# TECHNICAL NOTES 5

# CRUSHERS

## 5.1 Jaw and Gyratory Crushers.

Jaw and gyratory crushers are used mostly for primary crushing. They are characterized by wide gape and narrow discharge and are designed to handle large quantities of material.

The capacity of the crusher is determined by its size.

The gape determines the maximum size of material that can be accepted. Maximum size that can be accepted into the crusher is approximately 80% of the gape.

Jaw crushers are operated to produce a size reduction ratio between 4:1 and 9:1. Gyratory crushers can produce size reduction ratios over a somewhat larger range of 3:1 to 10:1.

The primary operating variable available on a crusher is the set and on jaw and gyratory the open-side set (OSS) is specified. This reflects the fact that considerable portions of the processed material fall through the crusher at OSS and this determines the characteristics size of the product. The set of a crusher can be varied in the field and some crushers are equipped with automatically controlled actuated for the automatic control of the set. The open- and closed-side sets and the gape are identified in Figure 5.1. The throw of the crusher is the distance that moving jaw moves in going from OSS to CSS.

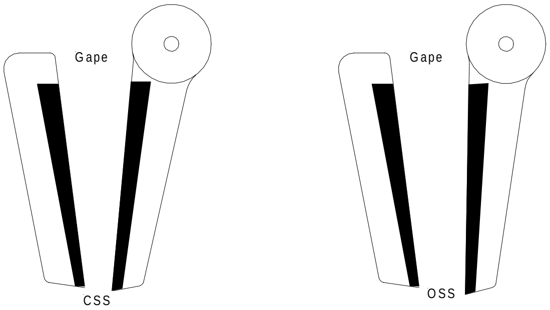

Figure 5.1 *Schematic diagram of a crusher showingg the open- and closed-side settings.*

Throw = OSS-CSS.

The capacity is a function of size and OSS. Manufacturers publish tables of capacity for their crushers of various size as a function of the open-side set.

### 5.1.1 Cone crushers

Cone crushers are commonly used for secondary, tertiary and quaternary crushing duties. Two variations are available - standard and short head

The chief difference between cone and gyratory or jaw crushers is the nearly parallel arrangement of the mantle and the cone at the discharge end in the cone crusher. This is illustrated in Figure 5.2.

Reduction ratios in the following ranges are common for cone crushers:
6:1 - 8:1 for secondaries
4:1 - 6:1 for tertiary and quaternary crushing.

The size distribution of the products tends to be determined primarily by the CSS since no particle can fall through during a single open side period and all particles will experience at least one closed side nip.

The CSS is adjusted by screwing the bowl up or down.

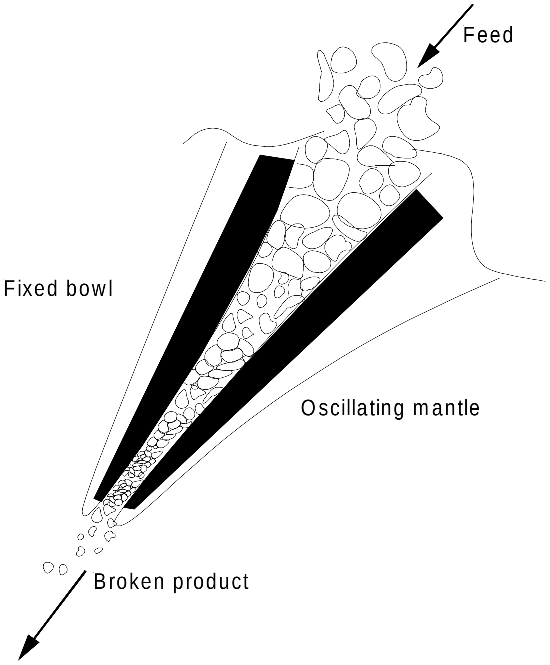

Figure 5.2 *Schematic view of the crushing zone of the cone crusher.*

### 5.1.2 Impact crushers

Breakage is achieved by impact using either hammer action on the individual particles or by sudden impact from a high velocity trajectory.

High reduction ratios of between 20:1 and 40:1 can be achieved with hammer type impact crushers.

