2

Conf-911182--6

DOE/MC/11089-92/C0005

DOE/MC/11089--92/C0005

DE92 011202

Cost Optimization of Stirred Ball Mill Grinding

Authors:
Schultz, C.W.
Mehta, R.K.

Contractor:
Institute of Gas Technology
3424 South State Street
Chicago, Illinois 60616

Contract Number:
DE-AC21-87MC11089

Conference Title:
1991 Eastern Oil Shale Symposium

Conference Location:
Lexington, Kentucky

Conference Dates:
November 15-17, 1991

Conference Sponsor:
University of Kentucky Institute for Mining and Minerals Research Center for Applied Energy Research, and the U.S. Department of Energy

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615)576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

COST OPTIMIZATION OF STIRRED BALL MILL GRINDING

by

C. W. Schultz and R. K. Mehta
Mineral Resources Institute
The University of Alabama
Box 870204
Tuscaloosa, Alabama 35487–0204

Abstract

On going research at The University of Alabama has shown that stirred ball mill grinding is the highest cost unit operation in the beneficiation of Eastern Oil Shales. Minimization of that cost is critical if oils derived by beneficiation and hydroretorting of Eastern shales are to become an economic alternative to conventional crude oils.

Cost optimization of stirred ball milling is a substantially different problem than optimizing a conventional (tumbling) mill operation. For conventional mills minimum cost is virtually synonymous with minimum energy consumption. Because the technology is mature and well understood, the operator can predictably optimize within a very narrow range of operating conditions.

In contrast, stirred ball milling offers the operator several more "degrees of freedom" in selecting operating conditions. An example is the selection of rotor speed. In general, lower speeds result in lower energy consumption per ton of material ground but at the cost of reduced mill capacity per unit volume. Because stirred ball mills have a high capital cost per unit volume the trade off between energy consumption and capacity becomes critical.

This paper presents a generalized total cost model for stirred ball milling and examines data generated in the grinding of oil shales in terms of the model. The paper also discusses the role of the cost model in guiding futureresearch in grinding circuit optimization.

INTRODUCTION

Research in the beneficiation of Eastern oil shales has shown that to achieve an acceptable level of concentration coincident with high oil recovery requires very fine grinding. For example, to prepare a concentrate containing 40 gal/ton with 90% oil recovery, the raw shale must be ground to $d_{90} \approx 10\mu^{(1)}$. Grinding to such a size is predictably the highest cost unit operation in the mineral beneficiation scheme. Hence a major portion of the on–going beneficiation research addresses the problem of ultra fine grinding in a stirred ball mill.

Research in this area is formed on two aspects; optimization of the integrated grinding – flotation circuit and optimization of the operating parameters on a cost basis. A previous paper(2) showed how various circuit configurations could reduce energy consumption and cost by reducing the fraction if the raw feed that is ultimately ground in the stirred ball mill.

This paper addresses the questions of how and why cost optimization may differ from energy minimization and in turn how experiments are planned and data analyzed to achieve cost optimization.

Capital Costs as a Variable

Traditional cost accounting practices treat capital costs of equipment as a fixed cost. For the most mineral processing equipment, including conventional ball mills, this is entirely appropriate. For stirred ball mills, however the capital cost per ton of finished (ground) product is variable because the capacity, at any specified feed and product size, is variable.

The variability of stirred ball mills capacity results from the degrees of freedom in their operating parameters which are not present in the operations of conventional mills. Most important of these is rotor speed. The rotor speed in a stirred ball mill is limited only by the size and design of the drive motor and not by any physical phenomena occurring in the mill. In contrast a conventional tumbling mill is limited to operating at less than its critical speed (i.e. the speed at which the ball charge centrifuges). Increases in the rotor speed of a stirred ball mill increases the capacity of the mill with a concurrent increase in power consumption per ton of product.

In addition to mill speed, other degrees of freedom present in the operation of a stirred ball mill are media size and media composition. Both factors as being studied in this on-going cost optimization.

Total cost optimization, as distinct from energy minimization, is only important if capital costs/ton are high and if they are of the same general magnitude are energy costs per ton.

