Handbook of Crushing

With POSIFLOW™ Feeders
# Handbook of Crushing

## Handbook of Crushing

### Table of Contents

The Technology of Crushing
- Introduction .................................................................................................................. 3
- The Technology of Crushing ......................................................................................... 3

Glossary of Terms ........................................................................................................... 4

Mechanical Reduction Methods .................................................................................... 5-6

Crusher Selection Criteria ........................................................................................... 7

Development of Job Specifications ................................................................................ 7

Materials Testing Facility ............................................................................................... 7

Application Analysis Form .............................................................................................. 8

Typical Screen Analysis ................................................................................................ 9

Crushing Tests ............................................................................................................. 10-11
- How to Take Samples ................................................................................................. 10
- Measuring Crushing Resistance ................................................................................ 10
- Measuring Relative Abrasiveness ............................................................................... 11
- Index of Abrasiveness ............................................................................................... 11

Definitions of Material Characteristics ....................................................................... 12
- Physical Characteristics of Materials ......................................................................... 12

Power Requirements ..................................................................................................... 13

Closed Circuit Crushing ............................................................................................... 13

Hammer Technology .................................................................................................... 14

Equipment Overview

**Bradford Breakers**
- Roller Mounted Breakers ......................................................................................... 15
- Tri-Mounted Breakers ............................................................................................... 15

**Granulators** ........................................................................................................... 15

**Impactors** .............................................................................................................. 16-17
- Coalpactor® .............................................................................................................. 16
- Reversible Impactors ............................................................................................... 16
- Reversible Impactors, Small .................................................................................... 17

**Jaw Crushers** ......................................................................................................... 17

**Single Roll Crushers** ............................................................................................. 18

**Mountaineer® II Sizers** ......................................................................................... 18

**POSIFLOW™ Feeders** ............................................................................................ 19

---

The brands comprising TerraSource Global are wholly-owned subsidiaries of Hillenbrand, Inc. (NYSE: HI), which is based in Indiana. © 2014 TerraSource Global. All Rights Reserved.
Introduction

We specialize in the manufacture of size reduction and feeding equipment and have pioneered many basic designs. Through our Pennsylvania Crusher brand we produce more types and sizes of crushers and breakers than any other firm in the world and are known for offering “The Most Choices, The Most Experience.”

Established in 1905, Pennsylvania Crusher equipment is used by numerous basic industries such as power generation, mining, cement plants, food & chemical processing, the glass industry and many others. In fact, a high percentage of the coal needed to generate electric power in the USA is crushed using our equipment.

Our application expertise is second to none. We invite you to take advantage of our help in solving your reduction and feeding problems.

The Technology of Crushing

The ability to crush material is governed by the laws of physics involving mass, velocity, kinetic energy and gravity. However, it is impractical to reduce the process of selecting and sizing a crusher to a series of formulas. The selection process is largely based on experience and testing — experience with actual field applications and laboratory tests that show how a given material will be reduced by a given crusher type.

The main purpose of this handbook is to explain the principles that govern the technology of crushing and also to impart the practical knowledge gained by our applications team over the past century.
Glossary of Terms

**Angle of Nip** — The angle formed between the moving surface of a crusher roll or jaw plate and the stationary plate surface at which point the material will be pinched. Angle varies with machine size and material lump size.

**Bond Work Index (BWI)** — Kilowatt hour (kWh) per short ton required to reduce the material to 80% passing 100 microns.

**Breaker Block (Breaker Plate)** — The steel anvil surface of a crusher against which material is crushed by impact or pressure.

**Bridging** — Blocking of crusher opening by large pieces of material.

**Burbank Abrasion Test** — A standard method of comparing the relative abrasiveness of rocks, minerals and ores.

**Cage** — A screening device, fixed or adjustable, made of precisely spaced bars or slotted plate, where final sizing is accomplished within the crusher.

**Choke Feed** — Operating the crusher with a completely filled crushing chamber.

**Choke Point** — Place in the crushing chamber having the minimum cross section. All compression type crushers have choke points, but this does not necessarily mean that choking is likely to occur.

**Choking** — Stoppage of the flow of material through the crusher, usually the result of wet and sticky material clogging exit points.

**Circulating Load** — The amount of oversize returned to the crusher from a screen in a closed-circuit system.

**Closed-Circuit Crushing** — A system in which oversize material is screened from the output and returned for another pass through the crusher.

**D<sub>50</sub>** — Denotes the output size is 50% smaller than a specified opening.

**Feed** — Input to the crusher.

**Feeder** — A device that regulates and distributes material into the crusher.

**Fines** — Material with particle size smaller than a specified opening.

**Finished Product (Output)** — The resulting material after it has been processed.

**Friable** — Material that breaks easily.

**Hammers** — Free-swinging or fixed metal impact surfaces attached to the rotor assembly of an impactor or hammermill crusher. Sometimes designated as “beaters.”

**Hardgrove Index (HGI)** — Grindability of a coal expressed as an index showing the relative hardness of that coal compared with a standard coal of 100 grindability.

**Height of Drop** — Vertical, free fall distance from the lip of the feeding device to the inlet opening of an impactor or hammermill crusher. Normally applies to reversible machines.

