Capacities and performance characteristics of jaw crushers

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Abstract — *By using the data of E.A. Hersam and F.C. Bond's equation for energy consumption in comminution, a method was developed to analyze the performance of industrial jaw crushers. The study showed that industrial jaw crushers are generally operated below capacity. The study also showed that industrial jaw crushers generally have sufficient installed power to operate at full capacity. The method presented can be used to estimate the capacities and power requirements of jaw crushers.*

Introduction

Although jaw crushers are extensively used for a variety of materials, their operational characteristics are not well understood. This lack of understanding makes selection of the proper machine difficult. Hersam (1923) proposed a method for calculating capacities using a Dodge-type jaw crusher. The equation proposed by Hersam includes a number of constants that are only qualitatively related to the machine and material characteristics. These constants include items such as speed, throw, setting, angle between the jaws, size and nature of the material. Rose and English (1967) proposed quantitative relationships for these constants and claimed good agreement with Hersam's data. Rose and English also attempted to analyze the performance characteristics of industrial jaw crushers based on their equations. However, a closer study of their data revealed a number of deficiencies. The most important of these are:

- the use of the imperial ton instead of the short ton used by Hersam without accounting for the difference;

- the use of a single set of values for the properties of materials crushed by the industrial machines (instead of selecting more appropriate values based on the material); and

- inadequacy of the proposed relationship to account for the effect of feed size (as can be seen from the data in Table 1).

To overcome these deficiences, an attempt was made in the present work to re-evaluate the empirical constants. The final equation presented here was tested against the laboratory data of Hersam. In addition, the performance of industrial jaw crushers was analyzed using the proposed equation in combination with that of Bond (1961) for calculating the energy requirement in size reduction.

Table 1 — Test of the Rose and English equation for the effect of feed size on jaw crusher capacity

Size of feed, m	Capacity, th^{-1} Hersam, W_a	Capacity, th^{-1} Rose and English, W_R	W_a/W_R
0.076 - 0.102[a]	0.271	0.368	0.74
0.051 - 0.076[a]	0.460	0.599	0.77
0.025 - 0.051[a]	0.494	0.774	0.64
0.013 - 0.025[a]	0.629	0.774	0.81
0.051 - 0.064[a]	0.449[c]	0.368	1.22
0.051 - 0.064[a]	0.554[d]	0.368	1.50
0.051 - 0.064[a]	0.589[e]	0.368	1.60
0.025 - 0.051[b]	0.584	0.944	0.62
0.025 - 0.038[b]	0.603	0.740	0.82

Feed material: .... Granite
Density: .... 2.66 tm^{-3}
Width of jaws: .... 0.159 m
Vertical dist. between jaws: .... 0.206 m
Speed of the machine .... 304 rpm
Throw: .... 0.0053 m
K_2 .... 1.0 (assumed)
K_3 .... 1.0 (assumed)

	Gape, m	Open side setting, m
a	0.122	0.114
b	0.124	0.132
c	Rough jaws	
d	Medium rough jaws	
e	Smooth jaws	

The equation for capacity

The volume of material (V) that passes through the crusher bottom opening per stroke is given by:

$$V = w(S+T/2)a \qquad (1)$$

If the machine is run at low speeds, the movement of the jaw allows sufficient time for the material to fall through under gravity, with the distance of fall depending on the geometry of the machine. However, if the machine is run at very high speeds, the interval between two strokes is not sufficient to allow free movement of the material between the jaws. Under this condition, the movement of the material is controlled by the speed of the machine (Hersam, 1923).

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Thus, in the former case:

$$a = DT/[G-(S+T)] \quad (2)$$

and in the latter case:

$$a = gt^2/2 \quad (3)$$

Where t is approximately the time for one half of a revolution or stroke of the machine, Eq. (3) becomes:

$$a = g(30/N)^2/2 \quad (4)$$
$$= 450\ g/N^2$$

From Eqs. (1), (2) and (4), the volumetric capacity of a jaw crusher can be written as:

$$V_h = 60N \times w(S+T)/2\ DT/[G-(S+T)] \quad (5)$$

at low speeds, and

$$V_h = 60N \times w(S+T)/2\ 450\ g/N^2 \quad (6)$$
$$= 2.645 \times 10^5\ (S+T/2)/N$$

at high speeds.