Only low reduction ratios of about 2:1 can be achieved with kinetic energy type impact crushers.

### 5.1.3 Crushing mechanisms and product size distributions.

The crushing action of a crushing machine is described most usefully through the classification - breakage cycle model. The operation of a crusher is periodic with each period consisting of a nipping action and an opening action. During the opening part of the cycle material moves downward into the crusher and some material falls through and out. A certain amount of fresh feed is also taken in. This is illustrated in Figure 5.3.

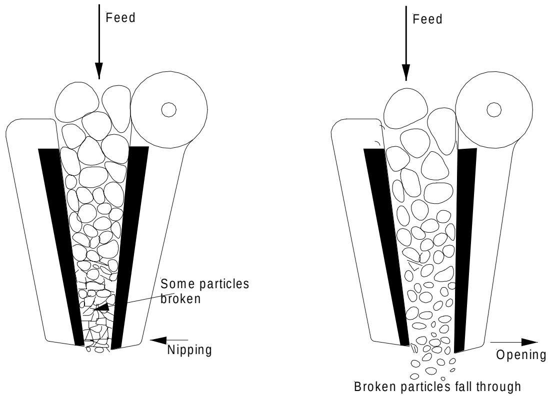

Figure 5.3 *The opening and nipping cycles in the crusher on which the model is based.*

Let us now describe this behavior quantitatively. It is best to work with a discrete size distribution. So define

$p_i^F$ = fraction of the feed in size class $i$,
$p_i$ = fraction of the product in size class $i$,
$M$ = mass of material held in the crusher,
$b_{ij}$ = fraction of particles breaking in size class $j$ by that end up in size class $i$.
$m_i$ = fraction of material in the crusher in size class $i$
$c_i$ = $c(d_i)$
= fraction of material in size class $i$ that is retained for breakage during the next nip of

the crusher.
$W$ = Mass of total feed that is accepted during a single opening
= mass of product discharged.

Size class 1 contains the largest particles.

Let us follow the fortunes of material in the largest size class starting with an amount $Mm_1$ in the crusher.

During an opening phase of the cycle:

Material discharged from the crusher = $(1-c_1)Mm_1$

Material positioned for breakage in the breakage zone during next nip = $c_1Mm_1$

Accepted from feed = $Wp_1^F$

After the next nip the crusher must again have an amount $Mm_1$ in the crushing zone since the operation is at steady state:

$$Mm_1 = Wp_1^F + c_1Mm_1b_{11}$$

$$\frac{Mm_1}{W} = \frac{p_1^F}{1 - c_1b_{11}} \tag{5.1}$$

Product discharged = $Wp_1 = (1-c_i)Mm_i$

$$p_1 = (1-c_1)\frac{Mm_1}{W} \tag{5.2}$$

Now consider the next size down:

During an opening phase of the cycle:

Material discharged = $(1-c_2)Mm_2$

Material positioned for breakage during next nip = $c_2Mm_2$

Accepted from feed = $Wp_2^F$

After next nip:

$$Mm_2 = Wp_2^F + c_2Mm_2b_{22} + c_1Mm_1b_{21}$$

$$\frac{Mm_2}{W} = \frac{1}{1 - c_2b_{22}}\left(p_2^F + c_1\frac{Mm_1}{W}b_{21}\right) \tag{5.3}$$

Product discharged = $Wp_2 = (1-c_2)Mm_2$

$$p_2 = (1-c_2)\frac{Mm_2}{W} \tag{5.4}$$

The next size down can be handled in exactly the same way to give

$$Mm_3 = Wp_3^F + c_3Mm_3b_{33} + c_2Mm_2b_{32} + c_1Mm_1b_{31}$$

$$\frac{Mm_3}{W} = \frac{1}{1-c_3b_{33}}\left( p_3^F + c_2\frac{Mm_2}{W}b_{32} + c_1\frac{Mm_1}{W}b_{31}\right) \tag{5.5}$$

This procedure can be continued from size to size.