**Hopper** — The area of the crusher preceding the crushing chamber. Also, an external bin that holds the feed material.

**MOH Scale** — Relative hardness of material compared to 1-Talc, 2-Gypsum, 3-Calcite, 4-Fluorite, 5-Apatite, 6-Feldspar, 7-Quartz, 8-Topaz, 9-Corundum and 10-Diamond.

**Nominal** — Describes product size (output size), usually denoting that at least 90% of product is smaller than size indicated.

**Oversize** — Material too large to pass through a specific screen size or grizzly opening.

**Plugging** — Restriction of material flow through a crusher.

**Primary Crusher** — The first crusher in a crushing system into which material is fed. Succeeding crushers in the system are referred to as secondary or tertiary crushers.

**Product** — Output from the crusher.

**Reduction Ratio** — The ratio of the top size of input material to the top size of crusher discharge.

**Reversible Crushers** — Hammermills and impactors with rotors that can be run both clockwise and counterclockwise.

**ROM (Run of Mine)** — Material from a mine that has not been crushed or screened.

**ROQ (Run of Quarry)** — Material from a quarry that has not been crushed or screened.

**Rotor** — Rotating assembly of shaft, discs and hammers within a crusher which imparts the crushing forces to the material.

**Scalping** — Removing all sizes smaller than output top size from the crusher input material.

**Screen Bars** — The bars in the cage of a hammermill or granulator, spaced to control the output size. Also called “cage bars” or “grate bars.”

**Slugger Teeth** — The large teeth on a single roll crusher which first strike the material.

**Sorbent** — Stone, usually containing calcium; used to capture sulfur in a fluid bed boiler.

**Tailings** — Refuse or residue material from a screening process.

**Top Size** — The largest particle size in an input or output size.

**Tramp Iron** — Bolts, shovel teeth, picks and other uncrushable metal that is often present in crusher output.
Mechanical Reduction Methods

There are four basic ways to reduce a material — by impact, attrition, shear or compression — and most crushers employ a combination of all these crushing methods.

Impact

In crushing terminology, impact refers to the sharp, instantaneous collision of one moving object against another. Both objects may be moving, such as a baseball bat connection with a fast ball, or one object may be motionless, such as a rock being struck by hammer blows.

There are two variations of impact: gravity impact and dynamic impact. Coal dropped onto a hard surface such as a steel plate is an example of gravity impact. Gravity impact is most often used when it is necessary to separate two materials which have relatively different friability. The more friable material is broken, while the less friable materials remain unbroken. Separation can then be done by screening.

The Pennsylvania Crusher Bradford Breaker employs gravity impact only. This machine revolves so slowly that for all practical purposes, gravity is the only accelerating force on the coal.

Material dropping in front of a moving hammer (both objects in motion) illustrates dynamic impact. When crushed by gravity impact, the free-falling material is momentarily stopped by the stationary object. But when crushed by dynamic impact, the material is unsupported and the force of impact accelerates movement of the reduced particles toward breaker blocks and/or other hammers.

Dynamic impact has definite advantages for the reduction of many materials, and it is specified under the following conditions:

• when a cubical particle is needed
• when finished product must be well graded and must meet intermediate sizing specifications, as well as top and bottom specifications
• when ores must be broken along natural cleavage lines in order to free and separate undesirable inclusions (such as mica in feldspars)
• when materials are too hard and abrasive for hammermills, but where jaw crushers cannot be used because of particle shape requirements, high moisture content or capacity

Dynamic impact is the crushing method used by Pennsylvania Crusher Impactors.

Attrition

Attrition is a term applied to the reduction of material by scrubbing it between two hard surfaces. Hammermills operate with close clearances between the hammers and the screen bars and they reduce by attrition combined with shear and impact reduction. Though attrition consumes more power and exacts heavier wear on hammers and screen bars, it is practical for crushing the less abrasive materials such as pure limestone and coal.

Attrition crushing is most useful in the following circumstances:

• when material is friable or not too abrasive
• when a closed-circuit system is not desirable to control top size

Shear

Shear consists of a trimming or cleaving action rather than the rubbing action associated with attrition. Shear is usually combined with other methods. For example, single roll crushers employ shear together with impact and compression. Shear crushing is normally called for under these conditions:

• when material is somewhat friable and has a relatively low silica content
• for primary crushing with a reduction ratio of 6 to 1
• when a relatively coarse product is desired, usually larger than 1-1/2" (38 mm) top size

(Mechanical Reduction Methods continued on next page)
Compression

As the name implies, crushing by compression is done between two surfaces, with work being done by one or both surfaces. Jaw crushers using this method of compression are suitable for reducing extremely hard and abrasive rock. However, some jaw crushers employ attrition as well as compression and are not suitable for abrasive rock since the rubbing action accentuates the wear on crushing surfaces. As a mechanical reduction method, compression should be used as follows:

- if the material is hard and tough
- if the material is abrasive
- if the material is not sticky
- where the finished product is to be relatively coarse, i.e. 1-1/2" (38 mm) or larger top size
- when the material will break cubically

The bottom of the Pennsylvania Crusher reversible impactor is open and the sized material passes through almost instantaneously. Liberal clearance between hammers and the breaker blocks eliminates attrition and crushing is by impact only.

The Pennsylvania Crusher jaw crusher crushes by compression without rubbing. Hinged overhead and on the centerline of the crushing zone, the swinging jaw meets the material firmly and squarely. There is no rubbing action to reduce capacity, to generate fines or to cause excessive wear.