It can be seen from Eqs. (5) and (6) that, for speeds below a certain value, the capacity varies directly with the speed of the machine, and above this speed, the capacity varies inversely with the speed. The transition at which this occurs is defined (Rose and English, 1967) as the critical speed (N_c), and it is obvious that the maximum capacity of a machine will be at the critical speed.

At the critical speed (N_c):

$$DT/[G-(S+T)] = 450\ g/N^2_c \quad (7)$$

or

$$N_c = 21.2\ g\ \{[G-(S+T)]/DT\}^{0.5} \quad (8)$$

$$= 66.4\ \{[G-(S+T)]/DT\}^{0.5}$$

Eqs. (5) and (6) give total volumes displaced under ideal conditions. The actual volume of solids handled would be less than this due to void spaces between the particles. Under operating conditions, further deviations from theoretical values occur due to the direct and indirect influences of the material characteristics and operating conditions on the bulk density of the material as it is discharged from the bottom opening of these machines. These deviations must be accounted for in order to convert the theoretical volumetric capacity to actual capacities in terms of weights.

The bulk density of the crushed material may be expected to be dependent on:

- the size characteristics of feed in relation to the size of the machine;
- the degree of compaction attained by the crushed material resulting from the vibratory effect of the throw of the machine; and
- the nature of the material, including the true density of the material.

The size characteristics of the feed are important considerations. The coarser the feed, the larger the number of crushing stages and degree of compaction the feed has to undergo before it is discharged. It is commonly observed that the degree of compaction of the product decreases with increasing coarseness of the feed. The dependence of the degree of compaction on the relative size of the feed may be studied as a function of the average feed size divided by the gape (Fav/G). This is considered to be the most appropriate parameter since the gape is the factor that controls the size of the material that can be fed to the machine and since it is related to all other dimensions of the machine (Rose and English, 1967).

However, when the feed contains sufficiently large quantities of particles with an average size close to that of the set size, these particles pass through the machine without being crushed. In such cases, the throughput exceeds the theoretical capacity.

The throw of the machine has a significant bearing on the effectiveness of crushing and on the degree of compaction attained by the product in the machine due to its vibratory action. The influence of the through (T) can be studied through the parameter T/G (Rose and English, 1967).

Characteristics such as hardness and surface friction determine the ease with which a particle is nipped and crushed,

Table 2 — Effect of throw on jaw crusher capacity (from Hersam, 1923)

Width of jaws: 0.159 m
Vertical dist. between jaws: 0.206 m
Speed of machine: 304 rpm
Close side setting: 0.00953 m
Size of feed material: 0.025 - 0.038 m
K_3: 1.0 (assumed)

Throw, m	Throw /gape	F_{av}/G	K_1	$V_hK_1K_3d$	W_a, th^{-1}	$K_2 = W_a/V_hK_1K_3$
0.00551[a]	0.0438	0.252	0.818	0.780	0.684	0.877
0.00551[a]	0.0484	0.279	0.809	0.864	0.699	0.809
0.00551[a]	0.0628	0.362	0.771	1.119	0.792	0.708
0.00551[a]	0.0839	0.483	0.688	1.434	0.782	0.545
0.00318[b]	0.0272	0.272	0.811	0.427	0.574	1.343
0.00396[b]	0.0337	0.270	0.812	0.566	0.688	1.215
0.00475[b]	0.0401	0.268	0.812	0.701	0.774	1.104
0.00551[b]	0.0463	0.266	0.814	0.842	0.793	0.942
0.00635[b]	0.0529	0.265	0.814	1.003	0.898	0.896

