AN INVESTIGATION OF THE CYCLONE
FOR
FINE COAL CLEANING

by
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An Investigation
Conducted Under the Auspices
of the

COAL RESEARCH BOARD
of the

COMMONWEALTH OF PENNSYLVANIA

Contract Number CR - 29

Special Research Report
Number SR - 45
May 30, 1964
STATEMENT OF TRANSMITTAL

Special Report SR-45 transmitted herewith has been prepared by the Coal Research Section of the Mineral Industries Experiment Station. Each of the Special Reports presents the results of a phase of one of the research projects supported by the Pennsylvania Coal Research Board or a technical discussion of related research. It is intended to present all of the important results of the Coal Board research in Special Reports, although some of the results may already have been presented in progress reports. The following is a list of Special Research Reports issued previously.

<table>
<thead>
<tr>
<th>Special Report</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-1</td>
<td>The Crushing of Anthracite</td>
<td>May 31, 1958</td>
</tr>
<tr>
<td>SR-2</td>
<td>Petrographic Composition and Sulfur Content of a Column of Pittsburgh Seam Coal</td>
<td>August 1, 1958</td>
</tr>
<tr>
<td>SR-3</td>
<td>The Thermal Decrepitation of Anthracite</td>
<td>September 15, 1958</td>
</tr>
<tr>
<td>SR-4</td>
<td>The Crushing of Anthracite with a Jaw Crusher</td>
<td>November 1, 1958</td>
</tr>
<tr>
<td>SR-5</td>
<td>Reactions of a Bituminous Coal with Sulfuric Acid</td>
<td>February 1, 1959</td>
</tr>
<tr>
<td>SR-6</td>
<td>Laboratory Studies on the Grindability of Anthracite and Other Coals</td>
<td>April 1, 1959</td>
</tr>
<tr>
<td>SR-7</td>
<td>Coal Characteristics and Their Relationship to Combustion Techniques</td>
<td>April 15, 1959</td>
</tr>
<tr>
<td>SR-8</td>
<td>The Crushing of Anthracite with an Impactor-Type Crusher</td>
<td>April 25, 1959</td>
</tr>
<tr>
<td>SR-9</td>
<td>The Ignitibility of Bituminous Coal (A Resume of a Literature Survey)</td>
<td>May 4, 1959</td>
</tr>
</tbody>
</table>
Effect of Gamma Radiation and Oxygen at Ambient Temperatures on the Subsequent Plasticity of Bituminous Coals

Properties and Reactions Exhibited by Anthracite Lithotypes Under Thermal Stress

Removal of Mineral Matter from Anthracite by Chlorination at High Temperatures

Radiation Stability of a Coal Tar Pitch

The Effect of Nuclear Reactor Irradiation During Low Temperature Carbonization of Bituminous Coals

Effect of Anthracite and Gamma Radiation at Ambient Temperatures on the Subsequent Plasticity of Bituminous Coals

The Isothermal Kinetics of Volatile Matter Release from Anthracite

The Combustion of Dust Clouds: A Survey of the Literature

The Ignitibility of Bituminous Coal

Changes in Coal Sulfur During Carbonization

The Radiation Chemistry of Coal in Various Atmospheres

Reaction of Bituminous Coal with Concentrated Sulfuric Acid

The Nature and Occurrence of Ash Forming Minerals in Anthracite
| SR-23 | A Phenomenological Approach to the Batch Grinding of Coals | January 20, 1961 |
| SR-24 | The Unsteady State Diffusion of Gases from Anthracite at High Temperatures | January 21, 1961 |
| SR-25 | Some Advances in X-Ray Diffractometry and Their Application to the Study of Anthracites and Carbons | February 24, 1961 |
| SR-26 | The Filtration of Coal Solutions | March 17, 1961 |
| SR-27 | A Preliminary Investigation into the Application of Coal Petrography in the Blending of Anthracite and Bituminous Coals for the Production of Metallurgical Coke | May 1, 1961 |
| SR-28 | Preparation and Properties of Activated Carbons Prepared from Nitric Acid Treatment of Bituminous Coal | August 15, 1961 |
| SR-29 | The Reactions of Selected Bituminous Coals with Concentrated Sulfuric Acid | August 31, 1961 |
| SR-31 | Mineral Matter Removal from Anthracite by High Temperature Chlorination | March 26, 1962 |
| SR-32 | The Effect of Crusher Type on the Liberation of Sulfur in Bituminous Coal | April 29, 1962 |
| SR-33 | Investigation of the Circular Concentrator - Flotation Circle System for Cleaning Fine Coal | September 10, 1962 |
| SR-34 | Reactions of Coal with Atomic Species | September 24, 1962 |
| SR-36 | A Study of the Burning Velocity of Laminar Coal Dust Flames | November 5, 1962 |
| SR-37 | Molecular Sieve Material From Anthracite | November 16, 1962 |
| SR-38 | Studies of Anthracite Coals at High Pressures and Temperatures | April 29, 1963 |
| SR-39 | Coal Flotation of Low-Grade Pennsylvania Anthracite Silts | May 13, 1963 |
| SR-41 | Some Aspects of the Chemistry of Sulfur in Relation to Its Presence in Coal | August 20, 1963 |
| SR-42 | The Unsteady State Diffusion of Gases from Coals | February 15, 1964 |
| SR-43 | The Effect of Concentration and Particle Size on the Burning Velocity of Laminar Coal Dust Flames | March 1, 1964 |
| SR-44 | The Electrokinetic Behavior of Anthracite Coals and Lithotypes | May 25, 1964 |

M. E. Bell, Director
M. I. Experiment Station
SUMMATION OF RESULTS

The depletion of good quality raw coal and mechanized mining methods, producing more fines, has caused an increase in the percentage of mechanically cleaned coal. As a result the coal industry is faced with the problem of choosing the proper fine coal preparation equipment based on efficiency, economics, and capital and operating costs.

The cyclone using only water as medium was investigated for fine coal cleaning. Preliminary work consisted of studies of the water flow rates and a sand suspension flow through the cyclone. Both constructional features of the cyclone and operating variables were considered. A new design feature consisting of a sleeve placed around the vortex finder to aid control of solids distribution was among the cyclone components investigated. Although a three inch cyclone was utilized for practical laboratory reasons, the parameters established may be reasonably transposed to large industrially-practical units.

Washability data indicated that the test coal considered would be very difficult to clean. It contained 51 per cent minus 325 mesh material having an ash content greater than 40 per cent. The clean coal product from the cyclone operation occurred as an underflow which had an ash content near 14 per cent and represented an ash rejection of over 75 per cent. The recovery of 1.45 float material exceeded 80 per cent. The sulfur occurred in particles of such size and gravity that much of it reported to the clean coal, however it is proposed that this sulfur can be effectively removed in subsequent processing stages.
SUMMATION OF RESULTS (continued)

Information has been provided on the ability of the cyclone to clean coal efficiently in the extreme fine sizes. From the current work which was actually a classification, it appears that the conventional cyclone using only water and coal feed will be most effective in fine coal cleaning as a unit operation in a multi-stage process. Substantial quality improvement with satisfactory recoveries can be made by treating fine coals in such a process.
ACKNOWLEDGEMENT

The authors wish to express their sincere appreciation to Heyl and Patterson, Inc. for supplying the original cyclone used in this study. The authors are also grateful to the Pittsburgh Coal Company for providing the coal sample used in this work.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>ii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>v</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vi</td>
</tr>
<tr>
<td>I. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Fine Coal Preparation</td>
<td>1</td>
</tr>
<tr>
<td>The Hydrocyclone</td>
<td>2</td>
</tr>
<tr>
<td>Potential Fine Coal Cleaning Method</td>
<td>4</td>
</tr>
<tr>
<td>Statement of the Problem</td>
<td>4</td>
</tr>
<tr>
<td>II. BACKGROUND AND RELATED STUDIES</td>
<td>5</td>
</tr>
<tr>
<td>III. DESCRIPTION OF EQUIPMENT</td>
<td>8</td>
</tr>
<tr>
<td>General Layout for Testing 3-Inch Cyclone</td>
<td>8</td>
</tr>
<tr>
<td>Three Inch Cyclone</td>
<td>10</td>
</tr>
<tr>
<td>IV. ANALYTICAL PROCEDURES</td>
<td>13</td>
</tr>
<tr>
<td>Size Analyses</td>
<td>13</td>
</tr>
<tr>
<td>Chemical Analyses</td>
<td>13</td>
</tr>
<tr>
<td>Sink-Float Analyses</td>
<td>13</td>
</tr>
<tr>
<td>V. CHARACTERISTICS OF TEST COAL USED</td>
<td>16</td>
</tr>
<tr>
<td>VI. PRELIMINARY STUDIES</td>
<td>20</td>
</tr>
<tr>
<td>Water Flow Rate Through 3-Inch Cyclone</td>
<td>20</td>
</tr>
<tr>
<td>Slurry Flow Through 3-Inch Cyclone</td>
<td>25</td>
</tr>
<tr>
<td>VII. EXPERIMENTAL PROCEDURE AND PRESENTATION OF RESULTS OF FINE COAL CLEANING</td>
<td>35</td>
</tr>
<tr>
<td>VIII. DISCUSSION OF RESULTS OF FINE COAL CLEANING</td>
<td>43</td>
</tr>
<tr>
<td>Tests</td>
<td>45</td>
</tr>
<tr>
<td>Effect of Inlet Pressure and Vortex Finder Sleeve</td>
<td></td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (continued)

| Effect of Apex Orifice Diameter and Vortex Finder Sleeve | 47 |
| Effect of Inlet Pressure and Apex Orifice Diameter | 49 |
| Effect of Inlet Sleeve Diameter | 51 |
| Summation of Parameter Effects | 58 |
| Operational Suggestions | 58 |

| IX. CONCLUSIONS | 60 |
| Conclusions | 60 |
| Suggestions for Further Research | 62 |