Pennsylvania Crusher single roll crushers reduce large input by a combination of shear, impact and compression. They are noted for low headroom requirements and large capacity.
Handbook of Crushing

Crusher Selection Criteria

When selecting a crusher, the following criteria must be considered:

• Will it produce the desired output size and shape at the required capacity?
• Will it accept the largest input size expected?
• What is its capacity?
• Will it choke or plug?
• Can it pass uncrushable debris without damage?
• How much supervision of the unit is necessary?
• Will it meet product specifications without additional crushing stages and auxiliary equipment?
• What is the crusher’s power demand per ton per hour of finished product?
• How does it resist abrasive wear?
• Does it operate economically with minimum maintenance?
• Does it offer dependable and prolonged service?
• Is there ready availability of replacement parts?
• Does it have acceptable parts replacement cost?
• Does it have easy access to internal parts?
• Is the crusher versatile?
• How does the initial cost of the machine compare with its long-term operating costs?
• Is experienced factory service readily available?

Development of Job Specifications

The initial steps in selecting the proper crusher require the development of complete job specifications, including the pertinent physical characteristics of the feed material.

Our Application Analysis Form (see next page) is designed to simplify the task of collecting job specifications. In most cases, the completed form will enable our engineering staff to recommend the crusher best suited to meet your requirements.

On occasion, it may also be necessary to supply actual samples of the material for test crushing in our test facilities (see page 10 for How to Take Samples).

Additional copies of our Application Analysis Form may be obtained by photocopying or by request. If you have any questions regarding the completion of this form, please contact us.

Material Testing Facility

The new TerraSource Global Demonstration & Development Center, located in Duncan, South Carolina, is our premier facility for conducting equipment demonstrations and materials testing.

This just-completed 9,000 sq. ft. state-of-the-art complex houses representative machinery and related auxiliary equipment from each of TerraSource Global’s three market-leading brands: Gundlach Crushers, Jeffrey Rader and Pennsylvania Crusher.

Activities conducted within the center include equipment demonstrations; sales, engineering and product development support; and crushing and feeding testing for existing and prospective TerraSource Global customers.

The center also includes over 1,800 sq. ft. of conference/office space for sales representative and client training, technical presentations and model displays.

To take advantage of the opportunity to have your company’s raw materials evaluated on the Center’s fully-operational equipment and visit the facility in person to watch the live testing of same, please contact your TerraSource Global representative.

Providing the TerraSource Global Demonstration & Development Center is just another way we ensure that our quality equipment, integrated systems and reliable services meet and exceed your expectations.
# Application Analysis Form

**APPLICATION ANALYSIS FORM**

Completion of this sheet will help our engineers select the crusher best suited to your requirements.

**COMPANY:**

**ADDRESS:**

**CITY:**

**STATE:**

**ZIP:**

**COUNTRY:**

**NAME:**

**TITLE:**

**PHONE:**

**FAX:**

**E-MAIL:**

**DATE:**

**PROJECT NAME:**

**PROJECT LOCATION:**

**PROJECT REF. NO.:**

---

## MATERIAL DESCRIPTION

1. **Material:**
   - a. Property:
   - b. Bulk Density:
   - c. Moisture:
   - d. Compressive Strength (PSI):
   - e. MOH Hardness / Hardgrove Index:
   - f. Material Temperature:
   - g. Material is:
     - Free-Flowing
     - Non-Abrasive
     - Sticky
     - Mildly Abrasive
     - Very Abrasive
   - h. Other Characteristics:

---

## APPLICATION REQUIREMENTS

2. **Material Description**
   - a. Property:
   - b. Material Temperature:
   - c. Material is:
     - Free-Flowing
     - Non-Abrasive
     - Sticky
     - Mildly Abrasive
     - Very Abrasive
   - d. Other Characteristics:

---

## GENERAL INFORMATION

3. **General Information**
   - a. Property:
   - b. Project is:
     - Study for feasibility or budget purposes
     - Funded for purchase. Expected purchase date:
   - c. Delivery is required by:

---

## OTHER INFORMATION WHICH MAY BE OF VALUE

- 
- 
- 

---
Deciding Factors

Tests may show that two or more types of crushers will perform equally well on a particular material. But other factors must still be considered such as headroom, desirability of fines, product shape, economics of maintenance and operations and the adaptability of the crusher to future plant expansions.

Measuring Crushing Resistance

A basic premise in equipment selection is that the crusher be stronger than the material it must crush. How strong are rocks and ore? While there is no direct measurement of “resistance to crushing,” it is possible to measure the compressive strength and the elastic properties of a material.

The above graph shows a typical plot of test results for different materials, and it demonstrates the relationship between compressive load and resulting displacement. The material exhibiting twice as much displacement under compression will normally require twice as much power to be crushed.
Crushing Tests (continued from previous page)

Measuring Relative Abrasiveness

It is difficult to predict the abrasive action of rocks, minerals and ores. Often, rocks belonging to the same geological classification will vary widely in abrasiveness from one locality to another. Therefore, in order to select the proper crusher, we must have some reliable measurement of the abrasiveness of the specific material.

Abrasiveness can be determined either from prior experience or by testing in semi-production plants, but we’ve developed a simpler method which involves testing and has been found as a reliable way to establish relative abrasiveness by using four 400-gram samples of the material to be crushed.