	Material	Density, tm^{-3}
a	Trap rock	2.61
b	Granite	2.66

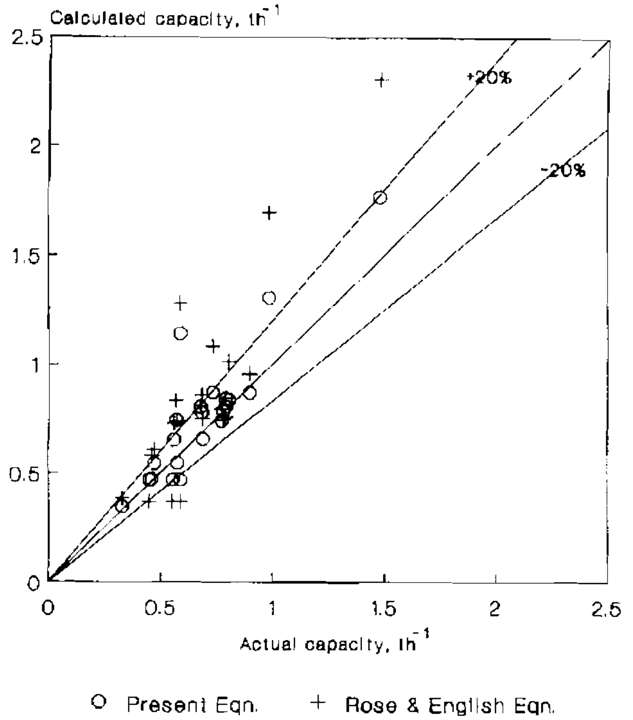

Fig. 1 — Comparison of calculated capacities with the data of Hersam (1923) for different machine parameters.

thereby influencing the degree of compaction of the product.

The final equation for the capacity of jaw crushers can now be written as

$$W = V_h K_1 K_2 K_3 d \qquad (9)$$

where K_1, K_2 and K_3 are related to the parameters F_{av}/G, T/G and the nature of the material, respectively. Using the data of Hersam (1923), quantitative relationships between these variables were developed as shown below.

Effect of the size of feed

The values of K_1 were calculated as a function of F_{av}/G from the data given in Table 1 using Eq. (9). For this purpose, K_2 and K_3 were arbitrarily set at one. The relationship between the calculated K_1 and F_{av}/G (Table 1) can be represented by the equation:

$$K_1 = 0.85 - (F_{av}/G)^{2.5} \qquad (10)$$

Effect of throw

The necessary data for studying the effect of throw on the performance of jaw crushers are given in Table 2 (Hersam, 1923). For calculating the values of K_2, the value of K_3 for materials like granite and traprock were set equal to one, and the values of K_1 were calculated with Eq. (10).

The variation of K_2 with T/G (Table 2) can be represented by the equation

$$K_2 = 1.92 \times 10^{-6.5T/G} \qquad (11)$$

Test of the proposed correlation

The validity of the proposed equations was established by comparing the capacities calculated by the present method and the method of Rose and English with the experimental data of Hersam. For convenience, the data were divided into two sets. In the first set (Fig. 1), the effects of the machine variables such as speed, setting, angle between the jaws, throw and the condition of the jaws on the capacity was studied. In the second set, the effect of the material characteristics such as feed size, density and nature of material on capacity was tested (Table 3).

As can be seen in Table 3 and Fig. 1, the present correlation is in better agreement with Hersam (with deviations of less than 20% in most cases) than that of Rose and English. In particular, the effect of feed size is represented more accurately by the present correlation. Contrary to the findings of Hersam (1923), Gieskieng (1949) and Gauldie (1953), the present study (as well as that of Rose and English) showed that the angle between the jaws need not be considered as an independent variable.

In addition, the capacities for crushers with smooth jaws are found to be about 20% higher compared to partly worn jaws.

Effect of nature of material

The relevant data shown in Table 3 indicate that the materials studied fall into two groups: one consisting of coke and coal and the other consisting of the remaining materials. When K_3 was assigned a value of one for the materials of the second group, it assumed a value of about 0.6 for the first group. Hersam stated that this discrepancy was probably due to the variation in the densities of the materials. The present study, however, indicated that this statement is not valid since the latter group also contains materials with widely varying densities (ranging from 2.61 to 6.15). In this connection, it may be noted that the first group consists of soft materials such as coal and coke while the other group consists of relatively harder materials. In view of this, it is suggested that the value of K_3 would be 0.6 for softer materials and 1.0 for the harder materials. However, this needs to be confirmed

Performance of industrial jaw crushers

The utility and reliability of the correlation was further tested by analyzing data on industrial machines compiled by Taggart (1945) and Weiss (1985). To accomplish this, a number of machine and material characteristics were estimated or assumed since data were not available. Data based on generalized relationships or operating practice were mainly used, and are discussed briefly below. As mentioned earlier, the gape of the jaw crusher is a unique property which has a relationship to almost all the other machine characteristics. In view of this, the other parameters are expressed in terms of the gape whenever possible.