| X. BIBLIOGRAPHY | 63 |

| XI. APPENDIX A | 67 |
| Water Flow Data | 67 |

| XII. APPENDIX B | 100 |
| Sand Slurry Flow Data | 100 |
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Chemical Analyses by Size Range of Pittsburgh Seam Coal Filter Cake</td>
<td>17</td>
</tr>
<tr>
<td>II</td>
<td>Washability Data of Minus 20-Mesh Pittsburgh Seam Coal Filter Cake</td>
<td>18</td>
</tr>
<tr>
<td>III</td>
<td>Size Analysis of River Sand</td>
<td>30</td>
</tr>
<tr>
<td>VI</td>
<td>Performance of 3-Inch Cyclone on Pittsburgh Seam Coal Filter Cake. Conditions: 7/8 Inch Vortex Finder Insert, 1/4 Inch Inlet Sleeve, 40 psig, and With Vortex Finder Sleeve</td>
<td>39</td>
</tr>
<tr>
<td>VIII</td>
<td>Performance of 3-Inch Cyclone on Pittsburgh Seam Coal Filter Cake. Conditions: 7/8 Inch Vortex Finder Insert, 1/4 Inch Inlet Sleeve, 1/2 Inch Underflow Orifice, and Without Vortex Finder Sleeve</td>
<td>41</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Laboratory Arrangement for Testing the 3-Inch Cyclone</td>
<td>9</td>
</tr>
<tr>
<td>2a</td>
<td>Experimental 3-Inch Cyclone</td>
<td>12</td>
</tr>
<tr>
<td>2b</td>
<td>Disassembled Experimental 3-Inch Cyclone</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Centrifuge Used During Washability Studies of Minus 20-Mesh Pittsburgh Seam Coal Filter Cake and Cyclone Products</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>Special Vacuum Apparatus Used for Removal of Sink Material During Washability Studies of Minus 20-Mesh Pittsburgh Seam Coal Filter Cake and Cyclone Products</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>Washability Curves of Minus 20-Mesh Pittsburgh Seam Coal Filter Cake</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>Water Flow Through 3-Inch Cyclone as a Function of Pressure - 1/4-Inch Inlet, With Sleeve</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>Water Flow Through 3-Inch Cyclone as a Function of Pressure - 1/4-Inch Inlet, Without Sleeve</td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>Water Flow Through 3-Inch Cyclone as a Function of Pressure - 5/8-Inch Inlet, With Sleeve</td>
<td>23</td>
</tr>
<tr>
<td>9</td>
<td>Water Flow Through 3-Inch Cyclone as a Function of Pressure - 5/8-Inch Inlet, Without Sleeve</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>Water Flow at Vortex Finder as a Function of Lower Orifice Diameter - With Sleeve</td>
<td>26</td>
</tr>
<tr>
<td>11</td>
<td>Water Flow at Vortex Finder as a Function of Lower Orifice Diameter - Without Sleeve</td>
<td>27</td>
</tr>
<tr>
<td>12</td>
<td>Water Flow at Lower Orifice as a Function of Vortex Finder Diameter - With Sleeve</td>
<td>28</td>
</tr>
<tr>
<td>13</td>
<td>Water Flow at Lower Orifice as a Function of Vortex Finder Diameter - Without Sleeve</td>
<td>29</td>
</tr>
</tbody>
</table>
**LIST OF FIGURES (continued)**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Recovery of Sand as a Function of Pressure</td>
<td>32</td>
</tr>
<tr>
<td>15</td>
<td>Recovery of Sand as a Function of Lower Orifice Diameter</td>
<td>32</td>
</tr>
<tr>
<td>16</td>
<td>Underflow Solids-Liquid Ratio as a Function of Pressure</td>
<td>33</td>
</tr>
<tr>
<td>17</td>
<td>Underflow Solids-Liquid Ratio as a Function of Lower Orifice Diameter</td>
<td>33</td>
</tr>
<tr>
<td>18</td>
<td>Yield of Clean Coal as a Function of Pressure</td>
<td>52</td>
</tr>
<tr>
<td>19</td>
<td>Yield of Clean Coal as a Function of Lower Orifice Diameter</td>
<td>53</td>
</tr>
<tr>
<td>20</td>
<td>Clean Coal Washability at 1.45 Sp. Gr. as a Function of Pressure</td>
<td>54</td>
</tr>
<tr>
<td>21</td>
<td>Clean Coal Washability at 1.45 Sp. Gr. as a Function of Lower Orifice Diameter</td>
<td>55</td>
</tr>
<tr>
<td>22</td>
<td>Ash Rejection as a Function of Pressure</td>
<td>56</td>
</tr>
<tr>
<td>23</td>
<td>Ash Rejection as a Function of Lower Orifice Diameter</td>
<td>57</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

Fine Coal Preparation

One of the greatest problems facing the coal industry today is that of fine coal cleaning. This results from the increasing quantities of fine coal, changing product specifications, complex engineering aspects of plant operation in fine coal cleaning, economic aspects of operation, and capital expenditure considerations. Industry must choose the proper combination from a wide assortment of preparation equipment and at the same time justify the cost of installing and operating these facilities.

In recent years there have been several factors which have contributed to the changes made in coal preparation. Among these are: (1) the advent of continuous mining, (2) the producers drive for increased recovery, (3) the depletion of good quality raw coal, (4) more rigid specifications by the consumer, and (5) legislation aimed at eliminating air and stream pollution \(^5, 12, 39, 40\). The utility and steel markets consume the greatest tonnage of coal and take the largest percentage of coal's total output. These markets do not require a coarse product and, as a result, the fines which were often considered waste about 20 years ago are now marketable. Although the utilities are beginning to use a much lower grade coal, the steel market needs a uniform high quality coal with a minimum percentage of ash and sulfur \(^5, 12, 19\).

The amount of bituminous and lignitic coal that was mechanically cleaned in the United States in 1963 was about the same as 1961 and 1962, or about 65.7 per cent of the total tonnage produced \(^41\).
The methods of mechanically cleaning bituminous and lignitic coal in 1962 were as follows: 52

- jigs - 50 per cent
- dense media - 25 per cent
- concentrating tables - 12 per cent
- pneumatic methods - 7 per cent
- classifiers - 2 per cent
- launders - 2 per cent
- flotation - 2 per cent

Equipment sales in 1963 ranked in terms of capacity were as follows: dense media, jigs, pneumatic devices, concentrating tables, and flotation machines 51.

Methods of fine coal (minus 3/8 inch) cleaning in the United States include jigs, tables, classifiers, launders, and flotation; with tables and jigs being most popular and flotation being applied for cleaning the extreme fines 5, 18, 28, 39, 40, 41. Of increasing importance is the feldspar jig 9, 17, 26, 44 and the heavy media cyclone 9, 10, 16, 18, 20, 22, 24, 25, 38, 45, 49. Generally the feed to a jig is classified at about 48-mesh, but in some plants the feed may include all of the fine sizes.

New methods for cleaning fine coal are constantly under investigation and research in this area of coal preparation is increasing. Among these methods are the circular concentrator, 27, 33 the flotation circle, 32 the Dynawhirlpool, 13, 47 the hydraulic cyclone using water as a medium, 4, 40, 48 and the sieve bend 37.

The Hydrocyclone

Hydrocyclones first appeared in coal preparation plants in the United States in the late 1930's functioning as thickeners and classifiers 3, 21.
The products from these cyclones in plants today are generally used as feed to tables, flotation machines, and feldspar jigs, or as intermediate stages in dewatering.

The first cyclone used for cleaning fine coal was developed in the Netherlands in 1948 by the Dutch State Mines. This method utilized a magnetite suspension as a medium. Other materials have been used in heavy media suspensions, e.g. galena and ferrosilicon. It was found, however, that in the gravity range used for coal, magnetite gave a more satisfactory viscosity which resulted in a superior recovery of clean coal on an economic basis. By 1960 there were 42 heavy media cyclone washing plants abroad either in operation or under installation. In 1960 the first heavy media cyclone washing plant was installed in the United States. Most authors agree that these cyclones will do an efficient and economical job of cleaning in the 1 1/2-inch to 48-mesh size range. The heavy media cyclone is also capable of making sharp separations in the finer sizes, but as the feed size decreases the magnetite consumption increases. Sokaski and Geer found a magnetite loss of 2 1/2 pounds per ton of feed when cleaning 1/2-inch by 0 coal.

Advantages of the heavy media cyclone operation are as follows: (1) less space, (2) easy arrangement in multiple units for separating at different gravities, (3) low manpower requirements, (4) low maintenance costs, (5) sharp separation regardless of variations in load and composition of raw coal, and (6) because of its sharp separation, it can cope with large amounts of near gravity material.
Among the disadvantages are the need for close control of specific gravity of medium, and recovery of the medium. The heavy media cyclone has been an efficient unit for making a sharp separation in fine coal cleaning. However, there still exist the problems of desliming, specific gravity control, and recovery of the medium. One potential method of cleaning the extreme fines would be through the use of a cyclone using only water as a medium. A unit such as this would be more economical, would eliminate the problems of specific gravity control and recovery of the medium, and have a capacity at least equal to the heavy media cyclone.

Statement of the Problem

It is the goal of this study of fine coal cleaning using a water-medium cyclone to gain a general understanding of the cyclone performance under varying conditions. Both constructional features of the cyclone and operating variables will be studied. It would be desirable to extend good cleaning efficiencies to the smaller sizes, namely, minus 28-mesh, and to minimize misplaced material. If successful results can be achieved, the consumption of magnetite or other medium would be eliminated.
CHAPTER II
BACKGROUND AND RELATED STUDIES

Although cyclones have been used as classifiers and thickeners for many years their use as a cleaning device for fine coal is relatively new. Since 1948 in Europe and 1960 in the United States the heavy media cyclone has increased in popularity as a fine coal cleaner because of its simplicity and its ability to make sharp separations. Even simpler and more economical is the water cyclone without use of a heavy medium such as magnetite. The literature indicates that only a few water cyclones used specifically for grade improvement are found in fine coal cleaning circuits today.

In many plants in Britain where jigs are employed as the washing unit, the cleaning results are not satisfactory because the raw feed coal contains a greater proportion of fines and incombustibles than that for which the unit was designed. The clean coal from one Baum jig treating 6-inch by 0 raw coal is inconsistent in quality and too high in ash content. Some plants are now going into operation using cyclone washers with water as the medium for cleaning 1/2-inch by 0 raw coal and have proved successful in producing a clean coal with the required ash content. This form of washing may be adapted as an aid in existing plants.

Mullins points out that in another washery in Britain the hydrocyclone is used to improve the performance of the jig. Here again the desired specific gravity separations are reached without heavy medium. They are retreating the 1/2-inch by 35-mesh clean coal from jigs in the water cyclones to further reduce the ash content. However, the extreme fines are being treated by flotation.
Benzon cites another case where four hydrocyclones are cleaning 28-mesh by 0 coal. These cyclones have the following dimensions: 14-inch diameter, 28 inch height, 2 1/2-inch feed inlet diameter, 6-inch vortex diameter, 2-inch apex opening, and a cone angle of 75-degrees. They are handling 1400 gallons per minute of slurry containing 16-17 tons per hour of plus 200-mesh solids. There was a significant reduction in ash content in the 48 by 200-mesh size range.

Krijgman's discussion of Benzon's paper included the following:

"The cyclone washer "water only" type for the minus 28-mesh material is important. This type of cyclone is different from the well-known cyclone classifier. As compared with flotation, it is a simple tool. The obtained ash of the clean coal can be altered, if desired, by making some simple changes in the hydrocyclone."

Vismans states that separation is not as sharp in the water cyclone as in the heavy media cyclone. Therefore, it is less efficient and inadequate for practical cleaning when used as a single unit. He suggests that the best method for treating friable high-ash coals is to obtain as clean a coal as possible from the first cyclone, then reclean the slimes in a second and third cyclone. The overflow from the last two cyclones can be recirculated to the feed.

Miller used a 14-inch, 45 degree hydrocyclone in combination with a sieve bend-froth cell arrangement in his work to remove the fine, high gravity, pyrite particles. The overflow contained high ash-low sulfur fines and clean coal of coarse and intermediate sizes each of a low sulfur content. The cyclone underflow was then passed over a 60-mesh sieve bend. The fine sulfur
was removed in the sieve bend effluent which contained 16.3 per cent ash and 3.05 per cent sulfur. The plus 60-mesh material from the sieve bend was combined with the overflow from the cyclone to provide the flotation feed containing 1.21 per cent sulfur and 7.59 per cent ash. There was a clean coal yield of 63.0 per cent from the flotation unit with 3.87 per cent ash and 1.08 per cent sulfur. Miller concluded the following:

"Hydrocyclones, because they separate primarily by specific gravity, are an effective means of removing pyritic sulfur. However, because they tend to throw extreme fines of all gravities to their clean coal product, they are best used in combination with froth flotation if high yields are to be obtained."

Abbot recommends inlet pressures of about 15 to 20 psig, claiming that excessive wear occurs at higher pressures with only small increases in capacity and efficiency. He also recommends venting of the underflow and overflow to the atmosphere.
CHAPTER III
DESCRIPTION OF EQUIPMENT

General Layout for Testing Three-Inch Cyclone

The laboratory layout, as shown in Figure 1, for the purpose of testing the 3-inch cyclone includes the following equipment:

1. Super-agitator tank - 700 gallons, 5 feet by 5 feet, with impeller V-belt driven by a 3 horsepower, 1735/1445 revolutions per minute, 220/440 volt, 3 phase motor. A 1/4-inch perforated pipe in the form of a cross was placed in the bottom of the tank. This was for additional agitation by air.

2. Volute pump - 4 inch, 75/440 gallons per minute, 55/140 foot head, 1590 revolutions per minute, 24.8 horsepower.


4. Six-inch header pipe assembly to permit use of different feed pressures. Tap sizes are 1/2, 1, 1 1/2, and 2 inches in diameter.

5. Ashcroft Chemical Pressure gauge with diaphragm, 4-1/2-inch dial, and a range from 0 to 160 psi to measure cyclone inlet pressures.

6. Cyclone mounting rack.

7. Two 4-inch gate valves.

8. Observation deck.

In a typical test run with this equipment, the pressure gauge and cyclone were connected to the 1/2-inch header pipe tap. Next, the material in the tank was agitated by starting the impeller in the
Figure 1. Laboratory Arrangement for Testing the 3-Inch Cyclone
Showing:
(1) Super-Agitator Tank
(2) Volute Pump and Motor
(3) Six-Inch Header Pipe With Taps
(4) Pressure Gauge
(5) Cyclone Mounting Rack
(6) Four-Inch Gate Valves
(7) Observation Deck
tank and connecting the perforated air pipe to the air line. Third, with the 4-inch valve at the header pipe exit open to allow material to return to the tank, the pump was started. The 4-inch valve between the tank and the pump was opened immediately. A valve between the header pipe and pressure gauge permits the material to enter the cyclone.