Each sample of material is rotated for 15 minutes in a drum with a steel paddle. After the four separate batches are run, the average milligrams of weight loss by the paddle is measured. This will serve as a relative index of abrasive action. The higher the index, the greater the abrasiveness.

This test provides the most practical index of abrasiveness today. Such test data has been collected for many years on numerous samples of rocks and ores. Typical scales of relative abrasiveness derived from this testing procedure are shown in the table below.

<table>
<thead>
<tr>
<th>Material and Source</th>
<th>Abrasiveness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Highly Abrasive</strong></td>
<td></td>
</tr>
<tr>
<td>Manganese Ore, Georgia</td>
<td>32,946</td>
</tr>
<tr>
<td>Aluminum Oxide, New York</td>
<td>14,114</td>
</tr>
<tr>
<td>Sandstone, Pennsylvania</td>
<td>13,121</td>
</tr>
<tr>
<td>Oxygen Furnace Slag, Ontario</td>
<td>10,828</td>
</tr>
<tr>
<td>Chert, Missouri</td>
<td>9,829</td>
</tr>
<tr>
<td>Stone and Bauxite Clinker, Indiana</td>
<td>9,489</td>
</tr>
<tr>
<td>Gravel, Mississippi</td>
<td>8,888</td>
</tr>
<tr>
<td>Stone, Virginia</td>
<td>7,969</td>
</tr>
<tr>
<td>White Quartz, Maine</td>
<td>7,000</td>
</tr>
<tr>
<td>Calcined Alumina, Louisiana</td>
<td>6,879</td>
</tr>
<tr>
<td>Open Hearth Pot Slag, New York</td>
<td>6,830</td>
</tr>
<tr>
<td>High-Silica Limestone, Pennsylvania</td>
<td>4,838</td>
</tr>
<tr>
<td>Granite, Puerto Rico</td>
<td>4,517</td>
</tr>
<tr>
<td>Feldspar, Virginia</td>
<td>3,650</td>
</tr>
<tr>
<td>Burned Brick and Tile, Pennsylvania</td>
<td>3,491</td>
</tr>
<tr>
<td>Sintered Ore, Alabama</td>
<td>3,065</td>
</tr>
<tr>
<td>Trap Rock, Pennsylvania</td>
<td>2,928</td>
</tr>
<tr>
<td>Feldspar, New Hampshire</td>
<td>2,871</td>
</tr>
<tr>
<td>Tungsten Ore, California</td>
<td>2,253</td>
</tr>
<tr>
<td>Cement Clinker, Pennsylvania</td>
<td>2,206</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material and Source</th>
<th>Abrasiveness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abrasive (wear can be minimized by design and materials of construction)</strong></td>
<td></td>
</tr>
<tr>
<td>Iron Ore, Missouri</td>
<td>1,992</td>
</tr>
<tr>
<td>Transvaal Chrome Ore, South Africa</td>
<td>1,755</td>
</tr>
<tr>
<td>Coke Breeze, Alabama</td>
<td>1,690</td>
</tr>
<tr>
<td>Calcined Bauxite, Missouri</td>
<td>1,671</td>
</tr>
<tr>
<td>Red Limestone, Vermont</td>
<td>1,452</td>
</tr>
<tr>
<td>Scoria Volcanic Cinder</td>
<td>1,352</td>
</tr>
<tr>
<td>Cement Clinker, Quebec</td>
<td>1,231</td>
</tr>
<tr>
<td>Grog, New Jersey</td>
<td>1,052</td>
</tr>
<tr>
<td>Amorphous Silica, Illinois</td>
<td>978</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material and Source</th>
<th>Abrasiveness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low in Abrasion (parts wear is not critical)</strong></td>
<td></td>
</tr>
<tr>
<td>Shale, Virginia</td>
<td>345</td>
</tr>
<tr>
<td>Antimony Ore, New Jersey</td>
<td>315</td>
</tr>
<tr>
<td>Oil Shale</td>
<td>270</td>
</tr>
<tr>
<td>Chamotte, Michigan</td>
<td>250</td>
</tr>
<tr>
<td>Zinc Sinter, Pennsylvania</td>
<td>249</td>
</tr>
<tr>
<td>Limestone, Ohio</td>
<td>241</td>
</tr>
<tr>
<td>Extruded Zircon, New Jersey</td>
<td>186</td>
</tr>
<tr>
<td>Weathered Shale, Virginia</td>
<td>131</td>
</tr>
<tr>
<td>Zinc Oxide, Pennsylvania</td>
<td>78</td>
</tr>
<tr>
<td>Diatomaceous Shale Clinker, England</td>
<td>78</td>
</tr>
<tr>
<td>Dolomite, Alabama</td>
<td>62</td>
</tr>
<tr>
<td>Sandstone, California</td>
<td>38</td>
</tr>
<tr>
<td>Red Flux, Australia</td>
<td>31</td>
</tr>
<tr>
<td>Shale, Virginia</td>
<td>30</td>
</tr>
<tr>
<td>Clay, Pennsylvania</td>
<td>25</td>
</tr>
<tr>
<td>Cement Rock, Pennsylvania</td>
<td>13</td>
</tr>
<tr>
<td>Anhydrite, Kansas</td>
<td>7</td>
</tr>
<tr>
<td>Limestone, Australia</td>
<td>7</td>
</tr>
</tbody>
</table>

www.terrasource.com  info@terrasource.com
**Definitions of Material Characteristics**

Selection of the most appropriate crusher is greatly influenced by the precise nature of the material to be crushed. The listings that follow serve to illustrate how even the same basic materials can vary widely. Such variances will definitely influence the type of crusher that should be employed.