In general

$$\frac{Mm_i}{W} = \frac{1}{1-c_ib_{ii}}\left( p_i^F + \sum_{j=1}^{i-1} c_j\frac{Mm_j}{W}b_{ij}\right) \tag{5.6}$$

The series of equations (5.6) can be easily solved recursively for the group $Mm_i/W$ starting from size class number 1. The size distribution in the product can then be calculated from

$$p_i = \frac{(1-c_i)Mm_i}{W} = \frac{1-c_i}{1-c_ib_{ii}}\left( p_i^F + \sum_{j=1}^{i-1} c_j\frac{Mm_j}{W}b_{ij}\right) \tag{5.7}$$

And the distribution of sizes in the product is completely determined from the size distribution in the feed and a knowledge of the classification and breakage functions.

The classification function is usually of the form shown in Figure 5.4.

$d_1$ and $d_2$ are parameters that are characteristic of the crusher. They are determined primarily by the setting of the crusher. Data from operating crusher machines indicate that both $d_1$ and $d_2$ are proportional to the closed side setting. $d_1$ is the smallest size particle that can be retained in the crushing zone during the opening phase of the cycle. $d_2$ is the largest particle that can fall through the crushing zone during the opening phase of the cycle.

A useful form of the classification function is

$$\begin{aligned} c_i &= 1 - \left(\frac{d_{pi}-d_2}{d_1-d_2}\right)^n && \text{for } d_1 < d_{pi} < d_2 \\ &= 0 && \text{for } d_{pi} \le d_1 \\ &= 1 && \text{for } d_{pi} \le d_2 \end{aligned} \tag{5.8}$$

For both standard and short-head Symons cone crushers,

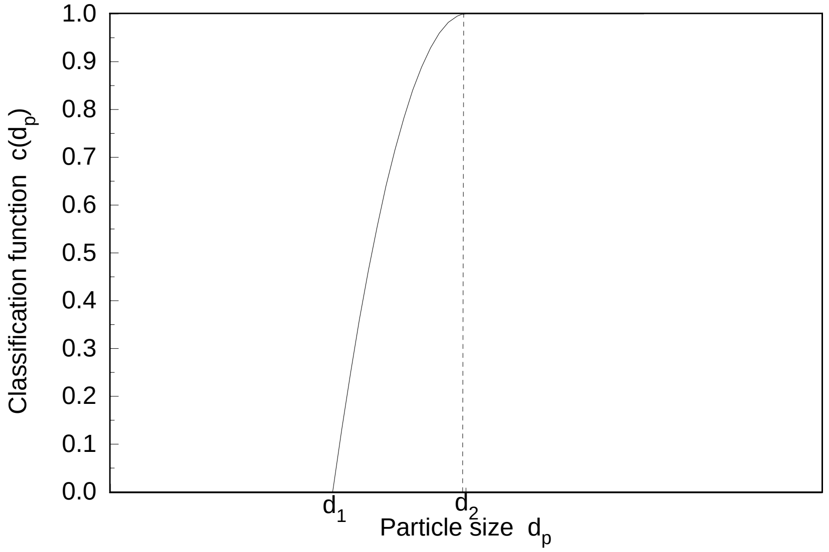

Figure 5.4 A typical internal classification function for a crusher

$$d_1 = \alpha_1 \, CSS \tag{5.9}$$

$$d_2 = \alpha_2 \, CSS + d^* \tag{5.10}$$

$\alpha_1$ varies from about 0.5 to 0.95 and $\alpha_2$ varies from about 1.7 to 3.5. $n$ is usually approximately 2 but can be as low as 1 and as high as 3. Higher values of $n$ usually require higher values of $\alpha_2$. $d^*$ is usually set to 0.