By the adjustment of the 4-inch valve at the header pipe exit and the selection of the appropriate diameter header pipe tap, a wide variety of pressures and velocities may be attained. Maximum pressure is reached with this valve closed. The pump is always operated at full capacity. The overflows from the 4-inch header valve and the cyclone products are returned to the tank for recirculation.

The uniformity of the feed should be consistent if the system is allowed to reach the stage of equilibrium prior to sampling. A major weakness of this laboratory system over an industrial set-up would be that of recirculation. However, as will be shown later in Chapter VII, degradation of the coal used was of minor importance.

Three-Inch Cyclone

The cyclone under investigation is a Heyl and Patterson 3-inch cyclone. Several modifications to this cyclone were designed by Professor H. L. Lovell and Mr. S. M. Koo of the Mineral Preparation Department, The Pennsylvania State University. They were machined in the College of Mineral Industries Machine Shop. These modifications were the following:

1. Feed inlet sleeves (1/4, 3/8, 1/2, and 5/8-inch diameter).
2. Vortex finder inserts (1/2, 5/8, 3/4, and 7/8-inch diameter and 5 inches long).

3. Vortex finder sleeve (2-inch diameter by 5 inches long). This innovation was suggested by Professor D. R. Mitchell, Acting Head of the Mineral Preparation Department, The Pennsylvania State University. It was proposed that by placing this sleeve around the vortex finder insert, it would reduce the amount of material being short-circuited to the overflow and keep it in the underflow.

Ceramic apex orifices were purchased from Heyl and Patterson, Inc. in the following sizes: 3/16, 1/4, 5/16, 3/8, and 1/2-inch diameter. The 3-inch cyclone and its parts are shown in Figure 2a and 2b.
Figure 2a. Experimental 3-Inch Cyclone

Figure 2b. Disassembled Experimental 3-Inch Cyclone Showing:

1. Vortex Finder Insert
2. Vortex Finder Sleeve
3. Inlet Sleeve
4. Ceramic Apex Orifice
CHAPTER IV
ANALYTICAL PROCEDURES

Screen Analyses

After drying, the samples from the various cyclone tests were split into two equal parts by riffling. One-half of the sample was used for chemical analyses and one-half was wet screened at 325-mesh. Eight-inch diameter U.S. Standard Sieves were used for all screen analyses. It was necessary to wet screen all coal samples because of the size range (100 per cent minus 20-mesh). The screened products were then dried, weighed, and approximately 5 grams of the minus 325-mesh material was taken for chemical analyses. The remaining minus 325-mesh material was recombined proportionately with the plus 325-mesh material to make a representative sample for sink-float analyses.

Chemical Analyses

Moisture, ash and sulfur contents were determined in accordance with the A. S. T. M., Standard Methods of Laboratory Sampling and Analysis of Coal and Coke D271-48. A few changes in the sulfur procedure as approved by the U. S. Bureau of Mines improved the efficiency of this analysis.

Sink-Float Analyses

The washability data were obtained according to the centrifugal float-and-sink test procedure for fine coal developed by the U. S. Bureau of Mines. This method recommends centrifuging the coal sample in a heavy liquid for 20 minutes at a speed of 1500 revolutions per minute. The sink material is removed using a
vacuum probe. Figures 3 and 4 show the equipment used for this method of sink-float determinations.
Figure 3. Centrifuge Used During Washability Studies of Minus 20-Mesh Pittsburgh Seam Coal Filter Cake and Cyclone Products.

Figure 4. Special Vacuum Apparatus Used for Removal of Sink Material During Washability Studies of Minus 20-Mesh Pittsburgh Seam Coal Filter Cake and Cyclone Products.
CHAPTER V
CHARACTERISTICS OF TEST COAL USED

The coal used for this work was a bituminous filter cake out of the Pittsburgh seam shipped from the Pittsburgh Coal Company, Library, Pennsylvania. A sample was taken by standard methods for analysis. The size data are given in Table I and results of washability studies in Table II and Figure 5. This coal contains 25.56 per cent ash, 1.83 per cent sulfur, and about 52 per cent minus 325-mesh material which analyzes 41.75 per cent ash and 2.02 per cent sulfur. In the normal cleaning range at a specific gravity of 1.45, these data permit a prediction of a recovery of 53.5 per cent float coal with 6.95 per cent ash and 1.49 per cent sulfur. The ± 0.10 specific gravity curve of Figure 5 indicates that at this gravity there would be about 20 per cent near gravity material making cleaning very difficult and at 1.50 specific gravity there would be 13 per cent near gravity material making cleaning difficult.
TABLE I
Chemical Analyses by Size Range of Pittsburgh Seam Coal Filter Cake

<table>
<thead>
<tr>
<th>Size (mesh)</th>
<th>Passed Wt.%</th>
<th>Ash %</th>
<th>Sulfur %</th>
<th>Cumulative Retained Wt.%</th>
<th>Cumulative Passed Wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Retained</td>
<td></td>
<td></td>
<td>Ash %</td>
<td>Sulfur %</td>
</tr>
<tr>
<td>20</td>
<td>28</td>
<td>0.5</td>
<td>4.40</td>
<td>1.27</td>
<td>6.4</td>
</tr>
<tr>
<td>28</td>
<td>48</td>
<td>5.9</td>
<td>4.40</td>
<td>1.27</td>
<td>6.4</td>
</tr>
<tr>
<td>48</td>
<td>100</td>
<td>14.1</td>
<td>5.43</td>
<td>1.48</td>
<td>20.5</td>
</tr>
<tr>
<td>100</td>
<td>200</td>
<td>15.8</td>
<td>8.33</td>
<td>1.70</td>
<td>36.3</td>
</tr>
<tr>
<td>200</td>
<td>325</td>
<td>11.8</td>
<td>12.89</td>
<td>1.88</td>
<td>48.1</td>
</tr>
<tr>
<td>325</td>
<td></td>
<td>51.9</td>
<td>41.75</td>
<td>2.02</td>
<td>100.0</td>
</tr>
</tbody>
</table>
**TABLE II**

Washability Data of Minus 20 Mesh Pittsburgh Seam Coal Filter Cake

<table>
<thead>
<tr>
<th>Specific Gravity</th>
<th>Sink</th>
<th>Float</th>
<th>Wt.%</th>
<th>Ash %</th>
<th>Sulfur %</th>
<th>Cumulative Float</th>
<th>Wt.%</th>
<th>Ash %</th>
<th>Sulfur %</th>
<th>Cumulative Sink</th>
<th>Wt.%</th>
<th>Ash %</th>
<th>Sulfur %</th>
<th>Elementary Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.30</td>
<td>31.2</td>
<td>4.90</td>
<td>1.33</td>
<td>31.2</td>
<td>4.90</td>
<td>1.33</td>
<td>100.0</td>
<td>25.56</td>
<td>1.83</td>
<td>15.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.30</td>
<td>1.40</td>
<td>18.7</td>
<td>8.26</td>
<td>.30</td>
<td>L</td>
<td>1.65</td>
<td>49.9</td>
<td>6.16</td>
<td>1.46</td>
<td>68.8</td>
<td>34.98</td>
<td>2.05</td>
<td>40.6</td>
</tr>
<tr>
<td></td>
<td>1.40</td>
<td>1.45</td>
<td>3.6</td>
<td>17.84</td>
<td>1.88</td>
<td>53.5</td>
<td>6.95</td>
<td>1.49</td>
<td>50.1</td>
<td>44.95</td>
<td>2.21</td>
<td>51.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.45</td>
<td>1.50</td>
<td>3.6</td>
<td>20.88</td>
<td>1.97</td>
<td>57.1</td>
<td>7.83</td>
<td>1.52</td>
<td>46.5</td>
<td>47.05</td>
<td>2.23</td>
<td>55.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.50</td>
<td>1.60</td>
<td>6.4</td>
<td>38.19</td>
<td>2.10</td>
<td>63.5</td>
<td>10.87</td>
<td>1.57</td>
<td>42.9</td>
<td>49.24</td>
<td>2.25</td>
<td>60.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.60</td>
<td>36.5</td>
<td>51.18</td>
<td>2.28</td>
<td>100.0</td>
<td>25.56</td>
<td>1.83</td>
<td>36.5</td>
<td>51.18</td>
<td>2.28</td>
<td>81.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5. Washability Curves of Minus 20 Mesh Pittsburgh Seam Coal Filter Cake.
CHAPTER VI
PRELIMINARY STUDIES

Water Flow Rate Through the 3-Inch Cyclone

Preliminary knowledge of the water flow rate through the 3-inch cyclone was deemed basic in evaluating its performance as a cleaning device. It was not possible to sample the feed to the cyclone in the test system, therefore, the feed rate was calculated from the weight of the overflow and underflow samples which were collected for a measured period of time. The water flow rate was studied by varying the inlet sleeve, vortex finder insert, and apex orifice diameters as a function of feed pressure. All combinations of these variables were studied first with the vortex finder sleeve in place and second without the sleeve. The length of the vortex finder insert was held constant at 5 inches although the equipment available would have permitted its variation. Only the 1/2-inch header pipe tap was used. Feed pressure was varied between 10 and 60 psig by adjusting the 4-inch gate valve at the header pipe outlet for each condition of cyclone variable. The cyclone was mounted in a vertical position.

The water flow rate data are presented in Appendix A as Tables A1 through A32. Tables A1 and A5 represent that combination of variables, both with and without the vortex finder sleeve, which produced the least total flow rate, whereas, Tables A28 and A32 represent that combination which produced the greatest flow rate.

Figures 6, 7, 8, and 9 are a graphic representation of the
Figure 6. Water Flow Through 3-Inch Cyclone as a Function of Pressure.

Water Flow Through 3-Inch Cyclone as a Function of Pressure.
Figure 7. Water Flow Through 3-Inch Cyclone as a Function of Pressure
Figure 8. Water Flow Through 3-Inch Cyclone as a Function of Pressure.
Figure 9. Water Flow Through 3-Inch Cyclone as a Function of Pressure.
data given in Tables A1, A5, A28, and A32. Figures 10 and 11 show
the flow rate at the vortex finder as a function of the apex diameter,
whereas Figures 12 and 13 give the flow rate at the apex as a
function of the vortex finder diameter. These last four figures
indicate close agreement with the work of Stas 46.

The graphs tend to indicate that the data are sufficiently
accurate for the purposes of the current studies. Points falling off
the curves may be caused by several errors including sampling,
timing, and weighing.

The results of these water flow rate tests are summarized
below:

<table>
<thead>
<tr>
<th>Increase</th>
<th>Overflow</th>
<th>Underflow</th>
<th>Total Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Diameter</td>
<td>increases</td>
<td>decreases</td>
<td>increases</td>
</tr>
<tr>
<td>Vortex Finder Diameter</td>
<td>increases</td>
<td>decreases</td>
<td>increases</td>
</tr>
<tr>
<td>Underflow Orifice Diameter</td>
<td>decreases</td>
<td>increases</td>
<td>increases</td>
</tr>
<tr>
<td>Pressure</td>
<td>increases</td>
<td>decreases</td>
<td>increases</td>
</tr>
</tbody>
</table>

By inserting the vortex finder sleeve, there was observed a slight
decrease in the overflow volume.