<table>
<thead>
<tr>
<th>Class</th>
<th>Abrasiveness</th>
<th>Flowability</th>
<th>Special Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>low abrasiveness</td>
<td>very free-flowing — angle of repose up to 30°</td>
<td>hygroscopic</td>
</tr>
<tr>
<td>2</td>
<td>mildly abrasive</td>
<td>free-flowing — angle of repose 30° to 45°</td>
<td>highly corrosive</td>
</tr>
<tr>
<td>3</td>
<td>very abrasive</td>
<td>sluggish — angle of repose 45° and up</td>
<td>mildly corrosive</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>degradable when exposed to air</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>very friable</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>mildly friable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>tough — resists reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>plastic or sticky</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Class</th>
<th>Physical Characteristics of Materials</th>
<th>Class</th>
<th>Physical Characteristics of Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. Weight (lbs./cu. ft.)</td>
<td></td>
<td>Avg. Weight (lbs./cu. ft.)</td>
</tr>
<tr>
<td>Alumina</td>
<td>3-5-G</td>
<td>60</td>
<td>Limestone (broken)</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>3-G</td>
<td>70-120</td>
<td>Manganese Ore</td>
</tr>
<tr>
<td>Bagasse</td>
<td>1-6-C</td>
<td>7-8</td>
<td>Marble (broken)</td>
</tr>
<tr>
<td>Barite</td>
<td>3-5</td>
<td>140-180</td>
<td>Marbl (raw &amp; wet)</td>
</tr>
<tr>
<td>Bark (wood refuse)</td>
<td>2-6-G</td>
<td>10-20</td>
<td>Middlings - Coal</td>
</tr>
<tr>
<td>Basalt (broken)</td>
<td>3-G</td>
<td>10-20</td>
<td>Phosphate – Rock-Ore</td>
</tr>
<tr>
<td>Bauxite (crushed)</td>
<td>3-5-F</td>
<td>75-85</td>
<td>Potash Ore</td>
</tr>
<tr>
<td>Bentonite</td>
<td>2-5</td>
<td>40-50</td>
<td>Potash Ore Compactor Flake</td>
</tr>
<tr>
<td>Brick</td>
<td>3-F</td>
<td>100-125</td>
<td>Quartz (broken)</td>
</tr>
<tr>
<td>Carbon Electrodes (baked)</td>
<td>2-G</td>
<td>—</td>
<td>Refusé (household)</td>
</tr>
<tr>
<td>Carbon Electrodes (unbaked)</td>
<td>1-F</td>
<td>—</td>
<td>Sand (dry bank)</td>
</tr>
<tr>
<td>Cement Clinker</td>
<td>3-5-F</td>
<td>75-95</td>
<td>Sand (foundry)</td>
</tr>
<tr>
<td>Cement Rock</td>
<td>2-5-F</td>
<td>100-110</td>
<td>Sandstone (broken)</td>
</tr>
<tr>
<td>Coal</td>
<td>2-5-D-F</td>
<td>18-25</td>
<td>Shale (broken)</td>
</tr>
<tr>
<td>Clay (dry)</td>
<td>3-5</td>
<td>60-75</td>
<td>Shells – Oyster</td>
</tr>
<tr>
<td>Calcined Clay</td>
<td>3-F</td>
<td>80-100</td>
<td>Diacalcium Phosphate</td>
</tr>
<tr>
<td>Coal – Anthracite</td>
<td>1-4-D-E</td>
<td>55-60</td>
<td>Dolomite</td>
</tr>
<tr>
<td>Coal – Bituminous</td>
<td>1-5-C-D-E</td>
<td>45-55</td>
<td>Slag – Open Hearth</td>
</tr>
<tr>
<td>Coal – Sub-Bituminous</td>
<td>1-5-C-D-E</td>
<td>45-55</td>
<td>Slag – Blast Furnace</td>
</tr>
<tr>
<td>Coke Petroleum</td>
<td>2-5</td>
<td>35-45</td>
<td>Slate</td>
</tr>
<tr>
<td>Cryolite</td>
<td>1-5-F</td>
<td>110</td>
<td>Soapstone – Talc</td>
</tr>
<tr>
<td>Cullet – Glass</td>
<td>3-5-E</td>
<td>80-120</td>
<td>Superphosphate</td>
</tr>
<tr>
<td>Diatomaceous Earth</td>
<td>2</td>
<td>11-13</td>
<td>Traropock (broken)</td>
</tr>
<tr>
<td>Dross – Aluminum</td>
<td>3-F-C</td>
<td>—</td>
<td>Triple Superphosphate</td>
</tr>
<tr>
<td>Fluorspar</td>
<td>2-5-F</td>
<td>90-100</td>
<td>Trona Ore</td>
</tr>
<tr>
<td>Fullers Earth (raw)</td>
<td>2-5</td>
<td>35-40</td>
<td>Tungsten Carbide</td>
</tr>
<tr>
<td>Granite (broken)</td>
<td>3-5-G-H</td>
<td>90-100</td>
<td>—</td>
</tr>
<tr>
<td>Gravel</td>
<td>3-5-F</td>
<td>90-100</td>
<td>—</td>
</tr>
<tr>
<td>Gypsum Rock</td>
<td>2-5-F</td>
<td>90-100</td>
<td>—</td>
</tr>
<tr>
<td>Lignite – Texas (ROM)</td>
<td>1-5-D-E</td>
<td>45-50</td>
<td>—</td>
</tr>
<tr>
<td>Lignite – Dakota (ROM)</td>
<td>1-6-D-F</td>
<td>45-50</td>
<td>—</td>
</tr>
<tr>
<td>Lime – Pebble</td>
<td>1-5-E</td>
<td>53-56</td>
<td>—</td>
</tr>
</tbody>
</table>