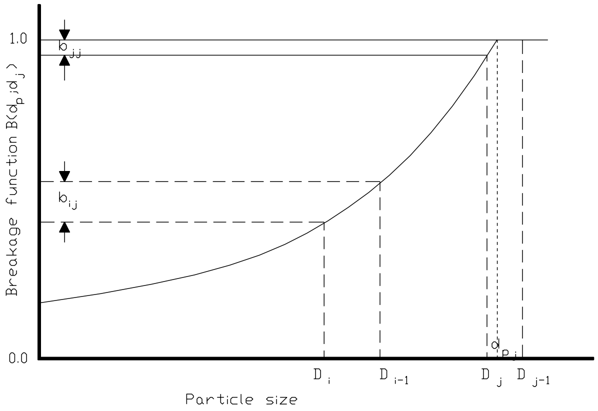

Figure 5.5 *The breakage function for crushing machines. This function has a value 1 at the representative size of the parent class. Compare this with the breakage function used for grinding machines.*

Breakage functions of the type

$$B(x;y) = K\left(\frac{x}{y}\right)^{n_1} + (1-K)\left(\frac{x}{y}\right)^{n_2} \tag{5.11}$$

are normally used to describe crusher behavior.

The values of $b_{ij}$ can be obtained from the cumulative breakage function by

$$b_{ij} = B(D_{i-1};d_{pj}) - B(D_i;d_{pj}) \tag{5.12}$$

and

$$b_{jj} = 1 - B(D_j;d_{pj}) \tag{5.13}$$

represents the fraction of material that remains in size interval j after breakage. These relationships are illustrated in figure 5.5. $n_1$ is approximately 0.5 for both standard and short-head crushers and $n_2$ is approximately 2.5 for short-head and 4.5 for standard crushers.

The parameters in the classification and breakage functions are obviously specific to the type and size of crusher. Unfortunately not many studies have been done to establish their values under a range of actual operating conditions. In practice it is often necessary to estimate them from measured particle distributions in the products from operating crushers. Once established for a particular material in a particular crusher, they should be independent of the closed side set. This allows the crusher performance to be simulated at the various CSS.

Model based on:

1. Whiten W.J. Walter G.W. and White M.E. A breakage function suitable for crusher models. 4th Tewkesbury Symposium, Melbourne (1979) p 19.1 - 19.3.
2. Whiten W.J. The simulation of crushing plants. Application of computer methods in the mineral industry. Apcom 10 S.Afr. Inst of Mining and Metall. Johannesburg (1973) p 317-323.
3. Karra V.K. A process performance model for ore crushers. Proc. 4th Int. Min. Proc. Congress Toronto (1982) III p 6.1-6.14.

Table 3.1 Approximate capacities of jaw crushers in tonnes/hr.

The size designation used here is the traditional one in which the feed opening is specified as gape × length in inches.

| Size Feed opening | Max rpm of flywheel | Motor kW | Open-side setting mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 25 | 32 | 38 | 51 | 63 | 76 | 102 | 127 | 152 |
| 10×20 | 300 | 15 | 12.7 | 15.4 | 18.2 | 23 | 31 | | | | |
| 10×24 | 275 | 11 | 14.5 | 17.3 | 20 | 23 | 30 | | | | |
| 15×24 | 275 | 22 | | 20.9 | 24.5 | 31 | 38.1 | 45.4 | | | |
| 14×24 | 275 | 19 | | | 23.6 | 30 | 37.2 | 45.4 | | | |
| 24×36 | 250 | 56 | | | | 70 | 86.3 | 103 | 136 | | |
| 30×42 | 200 | 75 | | | | | 113 | 136 | 1182 | 227 | 272 |
| | | | Open side setting mm | | | | | | | | |
| | | | 63 | 76 | 102 | 127 | 152 | 178 | 203 | 229 | 254 |
| 32×42 | 200 | 75 | | | 227 | 263 | 300 | 327 | 363 | | |
| 36×48 | 180 | 93 | | 189 | 245 | 300 | 354 | 409 | | | |
| 42×48 | 180 | 110 | | | | 345 | 381 | 426 | 463 | 490 | 527 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 48×60 | 170 | 150 | | | | | 436 | 481 | 517 | 554 | 600 |
| 56×72 | 120 | 186 | | | | | | 454 | 500 | 567 | 617 |
| 66×84 | 90 | 225 | | | | | | 700 | 772 | 863 | 950 |

Table 3.2 Approximate capacities of gyratory crushers in tonnes/hr.