Machine characteristics

These include data on the vertical depth between jaws (D), the speed of the crusher (N), the throw of the crusher (T) and K_2, among others.

Vertical depth between jaws: Rose and English assumed a constant ratio of 2 for D/G. However, available data (K. Van Saun; Hewitt Robbins; and Pryor, 1965) shown in Fig. 2 give the following relationships:

$$D = 3.25G^{1.15} \text{ for } G \leq 0.25 \text{ m} \qquad (12)$$

$$D = 0.21 + 1.8\,G \text{ for } G \geq 0.25 \text{ m} \qquad (13)$$

Operating speed: The machines are generally found to operate below the critical speeds (Rose and English, 1967).

Table 3 — Comparison of calculated capacities with the data of Hersam (1923): Effect of material characteristics*

(a) Size of feed

Gape:	0.122 m
Close side setting:	0.0061 m
Throw:	0.00533 m
Material:	Granite
Density:	2.66 tm^{-3}
Size of feed:	0.025 - 0.038 m
K_3:	1 (assumed)

Size of feed, m	Capacity, th^{-1} Hersam W_a	Present W	Rose and English W_R	W_a/W	W_a/W_R
0.076 - 0.102	0.271	0.264	0.368	1.02	0.74
0.051 - 0.076	0.460	0.439	0.599	1.05	0.77
0.025 - 0.051	0.494	0.534	0.774	0.93	0.64
0.013 - 0.025	0.629	0.563	0.774	0.93	0.64
0.003 - 0.013†	1.136	0.570	0.814	1.99	1.40

† Feed contained large amounts of material finer than the set of the crusher

(b) Toughness

Gape:	0.124 m
Close side setting:	0.00795 m
Throw:	0.00526 m
Size of feed:	0.025 - 0.038 m
K_3:	1.00 (assumed)

Material	Density, tm^{-3}	Degree of elasticity	Capacity, th^{-1} Hersam W_a	Present W	Rose and English W_R	W_a/W	W_a/W_R
Quartz	2.68	high	0.674	0.669	0.749	1.01	0.90
Trap rock	2.61	low	0.560	0.652	-.729	0.86	0.80
Granite	2.66	medium	0.603	0.664	0.743	0.91	0.81

(b) Density of material

Gape:	0.124 m
Close side setting:	0.00795 m
Throw:	0.00526 m
Size of feed:	0.025 - 0.051 m
K_3:	1.00 (assumed)

Material	Density, tm^{-3}	Capacity, th^{-1} Hersam W_a	Present W	Rose and English W_R	W_a/W	W_a/W_R
Granite	2.66	0.584	0.649	0.958	0.90	0.61
Stibnite in quartz	3.03	0.668	0.738	1.096	0.91	0.61
Chalcocite in quartz	4.40	0.983	1.073	1.588	0.92	0.62
Galena in quartz	6.15	1.458	1.499	2.344	0.97	0.62
Coke	1.11	0.153	0.271	0.401	0.56	0.37
Coal	1.91	0.261	0.466	0.687	0.56	0.38

* Fixed conditions:

Width of jaws:	0.159 m
Vertical depth between jaws:	0.206 m
Speed of the machine:	304 rpm

The normal operating speeds (Taggart, 1945; Weiss, 1985; Kennedy Van Saun; Hewitt Robbins; Pryor, 1965; Gaudin, 1939; and Cremer and Davies, 1957) are given by

$$N_{op} = 280 \times 10^{-0.175G^2} \tag{14}$$

Throw of the machine: Since throw is relatively small compared to the close side setting, substitution of S+T/2 by S+T or S (depending on available data) in Eqs. (5) and (6) is not likely to result in significant error. Equation (9) still contains T (from Eq. (5)) and K_2 which is again a function of T/G. Data available from other sources on throw (Weiss, 1985; Kennedy Van Saun; Hewitt Robbins) and the relationship between K_2 and T/G established earlier (Eq. (11)) showed that it is possible to lump the parameters K_2 and T together as shown in Fig. 3.