*Refer to table above for class definitions*
In crushing, the useful or meaningful work is that expended to reduce the material to a given size. A number of theories have been expressed to define the relationship between work input and size reduction. Kick’s Law states that work done is proportional to the reduction in volume of particles, a theory which applies to crushing of large particles. However, finer product sizes conform more closely to Rittinger’s Theory, which concludes that work required is proportional to the new surface area formed, and inversely proportional to the product diameter.

In any case, reduction ratio is not the only factor in determining power requirements. Nearly all crushing projects differ from one another in one or more aspects, and no hard and fast rule can be applied with regard to power consumption. However, through extensive experience in the field of mechanical reduction, some average values have been compiled regarding the power requirements of different types of crushers.

**Typical Horsepower Requirements**

It has been determined that a primary single roll crusher, reducing run-of-quarry medium-hard limestone to a 6" (152 mm) product will require approximately 1/2 horsepower per ton per hour (HP per TPH). However, when crushing medium-hard bituminous coal to the same specifications, the power demand is only 1/12 HP per TPH. Even on the hardest materials, single rolls do not require more than one full HP per TPH and may demand as little as 1/25 HP per TPH.

Coalpactor® crushers for preparing coking coal for coke ovens are fed with 3" (76 mm) and under bituminous coal. The product usually desired is 80-85% minus 1/8" (3 mm). For this service, 1-1/2 to 2 HP per TPH is normally required.

In cement plants, where hammermills or impactors are used for secondary crushing of cement rock, the feed is approximately 6-10" (152-254 mm) and the product is a nominal 1/2" (13 mm). This reduction needs 1-1/3 to 1-1/2 HP per net TPH.

Impactors generally require approximately 1 HP per TPH (gross load) to drive them. This may be slightly increased if an extremely fast rotor speed is required.

Granulators (ring hammermills) are most often used in the coal handling facilities of power stations where they reduce run-of-mine coal to a nominal 3/4" (19 mm) product. This typically requires 1/2 HP per TPH.

The Pennsylvania Crusher jaw crusher requires approximately 1/3 or less HP per TPH, depending upon the reduction ratio desired.

**Motor Selection**

The foregoing figures are averages, and each crushing problem should be carefully studied before selecting motors. We urge all prospective customers to consult us prior to selecting motors, since so many factors will affect power demand. Our experience with such diverse types of crushers will serve as a guide for proper motor selection.

**Closed Circuit Crushing**

Closed-circuit crushing is a means of controlling product top size by screening the product and then returning oversize material to the feed end of the crusher for another pass through the machine. While it may be possible to obtain a specified top size from crushers without using a closed-circuit system, it is not always desirable. To control top size from a single crusher operating in an open circuit, material must remain in the crushing chamber until it is reduced. This results in overgrinding a percentage of the product, with a corresponding increase in fines and a loss of efficiency.

In a typical multi-stage crushing plant with the last stage operated in closed-circuit, the primary crusher operates at a setting which produces a satisfactory feed size for the secondary crusher, so that a balance exists for the work done by each crusher.
Basic Hammer Types

- **Bar Hammer**
- **T-Head Hammer**
- **Ring-Type Hammer (plain)**
- **Ring-Type Hammer (toothed)**

**Crusher Hammer Technology**

Hammer design plays a significant role in crusher efficiency, because in most types of crushers, the hammers do most of the work. Early hammer designs were only concerned with mass and general shape of the hammer. Today the technology of Pennsylvania Crusher hammers is highly developed and we give careful consideration to a great many factors, including:

**Location of the Hammer’s Center of Gravity**

The center of gravity determines the focus of impact, which in turn helps to control the amount of impact and the general shape of the shattered particle. The center of gravity must be controlled to utilize the full mass of the hammer against the feed.

**Air Paths Created by Hammer Rotation**

The air paths created by the hammer sweep usually contain a certain amount of fines and other small particles which must be directed away from the hammer shanks and rotor discs; otherwise premature wear would occur. Pennsylvania Crusher hammers are designed so that the resulting air paths are directed toward the open areas of the crushing chamber, away from vital parts.

**Edge Configuration of the Hammer Head**

The edges of each Pennsylvania Crusher hammer face are shaped to a special geometry in order to produce maximum hammer life with the lowest amount of friction.

**Heat Treating**

Hammer hardness is the most essential factor in determining hammer life, for while the hammer head must be extremely hard and resistant to wear, the shank must be more ductile in order to absorb shock. To produce this on certain designs, we use a special method of heat treating that creates a gradually varying hardness between the shank and the tip, without any abrupt changes. However, in cross section, the hardness extends for the full depth instead of merely the surface. Hammer hardness is normally gauged according to the Brinnel method.