**Slurry Flow Through the 3-Inch Cyclone**

To the knowledge of water flow rates, it was desirous to add
the knowledge of cyclone performance when dealing with a homo-
genous solid of a distinct size distribution. This information would
not only give an insight into variations in performance by the addition
of solids, but also the distribution of the solids with respect to its
size and other cyclone variables. The river sand used for these
tests had a size analysis as given in Table III.
Figure 10. Water Flow at Vortex Finder as a Function of Lower Orifice Diameter.
Figure 11. Water Flow at Vortex Finder as a Function of Lower Orifice Diameter.
Figure 12. Water Flow at Lower Orifice as a Function of Vortex Finder Diameter
1/4" Inlet Sleeve
10 psig
Without Vortex Finder Sleeve

Figure 13. Water Flow at Lower Orifice as a Function of Vortex Finder Diameter.
To conduct these tests a known weight of sand was added to a known weight of water to give a solids-liquid ratio of approximately 5 per cent solids on the first test series and on the second series a solids-liquid ratio of approximately 10 per cent solids. In these two test series it was attempted to reproduce the flows shown in Figures 6 and 7 for a water system, first by using the 1/4-inch inlet sleeve, the 1/2-inch vortex finder, and the 3/8 inch underflow orifice at inlet pressures of 10, 20, 40, and 60 psig; second, by varying the underflow orifices and holding pressure constant at 40 psig. Each series was conducted first with the vortex finder sleeve in place and then without the sleeve. Samples were collected from the overflow and underflow outlets, weighed and dried to determine the weight and size of the solids. Again the overflow and underflow quantities determined the feed rate. Because of the small amount of plus 10 mesh and minus 100 mesh material in the sand, only the 28, 48, and 100 mesh size sieves were used.

<table>
<thead>
<tr>
<th>Size (mesh)</th>
<th>Passed</th>
<th>Retained</th>
<th>Weight %</th>
<th>Cumulative Wt.% Retained</th>
<th>Cumulative Wt.% Passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>8.4</td>
<td>8.4</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>48</td>
<td>41.8</td>
<td>50.2</td>
<td>91.6</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>100</td>
<td>38.8</td>
<td>89.0</td>
<td>49.8</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>11.0</td>
<td>100.0</td>
<td>11.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The screen analyses of the products indicated that there was 100 per cent recovery of the plus 100 mesh material in the underflow in all tests except when using the 3/16-inch diameter underflow orifice at the 10 per cent solids level. This was a "plugging" condition described as a rope-type discharge by Patterson 43. An analysis made on the overflow slurry indicated that about 90 per cent of the solids were minus 400-mesh in all tests except the one example mentioned above. The data given in Appendix B show the performance of the 3-inch cyclone on river sand under varying conditions.

The curves showing slurry flow rates would be very similar to those of the water flow rates as given in Figures 6 and 7 because of the low solids-liquid ratio. Figures 14 and 15 show the recovery of solids in the underflow as a function of pressure and underflow orifice diameter respectively. Figure 16 and 17 show how the solids-liquid ratio in the underflow varies with pressure and underflow orifice respectively.

The weight per cent solids in the underflow could be controlled by the variables studied to result in a product which ranged in solids-liquid ratio from that of the feed to a high of about 75 per cent. The results of these tests may be summarized as follows:

1. An increase in feed pressure: (a) increases the weight per cent solids in the underflow, (b) increases the volume of slurry in the underflow, and (c) has little effect on the underflow solids recovery in the size range studied.

2. An increase in the underflow orifice diameter: (a) decreases the weight per cent solids in the underflow, (b) increases the volume of slurry in the underflow, and (c) increases
Figure 14. Recovery of Sand as a Function of Pressure

Figure 15. Recovery of Sand as a Function of Lower Orifice Diameter.
Figure 16. Underflow Solids-Liquid Ratio as a Function of Pressure.

Figure 17. Underflow Solids-Liquid Ratio as a Function of Lower Orifice Diameter.
the recovery of solids in the underflow.

3. The effectiveness of the vortex finder sleeve was most evident at pressures below 40 psig affecting the classification size with varying pressures and underflow orifice diameters.

4. The effectiveness of the vortex finder sleeve on recovery varied with the solids-liquid ratio of the feed.

5. The sleeve had little or no effect on the solids-liquid ratio of the product slurries.

6. Recovery of the plus 100-mesh solids in the underflow was 100 per cent and approximately 90 per cent of the overflow solids was minus 400-mesh under all conditions, except when using the 3/16-inch diameter underflow orifice at the 10 per cent solids level.
CHAPTER VII

EXPERIMENTAL PROCEDURE AND PRESENTATION
OF RESULTS OF FINE COAL CLEANING

Coal and water were added to the super-agitator tank in correct proportions to make a suspension of 10 per cent solids by weight. From a study of the size and washability data of the coal and the performance of the cyclone with water and sand, it was indicated that cleaning of this particular coal would be improved by sending more material to the cyclone overflow. Accordingly, the largest vortex finder insert (7/8-inch) was installed in the cyclone. The system was started, as outlined in Chapter III, and allowed to come to equilibrium before each new test. Following collection at the underflow and overflow, the samples were weighed, dried, and re-weighed prior to riffling for analytical procedures.

Tables IV through IX show the results of these tests under the conditions studied. Figures 18 through 23 of Chapter VIII are a graphic presentation of some of these data. The ash and sulfur analyses are expressed on a moisture-free basis. Misplaced material was based on the sink-float data, i.e. the per cent sink in the underflow clean coal and the per cent float in the overflow refuse. The Fraser-Yancey 38 efficiencies were determined from the following equation:

\[ E = \frac{\text{Rec. of CC} \times \% \text{ash in feed} - \% \text{ash in CC}}{\text{Theo. Rec.} \times \% \text{ash in feed} - \% \text{ash in TCC}} \times 100. \]

where:  
CC = clean coal  
TCC = Theoretical clean coal
The size index is a parameter developed during this study to give an indication of the classification efficiency of the cyclone at 325-mesh. It was determined by the following equation:

\[
\text{Size index} = \frac{\text{plus 325-mesh in underflow}}{\text{plus 325-mesh in feed}} \times 100.
\]

This index does not take into consideration the minus 325-mesh material in the underflow clean coal.
### TABLE IV
Performance of 3-Inch Cyclone on Pittsburgh Seam Coal Filter Cake

Conditions: 7/8 Inch Vortex Finder Insert, 1/4 Inch Inlet Sleeve, 3/8 Inch Underflow Orifice, and With Vortex Finder Sleeve

<table>
<thead>
<tr>
<th>Inlet Pressure (psig)</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FEED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-325-m, % (calculated)</td>
<td>56.5</td>
<td>55.7</td>
<td>57.6</td>
<td>56.3</td>
</tr>
<tr>
<td>Ash, % (calculated)</td>
<td>26.5</td>
<td>26.6</td>
<td>26.6</td>
<td>26.9</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>9.4</td>
<td>9.6</td>
<td>9.5</td>
<td>9.2</td>
</tr>
<tr>
<td>Solids Rate, (lb/hr)</td>
<td>238</td>
<td>316</td>
<td>454</td>
<td>580</td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>5.4</td>
<td>7.1</td>
<td>10.5</td>
<td>13.5</td>
</tr>
<tr>
<td><strong>UNDERFLOW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Yield, %</td>
<td>42.4</td>
<td>41.1</td>
<td>28.9</td>
<td>30.8</td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>0.9</td>
<td>0.7</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>28.6</td>
<td>57.1</td>
<td>72.0</td>
<td>79.4</td>
</tr>
<tr>
<td>Ash, %</td>
<td>14.33</td>
<td>13.51</td>
<td>14.07</td>
<td>14.39</td>
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<tr>
<td>Float, % (1.45 Sp.Gr.)</td>
<td>74.4</td>
<td>80.3</td>
<td>83.3</td>
<td>79.0</td>
</tr>
<tr>
<td>Misplaced Material, %</td>
<td>10.9</td>
<td>8.1</td>
<td>4.8</td>
<td>6.5</td>
</tr>
<tr>
<td>-325-m, %</td>
<td>16.2</td>
<td>12.8</td>
<td>9.5</td>
<td>10.1</td>
</tr>
<tr>
<td>-325-m, Ash, %</td>
<td>42.4</td>
<td>46.4</td>
<td>58.9</td>
<td>59.9</td>
</tr>
<tr>
<td><strong>OVERFLOW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>4.5</td>
<td>6.4</td>
<td>9.9</td>
<td>12.8</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>6.3</td>
<td>6.1</td>
<td>7.1</td>
<td>6.6</td>
</tr>
<tr>
<td>Ash, %</td>
<td>35.53</td>
<td>35.79</td>
<td>31.66</td>
<td>32.52</td>
</tr>
<tr>
<td>Ash Rejection, %</td>
<td>77.2</td>
<td>79.1</td>
<td>84.7</td>
<td>83.7</td>
</tr>
<tr>
<td>Sink, % (1.45 Sp.Gr.)</td>
<td>75.0</td>
<td>77.4</td>
<td>73.4</td>
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<td>Misplaced Material, %</td>
<td>14.4</td>
<td>13.3</td>
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<td>22.1</td>
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<td>-325-m, %</td>
<td>86.1</td>
<td>85.6</td>
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<td>-325-m Rejection, %</td>
<td>87.8</td>
<td>90.5</td>
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<td>94.6</td>
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<td>-325-m Ash, %</td>
<td>40.04</td>
<td>40.59</td>
<td>39.99</td>
<td>40.67</td>
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<tr>
<td>Total Misplaced Material, %</td>
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<td>21.4</td>
<td>23.7</td>
<td>28.6</td>
</tr>
<tr>
<td>F-Y Efficiency, %</td>
<td>53.0</td>
<td>55.6</td>
<td>40.0</td>
<td>43.3</td>
</tr>
<tr>
<td>Size Index, %</td>
<td>81.7</td>
<td>80.8</td>
<td>61.7</td>
<td>64.4</td>
</tr>
</tbody>
</table>
### TABLE V

Performance of 3-Inch Cyclone on Pittsburgh Seam Coal Filter Cake

**Conditions:** 7/8 Inch Vortex Finder Insert, 1/4 Inch Inlet Sleeve, 3/8 Inch Underflow Orifice, and Without Vortex Finder Sleeve

<table>
<thead>
<tr>
<th>Inlet Pressure (psig)</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>60</th>
</tr>
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<tr>
<td><strong>FEED</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-325-m, % (calculated)</td>
<td>57.5</td>
<td>57.3</td>
<td>57.9</td>
<td>57.1</td>
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<tr>
<td>Ash, % (calculated)</td>
<td>27.0</td>
<td>26.6</td>
<td>28.1</td>
<td>27.2</td>
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<td>Sulfur, % (calculated)</td>
<td>1.66</td>
<td>1.60</td>
<td>1.73</td>
<td>1.77</td>
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<tr>
<td>Solids, % (weight)</td>
<td>9.4</td>
<td>9.5</td>
<td>9.3</td>
<td>9.3</td>
</tr>
<tr>
<td>Solids Rate, (lb/hr)</td>
<td>244</td>
<td>316</td>
<td>459</td>
<td>541</td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>5.6</td>
<td>7.2</td>
<td>10.6</td>
<td>12.4</td>
</tr>
<tr>
<td><strong>UNDERFLOW</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Yield, %</td>
<td>43.9</td>
<td>43.6</td>
<td>43.3</td>
<td>45.4</td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>0.7</td>
<td>0.8</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>40.0</td>
<td>50.7</td>
<td>55.0</td>
<td>60.2</td>
</tr>
<tr>
<td>Ash, %</td>
<td>14.26</td>
<td>13.59</td>
<td>13.97</td>
<td>14.91</td>
</tr>
<tr>
<td>Sulfur, %</td>
<td>2.09</td>
<td>2.21</td>
<td>2.44</td>
<td>2.48</td>
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<tr>
<td>Float, % (1.45 Sp.Gr.)</td>
<td>82.4</td>
<td>77.5</td>
<td>80.9</td>
<td>85.4</td>
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<td>Misplaced Material, %</td>
<td>7.8</td>
<td>9.8</td>
<td>8.3</td>
<td>6.6</td>
</tr>
<tr>
<td>-325-m, %</td>
<td>15.8</td>
<td>14.6</td>
<td>15.3</td>
<td>15.3</td>
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<tr>
<td>-325-m Ash, %</td>
<td>41.34</td>
<td>43.15</td>
<td>45.81</td>
<td>47.28</td>
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<td>-325-m Sulfur, %</td>
<td>5.25</td>
<td>6.41</td>
<td>6.72</td>
<td>6.75</td>
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<tr>
<td><strong>OVERFLOW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>4.9</td>
<td>6.4</td>
<td>9.6</td>
<td>11.2</td>
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<td>Solids, % (weight)</td>
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<td>5.9</td>
<td>5.6</td>
<td>5.5</td>
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<tr>
<td>Ash, %</td>
<td>36.93</td>
<td>36.61</td>
<td>38.88</td>
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<td>Ash Rejection, %</td>
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<td>77.8</td>
<td>78.8</td>
<td>75.2</td>
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<td>1.13</td>
<td>1.18</td>
<td>1.18</td>
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<tr>
<td>Sink, % (1.45 Sp.Gr.)</td>
<td>83.9</td>
<td>80.8</td>
<td>83.8</td>
<td>83.8</td>
</tr>
<tr>
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<td>10.8</td>
<td>9.2</td>
<td>8.9</td>
</tr>
<tr>
<td>-325-m, %</td>
<td>90.1</td>
<td>90.3</td>
<td>90.5</td>
<td>91.9</td>
</tr>
<tr>
<td>-325-m Rejection, %</td>
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<td>88.8</td>
<td>87.8</td>
</tr>
<tr>
<td>-325-m Ash, %</td>
<td>39.04</td>
<td>39.33</td>
<td>38.90</td>
<td>39.44</td>
</tr>
<tr>
<td>-325-m Sulfur, %</td>
<td>1.29</td>
<td>1.21</td>
<td>1.16</td>
<td>1.08</td>
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<tr>
<td><strong>Total Misplaced Material, %</strong></td>
<td>16.8</td>
<td>20.6</td>
<td>17.5</td>
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<tr>
<td><strong>F-Y Efficiency, %</strong></td>
<td>56.9</td>
<td>57.7</td>
<td>62.3</td>
<td>56.2</td>
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<td><strong>Size Index, %</strong></td>
<td>87.1</td>
<td>87.1</td>
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TABLE VI