This relationship can be written as:

$$K_2T = 0.037\ G \tag{15}$$

Material characteristics

Feed size: The maximum size of feed is taken as 0.85 G. The feed to the crusher follows a straight line relationship between cumulative weight percent passing and size (Taggart, 1945). Hence, the 80% passing size of the feed (F) is given by:

$$F = 0.8\ F_{max} \qquad (16)$$

for unscalped feed, and by:

$$F = 0.8\ F_{max} + 0.2\ S_c \qquad (17)$$

for feed scalped at S_c (Taggart, 1945).

Product size: The product size is mainly dependent on the setting, and the other parameters have only a marginal effect (Zeng and Forssberg, 1991). The 80% passing size of product (P) can be estimated (Narasimhan and Sastri, 1975) from the equation:

$$P = 0.85\ (S+T) \qquad (18)$$

Density of feed material: Actual density data were used when available. In other cases, average values for similar materials, as reported by Bond (1961), were used.

Work index: It was assumed that Bond's equation (Bond, 1961) is valid for calculating the power required for crushing. Average work index values for similar materials, as reported by Bond, were used.

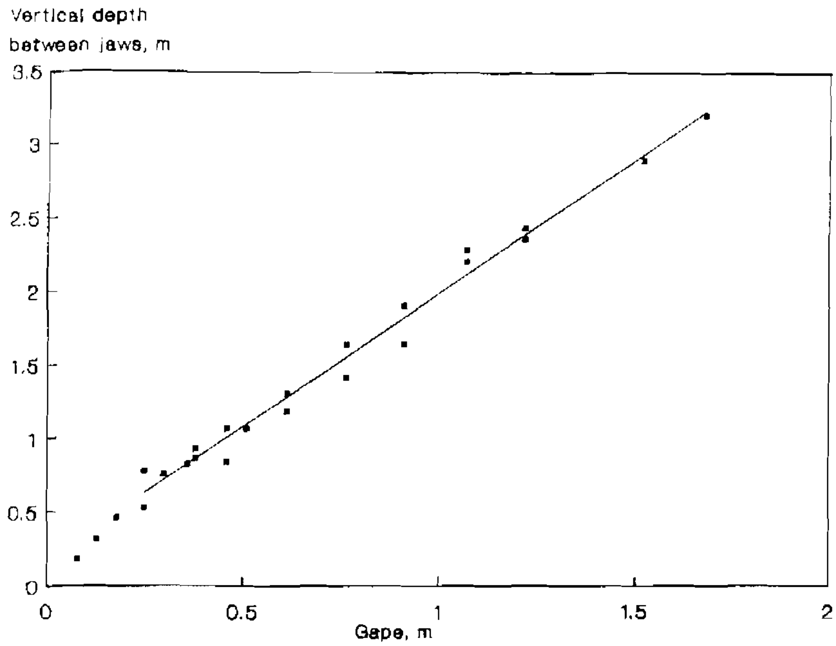

Fig. 2 — Variation of vertical depth between jaws with gape for jaw crushers.