Size is specified as gape × lower mantle diameter in inches.

| Size | Speed rpm | Motor kW | Open-side setting mm | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 51 | 63 | 76 | 89 | 102 | 114 | 127 | 140 | 152 | |
| 30×60 | 425 | 150 | 313 | 381 | 450 | 508 | 567 | 630 | 695 | 760 | | |
| 30×55 | 600 | 300 | | 381 | 463 | 518 | 590 | 663 | 735 | 817 | | |
| 36×60 | 375 | 186 | | 458 | 540 | 604 | 680 | 755 | 830 | 900 | 970 | |
| 42×65 | 514 | 400 | | | | | | 800 | 908 | 1017 | 1317 | 1500 |
| | | | Open-side setting mm | | | | | | | | | |
| | | | 127 | 140 | 152 | 178 | 190 | 203 | 216 | 229 | 241 | 254 |
| 42×70 | 380 | 300 | 708 | 790 | 863 | 944 | 1017 | 1090 | | | | |
| 48×74 | 514 | 500 | 1544 | 1680 | 1816 | 1952 | 2088 | 2452 | | | | |
| 48×80 | 330 | 500 | | | 1376 | 1462 | 1562 | 1662 | 1770 | 1870 | | |
| 54×74 | 514 | 500 | | 1634 | 1771 | 1907 | 2043 | 2180 | 2315 | | | |
| 54×80 | 330 | 500 | | | 1307 | 1394 | 1490 | 1580 | 1680 | 1770 | | |
| 60×89 | 514 | 600 | | | 2270 | 2424 | 2580 | 2815 | 2960 | 3270 | | |
| | | | Open-side setting mm | | | | | | | | | |
| | | | 190 | 203 | 216 | 229 | 241 | 254 | 267 | 279 | 292 | 305 |
| 60×102 | 300 | 800 | | 2542 | 2760 | 2974 | | 3396 | | 3827 | | 4254 |
| 60×109 | | | | | 3904 | 4195 | 4485 | 4776 | 5067 | 5357 | 5675 | 5993 |

## Table 3.3 Approximate capacities of standard Symons cone crushers in tonnes/hr.

Open-circuit operation.

| Size (Max. power kW) | Type of cavity | Feed opening on the closed side[*] with minimum CSS mm | Closed-side setting mm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 6 | 9 | 13 | 16 | 19 | 22 | 25 | 31 | 38 | 51 | 64 |
| 2 ft<br>(22) | Fine | 57 | 16 | 18 | 23 | 27 | 32 | 36 | 41 | 45 | 54 | | |
| | Coarse | 83 | | 18 | 23 | 27 | 32 | 41 | 45 | 54 | 68 | | |
| | Extra coarse | 100 | | | 23 | 27 | 36 | 45 | 50 | 63 | 72 | | |
| 3 ft<br>(56) | Fine | 83 | | 45 | 59 | 72 | 81 | 91 | | | | | |
| | Coarse | 119 | | | 59 | 72 | 91 | 99 | 118 | 136 | 163 | | |
| | Extra coarse | 163 | | | | | 99 | 109 | 118 | 136 | 163 | | |
| 4 ft<br>(93) | Fine | 127 | | 63 | 91 | 109 | 127 | 140 | 154 | 168 | | | |
| | Medium | 156 | | | 99 | 118 | 136 | 145 | 163 | 181 | 199 | | |
| | Coarse | 178 | | | | | 140 | 154 | 181 | 199 | 245 | 308 | |
| | Extra coarse | 231 | | | | | | | 190 | 208 | 254 | 317 | |
| 4½ ft<br>(112) | Fine | 109 | | | 109 | 127 | 145 | 154 | 163 | 181 | | | |
| | Medium | 188 | | | | 131 | 158 | 172 | 199 | 227 | 264 | | |
| | Coarse | 216 | | | | | 172 | 195 | 217 | 249 | 295 | 349 | |
| | Extra coarse | 238 | | | | | | | 236 | 272 | 303 | 358 | |
| 5½ ft<br>(150) | Fine | 188 | | | | 181 | 204 | 229 | 258 | 295 | 326 | | |
| | Medium | 213 | | | | | | 258 | 290 | 335 | 381 | 417 | |
| | Coarse | 241 | | | | | | | 290 | 354 | 417 | 453 | 635 |
| | Extra coarse | 331 | | | | | | | | | 431 | 476 | 680 |
| 7 ft<br>(224)<br>(260 EHD) | Fine | 253 | | | | | 381 | 408 | 499 | 617 | 726 | | |
| | Medium | 303 | | | | | | | 607 | 726 | 807 | 998 | |
| | Coarse | 334 | | | | | | | | 789 | 843 | 1088 | 1270 |
| | Extra coarse | 425 | | | | | | | | | 880 | 1179 | 1380 |
| 10 ft<br>(450) | Fine | 317 | | | | | | 934 | 1179 | 1469 | 1632 | | |
| | Medium | 394 | | | | | | | 1570 | 1633 | 1814 | 2267 | |
| | Coarse | 470 | | | | | | | | | 1905 | 2449 | 2857 |
| | Extra coarse | 622 | | | | | | | | | 1995 | 2630 | 3084 |