As a result of continued improvements, our hammer design plays a major role in producing high efficiency and in reducing maintenance problems. As we introduce refinements to our hammers, users are provided with the latest designs as part of their normal resupply orders.
Equipment Overview

Bradford Breakers
These machines are used for crushing, sizing and cleaning run-of-mine coal and other friable materials. They are used to produce a product that is relatively coarse, with minimum fines, and that is 100% to size.

Bradford Breakers crush by gravity impact only. A large cylinder made of perforated screen plates is fitted with internal shelves. As the cylinder rotates, the shelves lift the feed, and in turn, the feed slides off the shelves and drops onto the screen plates below, where it shatters along natural cleavage lines.

The size of the screen plate perforations determines the product size. Sized product falls through these perforations but oversized pieces will again be lifted and dropped by the shelves until they too pass through the screen plates.

Tramp iron, lumber or other uncrushable debris that enter the breaker along with the feed are transported to the discharge end of the cylinder. There, these uncrushables are scooped out continuously by a refuse plow which channels this debris out of the cylinder and into a disposal bin.

Often a Bradford Breaker is used merely to clean debris from coal that has already been sized. This gives some indication of the economy of operation and versatility of this machine.

Breaker cylinders rotate at slow speeds of 12 to 14 RPM, depending upon cylinder diameter. Compared with most other crushers, Bradford Breakers are extremely long lived. Screen plates, for example, frequently last ten years or more, crushing millions of tons of coal, and there are numerous examples of Bradford Breakers in continuous service for upwards of 40 years.

We’ve also designed the screen plates in Bradford Breakers to be interchangeable, so that the screen plates from the feed end, where the wear is greatest, can be switched with the screen plates from other areas of the cylinder where there is less wear.

The profile of the perforations in the screen plates has been scientifically designed to obtain a maximum self-cleaning effect, without product bridging across the perforation itself.

Roller Mounted Bradford Breakers
The roller mounted Bradford Breaker is suited for coal mines where the feed often includes unusually large pieces of coal. This model will readily accept these large pieces of coal without blocking the entry.

Tri-Mounted Bradford Breakers
Many prefer this model because its three support points provide a stable yet forgiving platform, minimizing the attention to wheel alignment needed with the roller mounted arrangement to compensate for shifting foundations.

This model also features the design standards found on our other Bradford Breakers such as lapped screen plates, adjustable feed plows and roller chain drive.

Longitudinal beams are bolted to the end cones — never welded — so that replacement can easily be accomplished at your job site. These, plus numerous other features, make this an extremely low maintenance breaker.

Granulators
Our granulators use rows of ring hammers, which crush with a slow, positive rolling action. This produces a granular product with minimum fines.

Offered in three models and nearly 50 sizes, granulators are used for crushing coal, particularly for power plants. They are also used for gypsum, salt, chemicals and moderately hard materials.

Granulators crush by a combination of impact and rolling compression, producing high reduction ratios at high capacities. Product size is determined by screen openings, and is adjusted by changing the clearance between the cage and the path of the ring hammers.
optimum percentage of product below 1/8" (3 mm), but with a minimum amount of fines (100 mesh or smaller). Coalpactors are also used for crushing coal and petroleum coke for fluid bed boilers which have similar output size requirements.

This crusher permits coke plant operators to obtain high stability coke from various grades of coal. When coke is produced from a blend of petrographically differing coals, the coke strength is improved by control of the minus 1/8" (3 mm) pulverization.

A Pennsylvania Crusher Coalpactor is similar to an impactor. It has breaker plates that are fully adjustable from outside of the frame to enable operators to vary the degree of pulverization. This allows maintenance of a uniform product size throughout the life of hammers and breaker plates.

The Coalpactor rotor may be run either clockwise or counterclockwise to provide for equal wear on both hammer faces. This helps to extend hammer life and to reduce maintenance problems. To facilitate servicing, all internal parts of the machine are readily accessible.

Pennsylvania Crusher Coalpactor crushers have largely replaced other types of crushers for crushing coking coals because the Coalpactor will maintain rated capacity even when the coal is wet, and it is not affected by uncrushables.

When used to crush fuel for fluid bed boilers, the FB-design Coalpactor crushers use an extended crushing path to further improve output size control.

Reversible Impactors

Reversible impactors are used for secondary and tertiary crushing, and occasionally for primary crushing. They are used for reduction of cement rock, gypsum, fertilizer, chemicals, lime and agricultural limestone, lightweight aggregate, ceramics and other materials.
Equipment Overview (continued)

Reversible impactors are normally recommended when certain requirements exist: high reduction ratio (35:1 or greater), high capacity, cubically shaped, well-graded product and minimum fines.

These crushers can be easily adjusted to produce a wide variety of product sizes. For coarser output sizes, impactors are operated at lower speeds. When finer output sizes are required, higher speeds are used. It is also possible to change product size by making adjustments to the breaker block assemblies.

Material drops through the centrally located feed chute directly into the rotor, where it is struck by the rotating hammers. The material then impacts against the breaker blocks and rebounds into the path of the hammers. There are no cage bars or screens; therefore, impact and some shear are the methods of reduction. The bottom of the crusher is entirely open and the sized material passes out freely.