Figure 1 shows the purchased price of stirred ball mills in dollars per liter of mill volume as a function of mill size. Predictably the cost per liter drops as mill size is increased. Figure 1 also shows that no further economics of scale can be expected for mills larger than 500 liters. Thus for purposes of this paper the cost of $460/liter or $46,000/100 liters is used for further discussion.

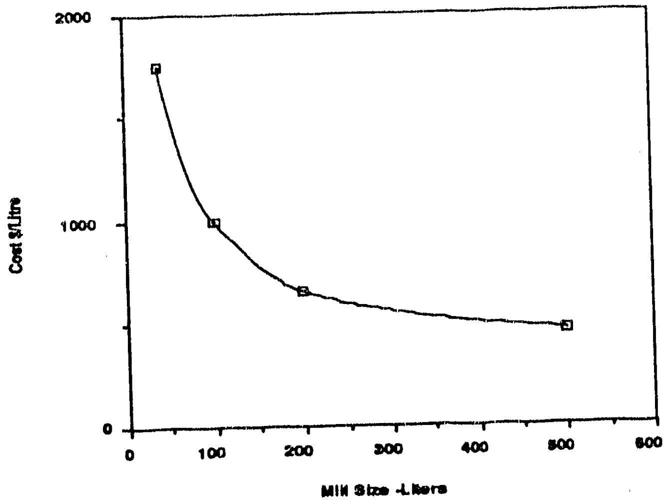

Figure 1
Stirred Ball Mill Cost ($/Liter) as a Function of Size

To put the purchased cost in closer perspective we assume that a stirred mill has a useful life of seven years and that interest rates are 12 percent. The amortization cost then for 100 liters of SBM volume is $812/month. If we further assume an average of 660 operating hours per month that cost becomes $1.23 per operating hour.

The foregoing are the fixed costs of owning 100 liters of stirred ball milling volume. To express these as variable costs we calculate the production rate from experimental data. Typically the feed to the stirred ball mill is a 53% solids slurry fed at a controlled rate. A feed rate of 1000 cc/minute in our 2.7 liter mill corresponds to 1.70 MT/hr/100 liters or a capital cost of $0.72/MT.

Using this same calculation we have projected the capital cost per ton of product as a function of feed rate. Figure 2 shows the result of those calculation. The projected capital costs (in an industrial size mill) are plotted against the volume flow rate in the experimental mill.

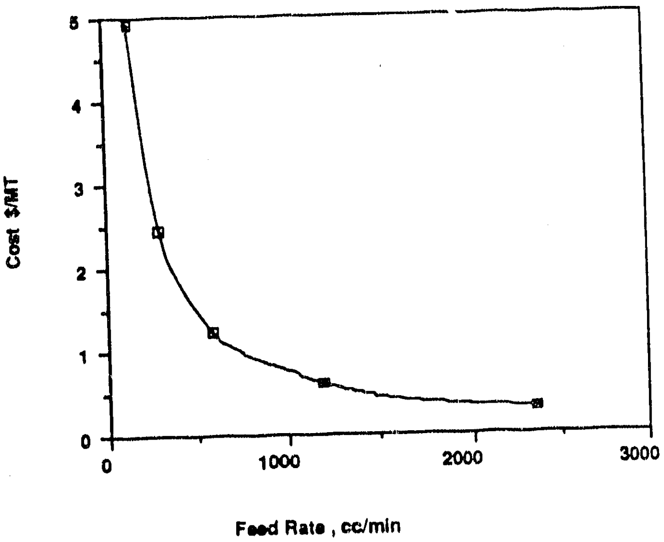

Figure 2
Projected Capital Cost as a Function of Feed Rate

Experimental Procedure for Cost Optimization

Figure 2 illustrates clearly that capital costs per unit of productivity are high enough to warrant total cost optimization rather than the previously assumed energy minimization.

The three major cost elements in stirred ball milling are energy consumption, media consumption, and capital. Each is a variable function of mill operating parameters. Most important of these is mill speed. In general, as mill speed is increased the energy consumption per ton at a specified product size increases, thus lower energy costs favor low operating speeds. This can be illustrated by Table 1 in which data from an earlier stirred ball milling test are tabulated.