Performance of 3-Inch Cyclone on Pittsburgh Seam Coal Filter Cake

Conditions: 7/8 Inch Vortex Finder Insert, 1/4 Inch Inlet Sleeve, 40 psig, and With Vortex Finder Sleeve

<table>
<thead>
<tr>
<th>Underflow Orifice Diameter (in.)</th>
<th>3/16</th>
<th>1/4</th>
<th>5/16</th>
<th>3/8*</th>
<th>1/2</th>
</tr>
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<tbody>
<tr>
<td>FEED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-325-m, % (calculated)</td>
<td>55.7</td>
<td>56.3</td>
<td>56.7</td>
<td>57.6</td>
<td>55.2</td>
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<td>Ash, % (calculated)</td>
<td>26.5</td>
<td>26.7</td>
<td>26.7</td>
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<td>26.8</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>9.4</td>
<td>9.6</td>
<td>9.4</td>
<td>9.5</td>
<td>9.4</td>
</tr>
<tr>
<td>Solids Rate, (lb/hr)</td>
<td>462</td>
<td>462</td>
<td>473</td>
<td>454</td>
<td>441</td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>10.6</td>
<td>10.5</td>
<td>10.8</td>
<td>10.5</td>
<td>10.5</td>
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<tr>
<td>UNDERFLOW</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Yields, %</td>
<td>14.8</td>
<td>25.7</td>
<td>27.3</td>
<td>28.9</td>
<td>48.4</td>
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<td>Slurry Flow, (gpm)</td>
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<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>1.5</td>
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<tr>
<td>Solids, % (weight)</td>
<td>58.2</td>
<td>60.7</td>
<td>65.6</td>
<td>72.0</td>
<td>36.2</td>
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<td>Ash, %</td>
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<td>14.81</td>
<td>15.04</td>
<td>14.07</td>
<td>15.14</td>
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<tr>
<td>Float, % (1.45 Sp. Gr.)</td>
<td>73.1</td>
<td>79.8</td>
<td>77.4</td>
<td>83.3</td>
<td>75.5</td>
</tr>
<tr>
<td>Misplaced Material, %</td>
<td>4.0</td>
<td>5.2</td>
<td>6.2</td>
<td>4.8</td>
<td>11.9</td>
</tr>
<tr>
<td>-325-m, %</td>
<td>6.9</td>
<td>9.1</td>
<td>8.9</td>
<td>9.5</td>
<td>17.0</td>
</tr>
<tr>
<td>-325-m Ash, %</td>
<td>57.36</td>
<td>59.74</td>
<td>58.67</td>
<td>58.97</td>
<td>39.84</td>
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<td>OVERFLOW</td>
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<td></td>
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</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>10.3</td>
<td>9.9</td>
<td>10.2</td>
<td>9.9</td>
<td>9.0</td>
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<td>Solids, % (weight)</td>
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<td>30.76</td>
<td>31.45</td>
<td>31.66</td>
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<td>76.4</td>
<td>84.7</td>
<td>72.8</td>
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<tr>
<td>Sink, % (1.45 Sp. Gr.)</td>
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<td>63.0</td>
<td>66.3</td>
<td>73.4</td>
<td>84.5</td>
</tr>
<tr>
<td>Misplaced Material, %</td>
<td>34.4</td>
<td>27.5</td>
<td>24.5</td>
<td>18.9</td>
<td>8.0</td>
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<tr>
<td>-325-m, %</td>
<td>64.3</td>
<td>72.8</td>
<td>74.7</td>
<td>77.1</td>
<td>91.0</td>
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<tr>
<td>-325-m Rejection, %</td>
<td>98.4</td>
<td>96.0</td>
<td>95.8</td>
<td>95.2</td>
<td>85.1</td>
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<td>40.30</td>
<td>40.56</td>
<td>39.99</td>
<td>40.72</td>
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<td>32.7</td>
<td>30.7</td>
<td>23.7</td>
<td>19.9</td>
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<tr>
<td>F-Y Efficiency, %</td>
<td>20.6</td>
<td>35.2</td>
<td>38.8</td>
<td>40.0</td>
<td>56.3</td>
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<tr>
<td>Size Index, %</td>
<td>31.2</td>
<td>53.5</td>
<td>57.5</td>
<td>61.7</td>
<td>89.8</td>
</tr>
</tbody>
</table>

* From Table IV
TABLE VII

Performance of 3-Inch Cyclone on Pittsburgh Seam Coal Filter Cake

Conditions: 7/8 Inch Vortex Finder Insert, 1/4 Inch Inlet Sleeve, 40 psig, and Without Vortex Finder Sleeve

<table>
<thead>
<tr>
<th>Underflow Orifice Diameter (in.)</th>
<th>3/16</th>
<th>1/4</th>
<th>5/16</th>
<th>3/8</th>
<th>1/2</th>
</tr>
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<td><strong>FEED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>↓325-m, % (calculated)</td>
<td>59.0</td>
<td>57.7</td>
<td>52.8</td>
<td>57.9</td>
<td>56.8</td>
</tr>
<tr>
<td>Ash, % (calculated)</td>
<td>27.3</td>
<td>26.9</td>
<td>25.8</td>
<td>28.1</td>
<td>27.4</td>
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<td>Sulfur, % (calculated)</td>
<td>1.73</td>
<td>1.71</td>
<td>1.81</td>
<td>1.73</td>
<td>1.69</td>
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<tr>
<td>Solids, % (weight)</td>
<td>9.1</td>
<td>9.6</td>
<td>10.5</td>
<td>9.3</td>
<td>9.6</td>
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<tr>
<td>Solids Rate, (lb/hr)</td>
<td>457</td>
<td>465</td>
<td>400</td>
<td>459</td>
<td>346</td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>10.7</td>
<td>10.5</td>
<td>8.3</td>
<td>10.6</td>
<td>8.0</td>
</tr>
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<td><strong>UNDERFLOW</strong></td>
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</tr>
<tr>
<td>Solids Yield, %</td>
<td>19.1</td>
<td>27.7</td>
<td>33.6</td>
<td>43.3</td>
<td>52.8</td>
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<tr>
<td>Slurry Flow, (gpm)</td>
<td>0.4</td>
<td>0.6</td>
<td>0.7</td>
<td>1.0</td>
<td>1.6</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>73.0</td>
<td>65.6</td>
<td>56.6</td>
<td>55.0</td>
<td>29.1</td>
</tr>
<tr>
<td>Ash, %</td>
<td>15.38</td>
<td>14.92</td>
<td>17.09</td>
<td>13.97</td>
<td>16.73</td>
</tr>
<tr>
<td>Sulfur, %</td>
<td>2.81</td>
<td>2.80</td>
<td>2.63</td>
<td>2.44</td>
<td>2.18</td>
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<tr>
<td>Float, (1.45 Sp.Gr.)</td>
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<td>78.1</td>
<td>79.9</td>
<td>80.9</td>
<td>69.1</td>
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<tr>
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<td>2.5</td>
<td>6.1</td>
<td>6.8</td>
<td>8.3</td>
<td>16.3</td>
</tr>
<tr>
<td>↓325-m, %</td>
<td>9.0</td>
<td>10.5</td>
<td>10.5</td>
<td>15.3</td>
<td>24.5</td>
</tr>
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<td>↓325-m Ash, %</td>
<td>57.40</td>
<td>57.66</td>
<td>56.64</td>
<td>45.81</td>
<td>36.65</td>
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<td>↓325-m Sulfur, %</td>
<td>11.52</td>
<td>10.42</td>
<td>10.04</td>
<td>6.72</td>
<td>3.84</td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>10.3</td>
<td>9.9</td>
<td>7.6</td>
<td>9.6</td>
<td>6.4</td>
</tr>
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<td>7.4</td>
<td>5.6</td>
<td>5.4</td>
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<tr>
<td>Ash, %</td>
<td>30.13</td>
<td>31.49</td>
<td>30.19</td>
<td>38.88</td>
<td>39.35</td>
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<tr>
<td>Ash Rejection, %</td>
<td>89.2</td>
<td>84.6</td>
<td>77.8</td>
<td>78.8</td>
<td>67.8</td>
</tr>
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<td>1.29</td>
<td>1.40</td>
<td>1.18</td>
<td>1.15</td>
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<tr>
<td>Sink, % (1.45 Sp.Gr.)</td>
<td>73.1</td>
<td>64.5</td>
<td>62.4</td>
<td>83.8</td>
<td>90.9</td>
</tr>
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<td>Misplaced Material, %</td>
<td>21.8</td>
<td>25.6</td>
<td>25.0</td>
<td>9.2</td>
<td>4.3</td>
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<td>↓325-m, %</td>
<td>70.9</td>
<td>75.8</td>
<td>74.3</td>
<td>90.5</td>
<td>93.1</td>
</tr>
<tr>
<td>↓325-m Rejection, %</td>
<td>97.2</td>
<td>95.0</td>
<td>93.4</td>
<td>88.8</td>
<td>77.3</td>
</tr>
<tr>
<td>↓325-m Ash, %</td>
<td>41.29</td>
<td>40.18</td>
<td>38.07</td>
<td>38.90</td>
<td>40.59</td>
</tr>
<tr>
<td>↓325-m Sulfur, %</td>
<td>1.51</td>
<td>1.29</td>
<td>1.43</td>
<td>1.16</td>
<td>1.21</td>
</tr>
<tr>
<td><strong>Total Misplaced Material, %</strong></td>
<td>24.3</td>
<td>31.7</td>
<td>31.8</td>
<td>17.5</td>
<td>20.6</td>
</tr>
<tr>
<td>F-Y Efficiency, %</td>
<td>31.7</td>
<td>38.3</td>
<td>30.0</td>
<td>62.3</td>
<td>54.0</td>
</tr>
<tr>
<td>Size Index, %</td>
<td>42.4</td>
<td>58.5</td>
<td>63.6</td>
<td>87.3</td>
<td>92.6</td>
</tr>
</tbody>
</table>

*From Table V
TABLE VIII

Performance of 3-Inch Cyclone on Pittsburgh Seam Coal Filter Cake

Conditions: 7/8 Inch Vortex Finder Insert, 1/4 Inch Inlet Sleeve, 1/2 Inch Underflow Orifice, and Without Vortex Finder Sleeve