When the product must be held to a specific top size, the machines should be operated in a closed-circuit system. When operating in closed-circuit, the mill discharge is carried to external screens or classifiers for separation, with the oversized particles being returned to the impactor for further reduction.

The size of the feed may vary up to sizes produced by primary crushers. In some instances, these crushers will handle material directly from quarries or other sources.

Pennsylvania Crusher originated the reversible impactor in order to eliminate manual turning of the hammers. The reversible impactor is symmetrical in design, and by simply pushing the reversing button, the operator can change the direction of the rotor, presenting a fresh hammer face to the feed.

Small Reversible Impactors

These smaller impactors have been designed for specialized crushing requirements at relatively low capacities.

Typical applications for these units include: “green” brick, mill scale, foundry sand, gypsum, phosphate rock, flake frit, graphite ore, glass tubing, salt cake, brass skimmings and tungsten carbide chips.

For servicing, the frame section on both ends of the machine may be removed to expose the breaker blocks, liners and rotor. The liners are made of carbon-manganese steel and are renewable.

The upper breaker blocks are made of cast alloy steel and are both reversible and interchangeable. The lower breaker blocks are supplied in fixed or adjustable configuration.

These impactors are offered in several sizes.

Jaw Crushers

For crushing of hard, abrasive materials, jaw crushers are often preferred, since this type of machine will crush virtually any mineral.

Jaw crushers differ substantially from other types of crushers. There is no rotary motion in the crushing cycle, and all crushing is done by compression of the feed material between two massive jaws, which in effect are a type of breaker plate. Jaw plates can be either smooth or corrugated.

While one jaw is fixed, the other jaw pivots about a top hinge. This moving jaw is shaped to move firmly and squarely against the material, at 250 to 400 strokes per minute. There is no rubbing or grinding, only compression, which produces a generally cubical product with minimum fines.

The moving jaw is so balanced that fully 95% of the drive motor power is used for crushing, while only 5% of the power is needed to move the jaw itself. As a result of this mechanical efficiency, smaller motors may be used, keeping power costs down.

Behind the stationary jaw are shims, used to compensate for plate wear and to adjust the closed side setting. For protection from uncrushables, there
The clearance between the breaker plate and the roll determines the product size. This clearance is adjustable from outside the machine by a shim arrangement. Adding or removing shims causes the plate to pivot about its top hinge, moving it into or away from the roll.

For protection against uncrushable debris, the breaker plate assembly is secured with an automatic release device. As pressure from the uncrushable is exerted against the plate, the device allows the entire breaker plate assembly to move away from the roll instantly. The uncrushable drops clear of the machine by gravity, and the breaker plate assembly immediately returns to its normal crushing position.

Pennsylvania Crusher builds several types of single roll crushers in a great number of sizes and capabilities, with product sizes ranging from 3” (76 mm) to 12” (305 mm), depending on the machine size.

Applications include petroleum coke, coal with rock, aggregate, limestone, chemicals, phosphate rock, shale and many other materials.

Mountaineer® II Sizers

The Mountaineer II Sizer crushes a wide variety of materials. It incorporates all of the features needed to do a better job than ordinary sizers, for primary or secondary sizing.

For example, it sizes very accurately, produces extremely low fines and operates at low speed. Such low speed also helps to extend component life. It also uses relatively low horsepower, resulting in reduced equipment wear and energy costs as well as low noise levels. Made in the USA, its construction is modular and employs standard components, meaning that maintenance can be performed more quickly and at less cost than others. Low headroom, as low as 40” (1016 mm), enables it to fit most plant layouts.
Equipment Overview (continued)

An extremely rugged, high-capacity machine, its crushing chamber is lined with heavy-duty liners, and all side liners are reversible. The sizing rolls are offered in a variety of tooth patterns to suit the application.

The Mountaineer II Sizer is offered in various lengths, with capacity dependent on many factors, the most important of which is the output size. The sizers are direct driven through a gearbox.

**POSIFLOW™** Feeders

This unique feeder handles materials having an extraordinary range of characteristics, including wet, dry, lumpy, sticky, abrasive or granular. Virtually immune to jams, it will feed dry, light particles at 1,200 lbs. per hour, or heavy, sticky materials at 120,000 cu. ft. per hour, with absolute consistency never before achieved in ordinary feeders.

It delivers material with unvarying accuracy of up to 99.5%, with no need to recalibrate unless the material changes. Regardless of moisture content, it delivers a constant rate of bulk solid material; each rotation delivers a fixed volume that cannot vary, meaning that it feeds at the desired rate with no surges and no partial feeding.

This feeder contains only a single moving part — the rotating duct. Because the feed material helps to turn this duct, only a small motor, usually under 10 HP, is required to drive it. Those factors result in very low stress and exceptionally low maintenance. In addition, wear is negligible because there is almost no abrasive action of the material against the working parts. Some units have been in service for up to 10 years without needing a single replacement part.

Specifications quoted herein are subject to change. Brochures providing specific descriptions, pictures, illustrations, specifications and dimensional data for each Pennsylvania Crusher brand crusher and feeder model are available. Additionally, application engineering assistance is available upon request. Please contact your TerraSource Global representative or visit our website (www.terrasource.com) to request brochures and find out more information.