***Table 1. Selected Data Showing the Increase in Specific Energy with Increasing Rotor Speed**

Rotor Speed (RPM)	Media Filling (%)	Feed Rate (cc/min.)	Net Power (Watts)	Specific Energy (kwh/t)	Product d90	Microns d50
1400	85	275	3172.7	317.2	10.3	3.7
1450	85	275	3499.3	349.9	9.9	3.5
1500	85	275	3786.1	378.6	9.8	3.5
1550	85	275	4153.3	415.3	9.4	3.4
1600	85	275	4450.2	445.0	9.2	3.4

Note that at constant feed rate the specific energy consumption increase as the rotor speed is increased. Concurrently, the size of the product decreases, indicating that the capacity of the mill should increase (thereby decreasing capital costs) at constant product size as the rotor speed is increased. Table 2 indicates that this presumption is correct.

***Table 2. Selected Data Showing Capacity Increase with Increasing Rotor Speed**

Rotor Speed (RPM)	Media Filling (%)	Feed Rate (cc/min.)	Net Power (Watts)	Specific Energy (kwh/t)	Product d90	Microns d50
1450	83	200	2829.3	387.5	10.6	3.7
1500	83	205	3026.1	403.5	10.5	3.7
1550	83	215	3243.3	415.8	10.4	3.6
1600	83	215	3590.2	460.2	10.1	3.5

In this case rotor speed and feed rate were increased simultaneously. In the first three cases the product size is essentially constant. Note however that the increase in specific energy still accompanies this increase in rotor speed.

These cases illustrate the basic "trade off" which must be made in optimizing stirred ball milling costs i.e. energy (operating) vs. capital costs. Unfortunately the data which have been gathered to date are insufficient and in the wrong form to permit the calculations of an optimum condition at this time. To fully optimize it will be necessary to first generate individual Charles law (log E vs. log D_{50}) relationships for each rotor speed. Hypothetically these would be of the form illustrated by Figure 3. Concurrently we shall determine the capacity (feed rate) as a function of product size for each rotor speed. These data should be of the general form shown in Figure 4.

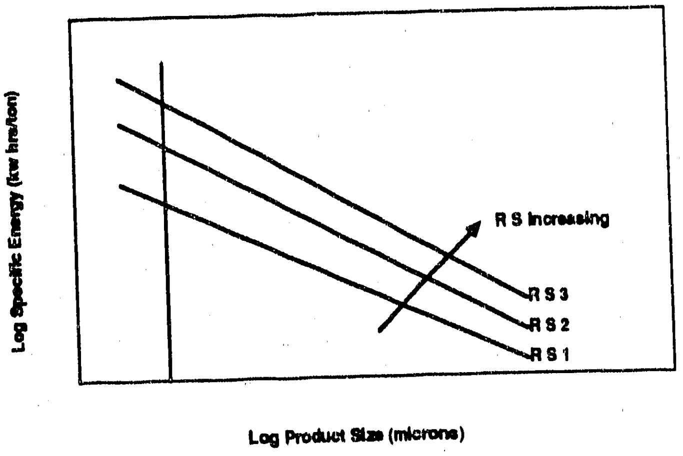

Figure 3

Idealized Charles Law Plot

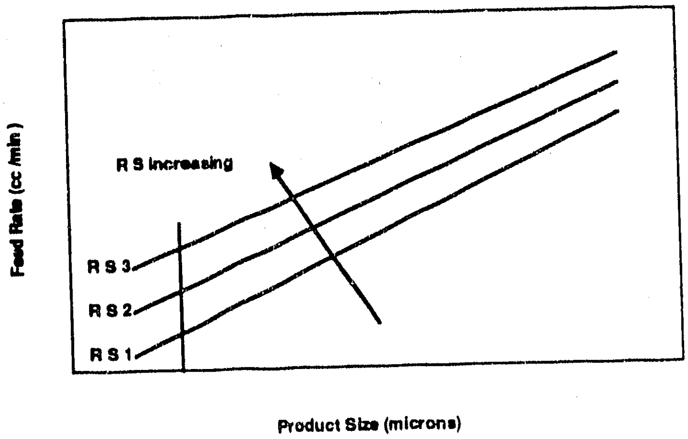

Figure 4

Feed Rate as a Function of Product Size

From Figures 3 and 4 then we establish the energy consumption/ton and the feed rate (mill capacity) at a specified size as a function of rotor speed by plotting the intercepts of the vertical lines, shown in Figures 3 and 4, with the individual rotor speed curves.