<table>
<thead>
<tr>
<th>Inlet Pressure (psig)</th>
<th>10</th>
<th>20</th>
<th>40*</th>
<th>60</th>
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<tr>
<td><strong>FEED</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>-325-m, % (calculated)</td>
<td>58.9</td>
<td>64.8</td>
<td>56.8</td>
<td>59.0</td>
</tr>
<tr>
<td>Ash, % (calculated)</td>
<td>28.8</td>
<td>29.4</td>
<td>27.4</td>
<td>27.9</td>
</tr>
<tr>
<td>Sulfur, % (calculated)</td>
<td>1.68</td>
<td>1.58</td>
<td>1.69</td>
<td>1.69</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>10.9</td>
<td>9.5</td>
<td>9.6</td>
<td>10.7</td>
</tr>
<tr>
<td>Solids Rate, (lb/hr)</td>
<td>279</td>
<td>332</td>
<td>346</td>
<td>633</td>
</tr>
<tr>
<td>Slurry Flow, (gpm)</td>
<td>8.5</td>
<td>7.9</td>
<td>7.0</td>
<td>8.2</td>
</tr>
</tbody>
</table>

| **UNDERFLOW**         |    |    |     |    |
| Solids Yield, %       | 56.9 | 48.1 | 52.8 | 48.1 |
| Slurry Flow, (gpm)    | 1.8  | 1.7  | 1.6  | 1.9  |
| Solids, % (weight)    | 20.7  | 22.4  | 29.1  | 42.5  |
| Ash, %                | 22.89 | 20.46 | 16.73 | 15.91 |
| Sulfur, %             | 1.98  | 1.99  | 2.18  | 2.33  |
| Float, % (1.45 Sp.Gr.)| 62.9  | 61.1  | 69.1  | 78.3  |
| Misplaced Material, % | 21.1  | 18.7  | 16.3  | 10.4  |
| -325-m, %             | 37.9  | 40.1  | 24.5  | 22.3  |
| -325-m Ash, %         | 40.50 | 40.54 | 36.65 | 41.68 |
| -325-m Sulfur, %      | 2.64  | 1.75  | 3.84  | 4.57  |

| **OVERFLOW**          |    |    |     |    |
| Slurry Flow, (gpm)    | 3.8  | 5.8  | 6.4  | 11.0 |
| Solids, % (weight)    | 6.7  | 6.2  | 5.4  | 6.3  |
| Ash, %                | 36.82 | 37.87 | 39.35 | 39.09 |
| Ash Rejection, %      | 54.9  | 66.7  | 67.8  | 72.4  |
| Sulfur, %             | 1.28  | 1.20  | 1.15  | 1.09  |
| Sink, % (1.45 Sp.Gr.) | 77.0  | 78.8  | 90.9  | 83.0  |
| Misplaced Material, % | 9.9  | 11.0  | 4.3  | 8.8  |
| -325-m, %             | 86.5  | 87.6  | 93.1  | 93.0  |
| -325-m Rejection, %   | 63.4  | 70.2  | 77.3  | 82.0  |
| -325-m Ash, %         | 40.74 | 42.00 | 40.59 | 41.87 |
| -325-m Sulfur, %      | 1.32  | 1.84  | 1.21  | 1.10  |

| Total Misplaced Material, % | 31.0 | 29.7 | 20.6 | 19.2 |
| F-Y Efficiency, %           | 21.7 | 36.4 | 54.0 | 57.0 |
| Size Index, %               | 85.9 | 81.7 | 92.6 | 91.3 |

* From Table VII
<table>
<thead>
<tr>
<th>Inlet Sleeve Diameter (in.)</th>
<th>1/4*</th>
<th>1/2</th>
<th>5/8</th>
</tr>
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<tbody>
<tr>
<td>FEED</td>
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<td></td>
</tr>
<tr>
<td>-325-m, % (calculated)</td>
<td>57.3</td>
<td>60.1</td>
<td>59.3</td>
</tr>
<tr>
<td>Ash, % (calculated)</td>
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<td>8.5</td>
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<td>Solids Rate, (lb/hr)</td>
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<td>1076</td>
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<tr>
<td>Slurry Flow, (gpm)</td>
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<td>27.1</td>
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<td>2.44</td>
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<td>79.5</td>
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<td>7.4</td>
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<td>-325-m, %</td>
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<td>87.1</td>
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</table>

*From Table V
CHAPTER VIII

DISCUSSION OF RESULTS OF FINE COAL CLEANING

The experimental cyclone used in this investigation was expected to function as a classifier because of the design of the conical section (12 degree included angle). The hydrocyclone designed to function as a cleaner has a much larger included angle of the conical bottom. In a classification operation, the overflow from the cyclone contains the fine material and underflow the coarse. In a gravity separation, the high gravity material is discharged in the underflow while the low gravity material is carried to the overflow.

In the sample of Pittsburgh seam coal filter cake used in this study, Table I, the large amount of extreme fines (52 per cent minus 325-mesh) were very high in ash (42 per cent). The action within the cyclone considered which is controlled to a significant extent by particle density was inadequate to overcome those forces resulting from particle size; consequently, most of the fine, high gravity particles reported to the overflow. Thus, although a sample classification was attained, a substantial grade improvement (cleaning) also resulted, but uniquely the clean coal in the larger sizes reported to the underflow. The average reduction of ash content from the feed to the underflow for all tests was about 46 per cent. The cyclone performance proved ineffectual in reducing the sulfur content in the clean coal. It was, in fact, an adverse effect, in that the clean coal sulfur content was higher than that of the head sample under all conditions studied. The average
increase in the clean coal sulfur was 0.66 per cent, while the average decrease in the refuse sulfur was 0.47 per cent.

Tables V and VIII show that the underflow content of minus 325-mesh material decreases with increasing pressure. However, the percentages of ash and sulfur which are very high in this size fraction of the underflow, increase with increasing pressure. Charmbury and Mitchell \(^{20}\) noted that the high pressure cyclone was particularly effective in concentrating sulfur in the underflow, undoubtedly due to the higher specific gravity of pyrite compared with slate and coal.

Other investigators \(^{7}\) reported that a coal of similar size consist (51% minus 325-mesh) was classified in a 3-inch cyclone at 40 psig feed pressure, flow rate of 10.5 gallons per minute, and 10 per cent solids concentration by weight. They recovered 71 per cent of the solids feed in the underflow that was 35 per cent solids by weight and 31 per cent minus 325-mesh material. The overflow was 100 per cent minus 325-mesh material at a 3.8 per cent concentration by weight. Chemical and sink-float analyses and dimensions of the cyclone components are not available. The results at 40 psig as tabulated in Table VIII are comparable to the findings of these investigators.

Effects to be considered in the following discussions are as follows:

1. Yield of clean coal as expressed by the total solids in the underflow.

2. Feed rate - underflow plus overflow solids.
3. Underflow solids concentration by weight.

4. Per cent 1.45 float material in the clean coal.

5. Ash rejection expressed as the percentage of feed ash rejected to the overflow refuse.

6. Size index = \[
\frac{\text{plus 325-mesh material in clean coal}}{\text{plus 325-mesh material in feed}} \times 100.
\]

**Effect of Inlet Pressure and Vortex Finder Sleeve**

These parameters were studied by varying the inlet pressure with and without the vortex finder sleeve included in the cyclone. See Tables IV and V. The effect of pressure and apex orifice diameter will be discussed later.

The yield of the clean coal product decreases as the inlet pressure increases up to 40 psig. As the pressure is further increased to 60 psig there is a small increase in yield. These variations in yield are more pronounced when the vortex finder sleeve is being used, decreasing 13 per cent with pressure increases up to 40 psig. Also, the per cent minus 325-mesh material in the underflow varies in the same manner with these pressure changes with the sleeve in place. This indicates, therefore, that as the pressure increases the sleeve enhances a density buildup within the cyclone and results in more fines being rejected to the overflow. Figure 18 is a graphic presentation of the yield as a function of pressure, with and without the sleeve.

The feed rate increases directly, about 300 pounds per hour, with pressure increases up to 60 psig. This represents about 5 pounds per hour increase in feed rate per pound pressure increase. The sleeve does not have a major effect on feed rate.
As pressure increases to 60 psig the underflow solids concentration by weight increases by 20 per cent without the sleeve. With the sleeve, the increase in per cent solids is from 29 per cent at 10 psig to about 80 per cent at 60 psig. The rate of change decreases from 40 to 60 psig being only 5 to 7 per cent; therefore, the solids-liquid ratio approaches its limit. The sleeve contributes to the higher concentration of solids with pressure increases.

With an increase in pressure to 40 psig there is a 9 per cent increase in the per cent 1.45 clean coal float, then as the pressure increases to 60 psig there is a 4 per cent decrease in the float coal using the sleeve. Without the sleeve there is a decrease in per cent float with a pressure increase to 20 psig, and as the pressure is increased to 60 psig the per cent float increases by about 8 per cent. These variations in content of 1.45 float coal are undoubtedly related to the variations in clean coal yield. These curves are shown in Figure 20.

Ash rejection increases with an increase in pressure to 40 psig and levels off or decreases slightly as the pressure is increased to 60 psig. The performance is consistent with the float material measured in the underflow. This occurs either with or without the vortex finder sleeve as seen in Figure 22. This would suggest an optimum pressure of about 40 psig for ash rejection.

The size indices decrease with pressure increases using the vortex finder sleeve. Without the sleeve, the size indices remain constant or increase slightly. The size indices are greater without the sleeve which indicates that more of the plus 325-mesh material is retained in the underflow and there is no density build-up within the cyclone.
Based on yield of solids in the underflow, its content of 1.45 float and the size index, the most desirable results were obtained at 60 psig without the vortex finder sleeve.

**Effect of Apex Orifice Diameter and Vortex Finder Sleeve**

By holding the pressure constant at 40 psig, these parameters were investigated by varying the apex orifice diameter, with and without the sleeve. See Tables VI and VII.

The yield of clean coal increases directly with the apex orifice diameter, either with or without the vortex finder sleeve. The overall increase is about 32 per cent when the apex orifice diameter is increased from 3/16 to 1/2-inch. All yields are somewhat lower (5 per cent) when the sleeve is included. This is probably due to a density build-up causing rejection of more fines to the overflow. Figure 19 shows the yield as a function of apex diameter.

The feed rate has a tendency to remain constant around 460 pounds per hour as the apex orifice diameter is increased to 3/8-inch. If the apex orifice diameter is increased to 1/2-inch, the capacity decreases as the apex orifice diameter approaches the diameter of the vortex finder.

The underflow solids concentration by weight increases as the apex orifice diameter is increased to 3/8-inch and the sleeve is in place. As the apex diameter is increased to 1/2-inch, the solids concentration decreases sharply from 72 to 36 per cent. Without the sleeve, the solids concentration decreases with an increase in the apex orifice diameter. Apparently the sleeve is effective until the apex orifice diameter approaches the diameter.
of the vortex finder at which point the capacity decreases. The highest solids concentration (73 per cent) occurred without the sleeve and with the 3/16-inch diameter apex orifice. With this combination of parameters for the sand, "plugging" occurred. However, with the coal this did not happen, perhaps because of the difference in specific gravities and/or the size of the particles.

With an increase in apex diameter and with the vortex finder sleeve, the content of 1.45 float coal tends to increase slightly or remain constant. Without the sleeve, the content of 1.45 float coal decreases about 18 per cent as the apex diameter is increased from 3/16 to 1/2-inch. Again these variations in content of 1.45 float coal are probably related to the variations in yield due to the density build-up. See Figure 21.

Ash rejection decreases, with or without the sleeve, about 20 per cent as the apex orifice diameter is increased from 3/16 to 1/2-inch. This again is probably due to the decrease in capacity related to the apex orifice diameter increase. This is shown in Figure 23.

The size indices increase with increases in apex orifice diameters, either with or without the sleeve. The indices' range is greater without the sleeve (42 to 93 per cent) indicating that less plus 325-mesh material is rejected to the overflow because of density build-up.

Based on pulp density in the underflow, its 1.45 float content and the ash rejection, more desirable results were obtained with the 3/16-inch diameter apex orifice without the vortex finder sleeve.
Effect of Inlet Pressure and Apex Orifice Diameter

To study this combination of parameters the 1/2-inch apex orifice was installed in the cyclone and the inlet pressure was varied. The vortex finder sleeve was not used. Compare these data, Table VIII, with that of Table V where the 3/8-inch diameter apex orifice was used.