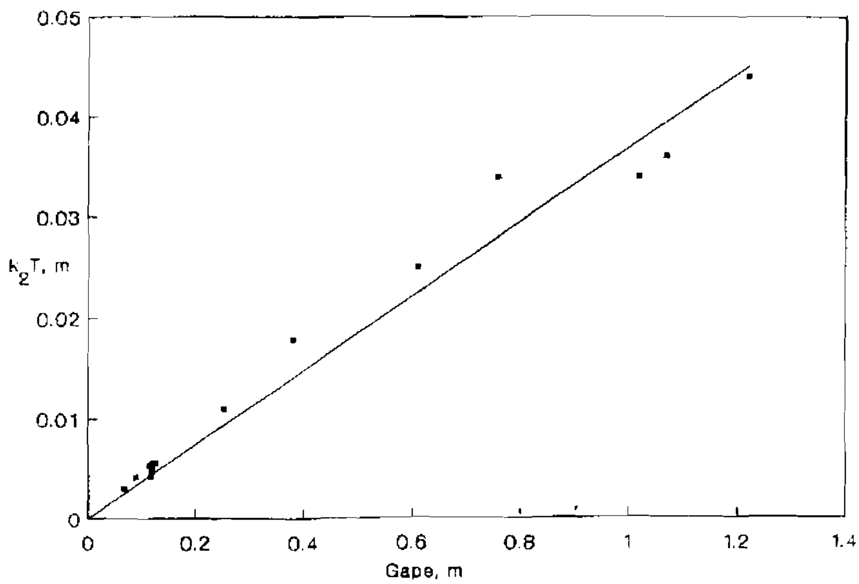

Fig. 3 — Variation of K_2T with gape for jaw crushers.

Results and discussion

The capacities at the operating speeds calculated by the present method (W) are compared with the actual values (W_a) in Table 4. The data on computed power consumption (P_c) and (P_m) at the operating and the calculated throughputs (W_a) and (W) respectively, are also given in Table 4.

Capacities

It can be seen from the data in Table 4 that, although some of the machines are operated close to the calculated throughputs, the actual feed rates to the crushers are generally below the calculated values.

The few cases in which the feed rates are considerably larger than the calculated throughputs may be due to:

- the use of a lower density for the material;
- the size characteristics of feed being different from those assumed; and
- the feed containing a large amount of fines that can pass through the bottom without being crushed (Zeng and Forssberg, 1991).

Power requirement

It can be seen from Table 4 that the ratio of power calculated at the actual throughput to power drawn (P_c/P_d), which may be considered as power efficiency, varies widely and is generally less than one. This is expected since the jaw crusher consumes energy even when idling, and the energy used for crushing varies directly with the throughput. Values greater than one for Pc/P_d can be logically attributed to the presence of large amounts of fines in the feed, which contributes to the throughput but does not consume energy for size reduction. There appears to be a fairly good relationship between the relative throughput (W_a/W) and the actual throughput to power drawn (P_c/P_d). Obviously, the calculated data on relative throughput and power efficiency is more reliable when actual data on material characteristics — true density, size and work index — are used. Figure 4, based on the data from Table 4 on crushers for which at least one material characteristic is known, illustrates the above point. The relationship in Fig. 4 can be expressed as:

$$P_c/P_d = W_a/W \qquad (19)$$

This observation is at variance with the conclusion of Rose and

Table 4 — Performance of industrial jaw crushers (from Taggart, 1945; and Weiss, 1985).