EHD = extra heavy duty.

## Table 5.4 Approximate capacities of short head Symons cone crushers in tonnes/hr.

Open-circuit operation.

| Size (Max power kW) | Type of cavity | Recommended minimum CSS mm | Feed opening with minimum CSS mm | | Closed-side setting mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Closed side | Open side | 3 | 5 | 6 | 10 | 13 | 16 | 19 | 25 |
| 2 ft | Fine | 3 | 19 | 35 | 9 | 6 | 18 | 27 | 36 | | | |
| (22) | Coarse | 5 | 38 | 51 | | 16 | 22 | 29 | 41 | | | |
| 3 ft | Fine | 3 | 13 | 41 | 27 | 41 | 54 | 68 | 91 | | | |
| (56) | Medium | 3 | 33 | 60 | 27 | 41 | 54 | 68 | 91 | 99 | | |
| | Extra coarse | 5 | 51 | 76 | | | 59 | 72 | 95 | 113 | 127 | |
| 4 ft | Fine | 5 | 29 | 57 | | 50 | 77 | 86 | 122 | 131 | | |
| (93) | Medium | 8 | 44 | 73 | | | | 91 | 131 | 145 | | |
| | Coarse | 13 | 56 | 89 | | | | | 140 | 163 | 181 | |
| | Extra coarse | 16 | 89 | 117 | | | | | 145 | 168 | 190 | 217 |
| 4½ ft | Fine | 5 | 29 | 64 | | 59 | 81 | 104 | 136 | 163 | | |
| (112) | Medium | 6 | 54 | 89 | | | 81 | 104 | 136 | 163 | | |
| | Coarse | 8 | 70 | 105 | | | | 109 | 158 | 181 | 199 | 227 |
| | Extra coarse | 13 | 98 | 133 | | | | | 172 | 190 | 254 | 238 |
| 5½ ft | Fine | 5 | 35 | 70 | | 91 | 136 | 163 | 208 | | | |
| (150) | Medium | 6 | 54 | 89 | | | 136 | 163 | 208 | 254 | 281 | |
| | Coarse | 10 | 98 | 133 | | | | 190 | 254 | 281 | 308 | 598 |
| | Extra coarse | 13 | 117 | 133 | | | | | 254 | 281 | 308 | 653 |
| 7 ft | Fine | 5 | 51 | 105 | | 190 | 273 | 326 | 363 | 408 | | |
| (224) | Medium | 10 | 95 | 133 | | | | 354 | 408 | 453 | 506 | |
| (260 | Coarse | 13 | 127 | 178 | | | | | 453 | 481 | 544 | 598 |
| EHD) | Extra coarse | 16 | 152 | 203 | | | | | | 506 | 589 | 653 |
| 10 ft | Fine | | 76 | 127 | | | 635 | 735 | 816 | 916 | 1106 | |
| (450) | Medium | | 102 | 152 | | | | 798 | 916 | 1020 | 1224 | |
| | Coarse | | 178 | 229 | | | | | | 1125 | 1324 | 1360 |
| | Extra coarse | | 203 | 254 | | | | | | | | 1478 |

EHD = extra heavy duty.