The yields at the different pressures are higher (3 to 13 per cent) with the 1/2-inch apex orifice than with the 3/8-inch apex orifice; but, the decrease in yield is much greater (8 per cent) with pressure increases to 60 psig when using the 1/2-inch apex orifice. This decrease is probably due to (1) higher pressures which cause density build-up and result in the rejection of more fines to the overflow, and (2) capacity decrease when the apex orifice diameter approaches the diameter of the vortex finder. This is shown graphically in Figure 18.

Feed rates increase with pressure increases. The overall increase, as pressure increases to 60 psig, amounts to 300 pounds per hour when using the 3/8-inch apex orifice and 350 pounds per hour with the 1/2-inch apex orifice. This difference in feed rate may be explained as a small loss of energy within the cyclone due to a lifting effect when a smaller apex orifice is used.

The underflow solids concentration by weight increases about 20 per cent with pressure increases up to 60 psig. However, with the 1/2-inch apex orifice the range of per cent solids is from 21 to 42 per cent, whereas with the 3/8-inch apex the range is from 40 to 60 per cent. Undoubtedly this was caused by the decreases
in capacity brought on by the apex orifice diameter approaching that of the vortex finder. It is noted also that the underflow slurry flow through the larger apex is about double that of the smaller apex orifice. Although the feed rate decreases with the larger orifices the slurry flow increases.

The overall increase (15 per cent) in the per cent of 1.45 float coal with the 1/2-inch apex orifice is much greater than that with the 3/8-inch apex (3 per cent). These variations are probably related to the yield of clean coal and the minus 325-mesh material in the clean coal. That is, although the yield decreases, the per cent minus 325-mesh material also decreases thereby giving a cleaner product. See Figure 20.

Ash rejection increases with pressure increases using the 1/2-inch apex orifice from 55 to 72 per cent overall. With the 3/8-inch apex orifice the ash rejection increases only about 2 per cent with pressure increases up to 40 psig, then decreases about 4 per cent when the pressure is increased to 60 psig. The ash rejection at most pressures is higher with the 3/8-inch orifice by about 10 per cent. The optimum pressure for ash rejection is 40 psig. These curves are shown in Figure 22.

The size indices increase with pressure increases, but the variation covers a wider range with the larger apex orifice. With the larger orifice, where the density build-up is of a reduced magnitude, more plus 325-mesh material reports to the underflow resulting in an increase in the size index.

Based on per cent solids of the underflow and its content of 1.45 float material and ash rejection, more desirable results were
obtained at 60 psig with the 3/8-inch apex orifice diameter.

**Effect of Inlet Sleeve Diameter**

To study this variable three inlet sleeves (1/4, 1/2, and 5/8-inch diameter) were individually tested while the pressure and apex orifice diameter were held constant. The vortex finder sleeve was not used. See Table IX.

The yield of clean coal decreases about 3 per cent as the inlet sleeve diameter is increased from 1/4 to 1/2-inch; it then remains constant with an increase in inlet sleeve size to 5/8-inch diameter.

As the inlet sleeve diameter is increased the feed rate increases at an even more rapid rate as would be expected since the inlet area controls the feed rate. The total increase from the 1/4-inch inlet to the 5/8-inch inlet is about 760 pounds per hour.

As the inlet sleeve increases from 1/4 to 1/2 to 5/8-inch diameter the solids concentration in the underflow increases from about 51 to 56 per cent.

The 1.45 float coal content increases in increments of 2 with each increase in inlet sleeve diameter.

Ash rejection and size indices remain constant with increases in the inlet sleeve diameter.

Based on solids content of the underflow and its content of 1.45 float material and the resulting feed rate, more desirable results were obtained with the 5/8-inch diameter inlet sleeve. It is to be noted that there is very little variation in the above effects except the feed rate.
Figure 18. Yield of Clean Coal as a Function of Pressure.
Figure 19. Yield of Clean Coal as a Function of Lower Orifice Diameter.
Figure 20. Clean Coal Washability at 1.45 Sp. Gr. as a Function of Pressure.

Graph showing clean coal washability at 1.45 specific gravity as a function of pressure with and without vortex finder sleeve. The graph compares inlet sleeve sizes: 3/8" and 1/2". The y-axis represents pressure (psig), and the x-axis represents underflow product loss in weight percent.
Figure 21. Clean Coal Washability at 1.45 sp. gr. as a Function of Lower Orifice Diameter.
Figure 22. Ash Rejection as a Function of Pressure.
Figure 23. Ash Rejection as a Function of Lower Orifice Diameter.
Summation of Parameter Effects

The greatest effect is produced by varying the inlet sleeve diameter. This observation is based on the feed rate which increases from 339 to 1076 pounds per hour between the 1/2 and 5/8-inch diameter inlet sleeves. See Table IX.

The most sensitive effects are produced by varying the apex orifice diameters. It can be seen in Tables VI and VII that for a small change in apex diameter there are large changes in (1) yield, (2) solids concentration in the underflow, (3) misplaced material, (4) ash rejection, (5) size indices and (6) minus 325-mesh material as well as the ash and sulfur content in this size fraction. Other parameters did not produce as large changes.

The least important effects are produced by the inclusion of the vortex finder sleeve. Tables IV through VII indicate that yield and 1.45 float percentages in the underflow are higher, in most cases, without the sleeve. Other effects are as good or better without the sleeve. Among these effects are feed rate, efficiency, size index, and total misplaced material.

Operational Suggestions

These suggestions are for the operation of the 3-inch water cyclone when the coal being investigated has characteristics similar to those of the Pittsburgh seam filter cake.

1. To increase the amount of underflow material, increase the inlet pressure, increase the apex orifice diameter, and increase the inlet sleeve diameter.

2. To increase the amount of overflow material, increase the inlet pressure, decrease the apex orifice diameter, and
increase the inlet sleeve diameter.

3. To increase the solids feed rate, increase the inlet pressure and increase the inlet sleeve diameter.

4. To increase the ash content of the overflow product, increase the inlet pressure and increase the apex orifice diameter.

5. To increase the sulfur content of the overflow product, decrease the pressure and decrease the apex orifice diameter.

6. To increase the solids concentration by weight of the underflow product, increase the inlet pressure, decrease the apex orifice diameter, and increase the inlet sleeve diameter.

7. To increase the per cent float material in the underflow product, increase the inlet pressure, decrease the apex orifice diameter, and increase the inlet sleeve diameter.

8. To reject more of the fines to the overflow product, increase the inlet pressure. This causes a density build-up within the cyclone thereby aiding in the rejection of the fine sizes.
CHAPTER IX
CONCLUSIONS

The objective of this investigation of fine coal cleaning was to enhance the understanding of the cyclone performance when fed with a coal-water slurry considering both constructional features and operating variables of the device. With further understanding of the influence of each of these variables, or combinations of them, on the cleaning operation, the ability of the cyclone to clean efficiently to the extreme fine sizes and to minimize misplaced material can be improved. In order to achieve maximum performance, it appears that the cyclone will be most effective in fine coal cleaning as a unit operation in a multi-stage process which will probably include other operations such as the sieve bend and flotation. It appears no single system will yield optimum results with all fine coal feed types; however, the product nature can be widely and effectively controlled.

Conclusions

1. This investigation proved to be a classification rather than a cleaning operation. However, because of the characteristics of the test coal used, there was a gravity separation as well.

2. The ash content of this coal was reduced from 26 to 14 per cent with 45 per cent yield. This is an ash reduction of 46 per cent and an ash rejection of 75 per cent.

3. The sulfur content of this coal sample cannot be reduced in one cyclone operation.

4. The vortex finder sleeve was of value in this investigation. Most important was the increase in underflow
solids concentration and, as a result, the increase in rejection of minus 325-mesh material and rejection of ash to the overflow.

5. The combination of cyclone components that gave the highest yields of clean coal was 1/2-inch apex orifice, 1/4-inch inlet sleeve, and low inlet pressures (10 to 40 psig).

6. The combination of cyclone components that gave the highest concentration of solids was 3/8-inch apex orifice, 5/8-inch inlet sleeve, and high pressures (40 to 60 psig).

7. The content of 1.45 float material in the clean coal was higher with the 3/8-inch apex orifice, higher pressures (40 to 60 psig), and the 5/8-inch inlet sleeve.

8. More of the total feed ash was rejected at a pressure of 40 psig and the smaller (3/16 to 1/4-inch) apex orifices. The inlet sleeve diameter was not a factor.

9. Better size indices were found when using the 1/2-inch apex orifice and higher pressures (40 to 60 psig).

10. Total misplaced material was lowest at higher pressures (40 to 60 psig) with the 3/8-inch apex orifice.

11. The optimum parameter values to express the most desirable results for this particular coal appear to be the following:
   a. Inlet sleeve - 5/8-inch diameter. This is based primarily on the solids feed rate.
   b. Inlet pressure - 40 psig. This choice rather than 60 psig is based primarily on ash rejection which tends to decrease at 60 psig with the 3/8-inch apex orifice.
   c. Apex orifice - 3/8-inch diameter. This is based on
feed rate, solids concentration of the underflow, per cent 1.45
float, and ash rejection.

12. For particular applications over the range of investigation, the data made available permit the estimation of effects for any combination of parameters studied.

Suggestions for Further Research

1. It is suggested that other coals with different characteristics be tested to determine their optimum conditions.

2. Varying the length of the vortex finder inserts and the length and diameter of the vortex finder sleeve might be beneficial.

3. An investigation into the use of a second or third cyclone operation for recleaning is suggested.

4. It might be helpful to increase the solids-liquid ratio of the feed. If this is done, the use of the smaller apex orifices should be discontinued to avoid the "plugging" condition.

5. The data made available here provide an excellent base for the development of theoretical equations for predicting cyclone performance.
BIBLIOGRAPHY


BIBLIOGRAPHY (continued)


APPENDIX A

Detailed Data of Water Flow Rates
Through a Three Inch Cyclone
TABLE A1

Dependent Variables: 1/4 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 68 psig.

Gallons Per Minute

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TABLE A2

Dependent Variables: 3/8 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 61 psig

Gallons Per Minute

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TABLE A3

Dependent Variables: 1/2 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 53 psig

Gallons Per Minute

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TABLE A4

Dependent Variables: 5/8 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 52 psig

Gallons Per Minute

<table>
<thead>
<tr>
<th>Orifice Dia. (in.)</th>
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<th>30 psig</th>
<th>40 psig</th>
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<td>Inlet</td>
<td>Over flow</td>
</tr>
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**TABLE A5**

**Dependent Variables:** 1/4 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert
Without Vortex Finder Sleeve
Maximum Pressure ~ 68 psig

**Gallons Per Minute**

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<td>3.96 5.94 9.90</td>
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TABLE A6

Dependent Variables: 3/8 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert
Without Vortex Finder Sleeve
Maximum Pressure - 61 psig

Gallons Per Minute

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<th>Under flow</th>
<th>20 psig Over flow</th>
<th>Under flow</th>
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<th>Under flow</th>
<th>50 psig Over flow</th>
<th>Under flow</th>
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**TABLE A8**

**Dependent Variables:** 5/8 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert  
Without Vortex Finder Sleeve  
Maximum Pressure - 54 psig  

Gallons Per Minute

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<td>Over flow</td>
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**TABLE A9**

Dependent Variables: 1/4 Inch Inlet Sleeve and 5/8 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 67 psig

Gallons Per Minute

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TABLE A10

Dependent Variables: 3/8 Inch Inlet Sleeve and 5/8 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 64 psig

Gallons Per Minute

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TABLE A11

Dependent Variables: 1/2 Inch Inlet and 5/8 Inch Vortex Finder
With Vortex Finder Sleeve
Maximum Pressure - 52 psig

Gallons Per Minute

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<td>Over</td>
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*48 psig
TABLE A12

Dependent Variables: 5/8 Inch Inlet Sleeve and 5/8 Inch Vortex Finder
With Vortex Finder Sleeve
Maximum Pressure - 43 psig

Gallons Per Minute

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TABLE A13

Dependent Variables: 1/4 Inch Inlet Sleeve and 5/8 Inch Vortex Finder Insert
Without Vortex Finder Sleeve
Maximum Pressure - 67 psig

Gallons Per Minute

<table>
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<th>Underflow Dia. (in.)</th>
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<th>40 psig</th>
<th>60 psig</th>
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TABLE A14

Dependent Variables: 3/8 Inch Inlet Sleeve and 5/8 Inch Vortex Finder Insert Without Vortex Finder Sleeve