Plant	Size of crusher gape x width m x m	Feed rate, W_a th^{-1}	Calculated throughput, W th^{-1}	Calculated at feed rate P_c	Drawn P_d	Installed P_i	Required at calculated throughput P_m	Relative throughput W_a/W	Power efficiency P_c/P_d
USSR and M Midvale	0.25 x 0.51	10	24	4	11	15	10	0.42	0.36
BlackHawk	0.33 x 0.61	20	76	5	15	30	18	0.26	0.31
Dome	0.61 x 0.91	91	162	28	45	56	50	0.56	0.62
ElPotosi	0.61 x 0.91	136	208	32	58	93	49	0.65	0.55
McIntyrePorcupine	0.91 x 1.22	155	392	29	60	112	52	0.40	0.48
Aldermac	0.91 x 1.22	291	256	79	84	93	70	1.14	0.95
Chino	1.68 x 2.13	909	948	197	187	224	205	0.96	1.06
TreadwellYukon	0.46 x 0.76	59	149	8	12	37	21	0.40	0.67
Buffalo	0.46 x 0.76	46	124	12	19	37	33	0.37	0.35
GrantsAnaconda	0.64 x 1.02	236	204	65	45	93	56	1.15	1.44
PhilexMining	0.76 x 1.07	546	232	156	60	112	66	2.36	2.60
St.JoeMineral	0.81 x 1.07	300	311	37	40	93	39	0.96	093
Outokumpu	1.22 x 1.52	818	1079	75	97	97	98	0.76	0.77
Plomosas	0.46 x 0.76	36	149	7	30	30	30	0.24	0.24
EaglePicher	0.36 x 0.61	27	41	10	24		14	0.65	0.40
Noranda	0.91 x 1.22	295	509	49	75	75	84	0.58	0.65
Bagdad	1.02 x 1;07	727	270	166	51	112	62	2.70	3.26
Noranda	1.07 x 1.52	364	513	81	150	149	114	0.71	0.54
	1.22 x 1.52	364	501	84	150	149	116	0.73	0.53
Kennecot	1.68 x 2.13	955	922	169	126	224	116	1.04	1.34
Suyoc	0.20 x 0.61	14	20	5	16	19	7	0.69	0.30
Outokumpu	0.30 x 0.61	55	47	14	49	65	11	1.18	0.28
EaglePicher	0.53 x 0.91	109	167	24	44	45	14	0.65	0.53
Engels	0.61 x 0.91	38	297	8	69	112	58	0.13	0.11
Hadley	0.61 x 0.91	91	93	31	30	56	32	0.97	1.04
Kelowna	0.61 x 0.91	68	159	17	45	56	39	0.43	0.37
Iderado	0.61 x 0.91	91	73	37	58	111	30	1.24	0.64
Outokumpu	0.91 x 1.22	159	494	32	77	112	100	0.32	0.45
Inco	1.07 x 1.52	427	450	90	150	149	94	0.95	0.61
	1.07 x 1.52	427	529	90	150	149	111	0.81	0.60
	1.07 x 1.22	291	450	61	149	149	94	0.65	0.41
Noranda	1.12 x 1.52	473	492	98	83	149	116	0.96	1.17
Asarco	1.22 x 1.52	436	485	113	144	149	126	0.90	0.79
Bethelham	1.22 x 1.52	364	406	74	100	112	82	0.90	0.74
Hadley	0.15 x 0.51	23	11	6		19	3	2.01	
	0.25 x 0.51	23	33	5		19	8	0.71	
Magma	0.30 x 0.61	68	85	13		26	16	0.80	
Crown Mines	0.30 x 0.76	20	54	8		45	21	0.37	
Mountain City	0.38 x 0.61	50	41	12		37	10	1.21	
Wtherbee Sherman	0.61 x 0.91	91	210	20		75	47	0.43	
Sheritt Gordon	0.76 x 1.07	127	234	30		75	55	054	
Britannia	0.91 x 1.22	273	330	60		112	71	0.83	
Falconbridge	0.91 x 1.22	164	302	36		93	66	0.54	
Homestake	0.91 x 1.22	182	437	13		56	30	0.42	

English that P_c/P_d is nearly constant. Using this relationship, it is possible to calculate the actual power requirements of jaw crushers when material characteristics are available.

The steps involved are:

- calculation of maximum throughput (W) using Eq. (9);
- calculation of power (P_c) at actual throughput (W_a) using actual throughput and Bond's equation; and
- the calculation of actual power drawn (P_d) using Eq. (19).

Significant deviations from the above relationship may occur if the actual work index of the material being crushed is different from the value used. This is in addition to the other reasons cited in connection with the discussion on capacities.

Crushers which gave relative throughput greater than one also showed similar trends for power efficiency, which is indicative of very fine feed passing through the crusher without being crushed.

It can also be seen from Table 4 that the calculated data on maximum power at running speeds (P_m) are, in general, sufficiently lower than the installed power (P_i). This contradicts the conclusion of Rose and English that some of the larger machines are under powered. These machines are operated below their capacities probably due to the lower tonnage requirements for downstream operations or the necessity to install a machine of larger capacity than required to meet the feed or product size limitation and not due to insufficient installed power.

