grinding in relay

where a fineness of 92% or finer is desired.

Another very important consideration of fine grinding is that the finer the material is ground the more perfectly the correct formula is set up in each molecule, making the cement more uniform, of much greater strength, and its soundness is assured to a much greater degree.

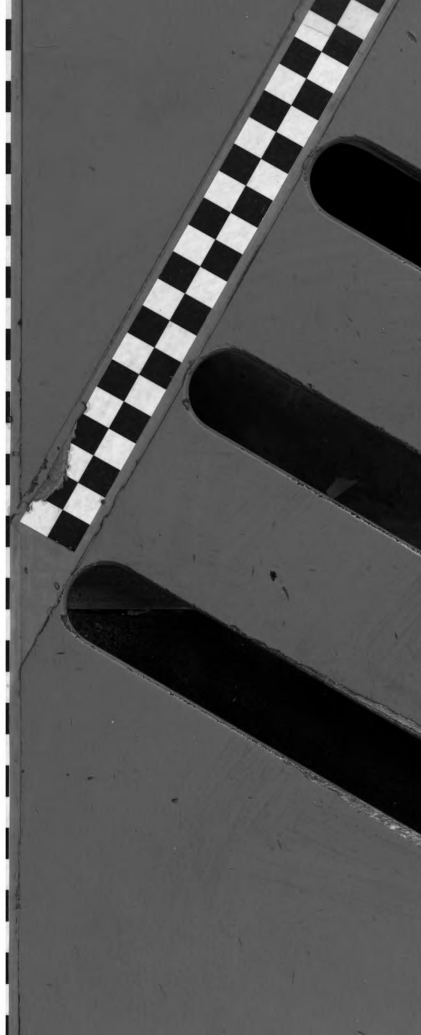
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