The energy consumption/ton as a function of rotor speed is now readily converted to cost/ton by multiplying the energy consumption by the current cost of electric power. The feed rate is then converted to capital cost using the relationships shown in Figure 2.

---

* The data presented in the Tables 1 and 2 are for -100 mesh Alabama shale. The data shown are for illustrative purposes only. Current specific energy data are substantially lower.

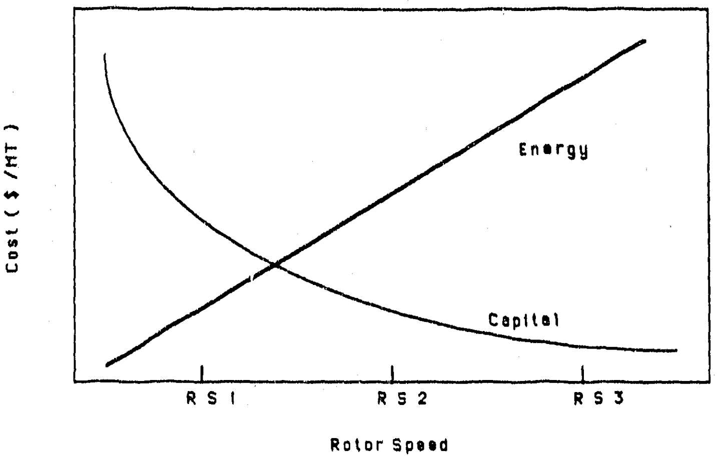

Figure 5

Capital and Energy Costs as a Function of Rotor Speed

Finally, plotting energy costs and capital costs as a function of rotor speed we expect curves of the general form shown in Figure 5. Since total cost is the sum of energy cost and capital cost we will see an optimum (minimized cost) at the intersection of the two curves.

In the foregoing discussion we have, for the sake of simplicity, omitted any reference to media consumption. In limited observations this does appear to be an important consideration. Media wear on this order of two lbs/tons have been measured. Wear tests are being incorporated into future test plans. Because the curve plotted in Figures 3 and 4 will be different for each different media size one would like to plot the curve for largest media size because of media size and wear considerations. Generally we expect media wear to vary with rotor speed in the same way that energy consumption does, (i.e. high media consumption with high rotor speeds). This adds another dimension to the optimization procedure but does not change the basic approach.

One cautionary note must be sounded here. All of the optimization tests, such as would generate Figures 3 and 4, must be performed in the range of realistic test conditions. These conditions generally include high slurry densities, low reduction ratios, truncated feed size distributions, (i.e. feed stocks with the fines removed), and coarse media. The test conditions over which we apply the optimization tests will be defined by the concurrent efforts being conducted in circuit optimization.

Summary

In summary, we feel that this paper has shown that capital costs, when reverted to a cost per ton of shale ground, are important and must be weighed against the cost of consumables (power and media) to achieve a total cost optimization. Such optimization can be achieved by the procedure outlined here. Following a rigorous cost optimization, procedure will also contribute to our full understanding of the stirred ball milling process and will increase the validity of our estimates of the cost of oil shale beneficiation.

Acknowledgments

This work is supported by a contract from the United States Department of Energy through a subcontract from the Institute of Gas Technology. Their support is gratefully acknowledged.

References

1. C.W. Schultz, J.B. Bates, and W.E. Lamont, 1989, "Column Flotation of Eastern Oil Shales", Proceedings of 1989 Eastern Oil Shale Symposium, Lexington, Kentucky, pp. 425–430.

2. C.W. Schultz and R.K. Mehta, "An Integrated Circuit for Beneficiating Eastern Oil Shales" Proceedings of 1990 Eastern Oil Shale Symposium, University of Kentucky, pp. 367–73.

END

DATE FILMED

5/14/92