Conclusions

The capacity of a jaw crusher can be calculated from the equation:

$$W = 60\ Nw\ (S+T/2)a\ K_1\ K_2\ K_3\ d \qquad (20)$$

where $a = DT/[G-(S+T)]$ for $N \le N_c$ and $a = 450\ g/N^2$ for $N \ge N_c$.

The capacity for softer materials like coal appear to be around 60% of those for harder materials having the same density.

Normal operating speeds (N_{op}) are given by:

$$N_{op} = 280 \times 10^{-0.175G^2} \qquad (21)$$

Analysis of operating data from industrial units showed that:

- these machines are generally operated below their capacities;
- the actual power drawn by these machines can be calculated by using Bond's equation and the operating throughput ratio; and
- the crushers generally have sufficient power to operate at their maximum capacities if required.

Although many assumptions were made regarding the feed materials, in most cases the proposed correlations were within ±20% of the actual data.

Acknowledgments

The author acknowledges the Director of the Regional Research Laboratory, Bhubaneswar, India, for permission to publish this paper, and acknowledges Mr. K.K. Rao and Dr. R. Bhima Rao, Scientists at the Regional Research Laboratory, for their critical comments and valuable discussion during the preparation of this paper.

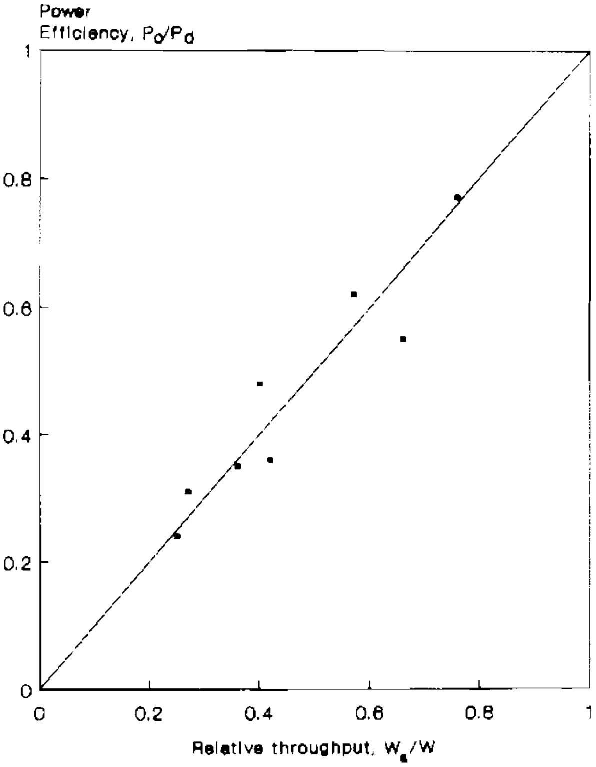

Fig. 4 — Relation between power efficiency and relative throughput for jaw crushers

Nomenclature

- a advance of material in the crusher, per stroke, m
- d density of material tm^{-3}
- D Vertical depth between jaws, m
- F 80% passing size of feed, m
- F_{av} average size of feed, m
- F_{max} maximum size of feed, m
- g acceleration due to gravity, m/sec^2
- G gape of the crusher, m
- K_1 parameter related to feed size
- K_2 parameter related to throw of the crusher
- K_3 parameter related to nature of material
- N speed of the crusher, rpm or strokes/min
- N_c critical speed of crusher, rpm or strokes/min
- N_{op} normal operating speed of industrial crushers, rpm or strokes/min
- P 80% passing size of product, m
- P_c calculated power for actual throughput, kW
- P_d power drawn, kW
- P_i installed power, kW
- P_m calculated power for theoretical throughput at operating speed, kW
- R reduction ratio at 80% passing size, F/P
- S close side setting, m
- S_c opening of scalping screen, m
- t time available for free fall of the material through the crusher when operating at high speeds, sec
- T throw of the crusher, m
- V volumetric throughput of the crusher, per stroke, m^3
- V_h volumetric throughput of the machine, m^3/hr
- w width of jaws, m
- W theoretical (calculated) throughput of the crusher, th^{-1}
- W_a actual throughput of the crusher, th^{-1}
- W_R throughput of the crusher calculated by Rose and English equation, th^{-1}

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