Maximum Pressure = 64 psig

Gallons Per Minute
### TABLE A15

**Dependent Variables:** 1/2 Inch Inlet Sleeve and 5/8 Inch Vortex Finder Insert

**Without Vortex Finder Sleeve**

**Maximum Pressure - 52 psig**

**Gallons Per Minute**

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<th>Flow</th>
<th>20 psig Over</th>
<th>Flow</th>
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* 48 psig
TABLE A16

Dependent Variables: 5/8 Inch Inlet Sleeve and 5/8 Inch Vortex Finder Insert Without Vortex Finder Sleeve Maximum Pressure - 43 psig

Gallons Per Minute

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**TABLE A17**

Dependent Variables: 1/4 Inch Inlet Sleeve and 3/4 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 67 psig

Gallons Per Minute

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TABLE A18

Dependent Variables: 3/8 Inch Inlet Sleeve and 3/4 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 55 psig

Gallons Per Minute

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85
TABLE A19

Dependent Variables: 1/2 Inch Inlet Sleeve and 3/4 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 52 psig

Gallons Per Minute

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TABLE A20

Dependent Variables: 5/8 Inch Inlet Sleeve and 3/4 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 42 psig

Gallons Per Minute

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**TABLE A21**

**Dependent Variables:** 1/4 Inch Inlet Sleeve and 3/4 Inch Vortex Finder Insert  
Without Vortex Finder Sleeve  
Maximum Pressure - 66 psig

_Gallons Per Minute_

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### TABLE A23

**Dependent Variables:** 1/2 Inch Inlet Sleeve and 3/4 Inch Vortex Finder Insert
Without Vortex Finder Sleeve
Maximum Pressure - 52 psig

**Gallons Per Minute**

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TABLE A24

Dependent Variables: 5/8 Inch Inlet Sleeve and 3/4 Inch Vortex Finder Insert
Without Vortex Finder Sleeve
Maximum Pressure - 42 psig

Gallons Per Minute

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<td>2.88</td>
<td>15.80</td>
<td>16.76</td>
</tr>
</tbody>
</table>

* 38 psig
TABLE A25

Dependent Variables: 1/4 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 66 psig

Gallons Per Minute

<table>
<thead>
<tr>
<th>Underflow Dia. (in.)</th>
<th>10 psig</th>
<th></th>
<th>20 psig</th>
<th></th>
<th>40 psig</th>
<th></th>
<th>60 psig</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Over</td>
<td>Under</td>
<td>Inlet</td>
<td>Over</td>
<td>Under</td>
<td>Inlet</td>
<td>Over</td>
</tr>
<tr>
<td>3/16</td>
<td>4.30</td>
<td>0.15</td>
<td>4.45</td>
<td>6.03</td>
<td>0.06</td>
<td>6.09</td>
<td>9.00</td>
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<td>1/4</td>
<td>4.14</td>
<td>0.27</td>
<td>4.41</td>
<td>5.94</td>
<td>0.20</td>
<td>6.14</td>
<td>8.64</td>
</tr>
<tr>
<td>5/16</td>
<td>4.05</td>
<td>0.39</td>
<td>4.44</td>
<td>5.76</td>
<td>0.26</td>
<td>6.02</td>
<td>8.64</td>
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<tr>
<td>3/8</td>
<td>3.69</td>
<td>0.66</td>
<td>4.35</td>
<td>5.49</td>
<td>0.45</td>
<td>5.94</td>
<td>8.28</td>
</tr>
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<td>1/2</td>
<td>2.43</td>
<td>1.92</td>
<td>4.35</td>
<td>4.68</td>
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<td>5.94</td>
<td>7.75</td>
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<td>Orifice Dia. (in.)</td>
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<td>20 psig</td>
<td>40 psig</td>
<td>50 psig</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------</td>
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<tr>
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<td>Under flow</td>
<td>Over flow</td>
<td>Under flow</td>
<td>Over flow</td>
<td>Under flow</td>
<td>Over flow</td>
</tr>
<tr>
<td>3/16</td>
<td>9.00</td>
<td>0.00</td>
<td>9.00</td>
<td>12.93</td>
<td>0.00</td>
<td>12.93</td>
<td>17.28</td>
</tr>
<tr>
<td>1/4</td>
<td>9.18</td>
<td>0.05</td>
<td>9.23</td>
<td>13.15</td>
<td>0.08</td>
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<td>17.64</td>
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<tr>
<td>5/16</td>
<td>9.00</td>
<td>0.17</td>
<td>9.17</td>
<td>12.43</td>
<td>0.15</td>
<td>12.58</td>
<td>17.28</td>
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<tr>
<td>3/8</td>
<td>9.00</td>
<td>0.29</td>
<td>9.29</td>
<td>12.60</td>
<td>0.30</td>
<td>12.90</td>
<td>16.20</td>
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<tr>
<td>1/2</td>
<td>7.56</td>
<td>0.96</td>
<td>8.52</td>
<td>11.52</td>
<td>0.99</td>
<td>12.51</td>
<td>15.84</td>
</tr>
</tbody>
</table>

TABLE A26

Dependent Variables: 3/8 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert With Vortex Finder Sleeve
Maximum Pressure - 56 psig

Gallons Per Minute
**TABLE A27**

Dependent Variables: 1/2 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert  
With Vortex Finder Sleeve  
Maximum Pressure - 44 psig  

Gallons Per Minute

<table>
<thead>
<tr>
<th>Dia. (in.)</th>
<th>Underflow 10 psig</th>
<th>Underflow 20 psig</th>
<th>Underflow 40 psig</th>
<th>Underflow 44 psig</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Over flow</td>
<td>Under flow</td>
<td>Over flow</td>
<td>Under flow</td>
</tr>
<tr>
<td>3/16</td>
<td>12.60 0.00</td>
<td>12.60 0.00</td>
<td>16.57 0.00</td>
<td>16.57 0.00</td>
</tr>
<tr>
<td>1/4</td>
<td>12.43 0.12</td>
<td>12.55 0.14</td>
<td>16.91 0.14</td>
<td>17.05 0.24</td>
</tr>
<tr>
<td>5/16</td>
<td>12.24 0.08</td>
<td>12.32 0.12</td>
<td>17.28 0.12</td>
<td>17.40 0.18</td>
</tr>
<tr>
<td>3/8</td>
<td>13.32 0.29</td>
<td>13.61 0.36</td>
<td>16.74 0.36</td>
<td>17.10 0.53</td>
</tr>
<tr>
<td>1/2</td>
<td>12.24 1.13</td>
<td>13.37 1.47</td>
<td>16.91 1.47</td>
<td>18.38 1.95</td>
</tr>
</tbody>
</table>
TABLE A28

Dependent Variables: 5/8 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert
With Vortex Finder Sleeve
Maximum Pressure - 35 psig

Gallons Per Minute

<table>
<thead>
<tr>
<th>Underflow</th>
<th>10 psig</th>
<th>20 psig</th>
<th>30 psig</th>
<th>33 psig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dia. (in.)</td>
<td>Over flow</td>
<td>Under flow</td>
<td>Over flow</td>
<td>Under flow</td>
</tr>
<tr>
<td>3/16</td>
<td>18.00</td>
<td>0.00</td>
<td>18.00</td>
<td>24.31</td>
</tr>
<tr>
<td>1/4</td>
<td>18.20</td>
<td>0.14</td>
<td>18.34</td>
<td>26.40</td>
</tr>
<tr>
<td>5/16</td>
<td>18.31</td>
<td>0.27</td>
<td>18.58</td>
<td>24.60</td>
</tr>
<tr>
<td>3/8</td>
<td>18.20</td>
<td>0.44</td>
<td>18.64</td>
<td>24.45</td>
</tr>
<tr>
<td>1/2</td>
<td>16.20</td>
<td>1.89</td>
<td>18.09</td>
<td>21.55</td>
</tr>
</tbody>
</table>
### TABLE A29

**Dependent Variables:** 1/4 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert Without Vortex Finder Sleeve

**Maximum Pressure - 65 psig**

**Gallons Per Minute**

<table>
<thead>
<tr>
<th>Underflow</th>
<th>10 psig</th>
<th>20 psig</th>
<th>40 psig</th>
<th>60 psig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dia. (in.) flow</td>
<td>Over</td>
<td>Under</td>
<td>Inlet</td>
<td>Over</td>
</tr>
<tr>
<td>3/16</td>
<td>4.51</td>
<td>0.12</td>
<td>4.63</td>
<td>6.84</td>
</tr>
<tr>
<td>1/4</td>
<td>4.31</td>
<td>0.20</td>
<td>4.51</td>
<td>6.31</td>
</tr>
<tr>
<td>5/16</td>
<td>4.32</td>
<td>0.27</td>
<td>4.59</td>
<td>6.12</td>
</tr>
<tr>
<td>3/8</td>
<td>3.69</td>
<td>0.54</td>
<td>4.23</td>
<td>5.73</td>
</tr>
<tr>
<td>1/2</td>
<td>2.61</td>
<td>1.71</td>
<td>4.32</td>
<td>4.86</td>
</tr>
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</table>
## TABLE A30

**Dependent Variables:** 3/8 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert
Without Vortex Finder Sleeve
Maximum Pressure - 56 psig

Gallons Per Minute

<table>
<thead>
<tr>
<th>Underflow Orifice Dia. (in.)</th>
<th>Over flow</th>
<th>Under flow</th>
<th>Inlet</th>
<th>10 psig</th>
<th>Over flow</th>
<th>Under flow</th>
<th>Inlet</th>
<th>20 psig</th>
<th>Over flow</th>
<th>Under flow</th>
<th>Inlet</th>
<th>40 psig</th>
<th>Over flow</th>
<th>Under flow</th>
<th>Inlet</th>
<th>50 psig</th>
<th>Over flow</th>
<th>Under flow</th>
<th>Inlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/16</td>
<td>8.61</td>
<td>0.00</td>
<td>8.61</td>
<td>10.99</td>
<td>0.00</td>
<td>10.99</td>
<td>16.20</td>
<td>0.00</td>
<td>16.20</td>
<td>17.64</td>
<td>0.00</td>
<td>17.64</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>8.61</td>
<td>0.00</td>
<td>8.61</td>
<td>12.24</td>
<td>0.03</td>
<td>12.27</td>
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<td>0.01</td>
<td>19.09</td>
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</tr>
<tr>
<td>5/16</td>
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<td>0.09</td>
<td>9.28</td>
<td>11.88</td>
<td>0.12</td>
<td>12.00</td>
<td>16.92</td>
<td>0.12</td>
<td>17.04</td>
<td>18.69</td>
<td>0.14</td>
<td>18.83</td>
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<tr>
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<td>0.27</td>
<td>8.91</td>
<td>12.07</td>
<td>0.30</td>
<td>12.37</td>
<td>16.56</td>
<td>0.41</td>
<td>16.97</td>
<td>17.83</td>
<td>0.45</td>
<td>18.28</td>
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<td></td>
</tr>
<tr>
<td>1/2</td>
<td>8.28</td>
<td>0.84</td>
<td>9.12</td>
<td>11.52</td>
<td>0.84</td>
<td>12.36</td>
<td>16.20</td>
<td>1.08</td>
<td>17.28</td>
<td>17.64</td>
<td>1.23</td>
<td>18.87</td>
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<td></td>
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</tr>
</tbody>
</table>
TABLE A31

Dependent Variables: 1/2 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert
Without Vortex Finder Sleeve
Maximum Pressure - 44 psig

Gallons Per Minute

<table>
<thead>
<tr>
<th>Underflow</th>
<th>10 psig</th>
<th>20 psig</th>
<th>40 psig</th>
<th>44 psig</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/16</td>
<td>14.40</td>
<td>18.00</td>
<td>22.80</td>
<td>25.20</td>
</tr>
<tr>
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<td>14.71</td>
<td>19.15</td>
<td>25.51</td>
<td>27.00</td>
</tr>
<tr>
<td>5/16</td>
<td>13.20</td>
<td>18.60</td>
<td>23.11</td>
<td>26.40</td>
</tr>
<tr>
<td>3/8</td>
<td>13.80</td>
<td>19.15</td>
<td>25.80</td>
<td>27.91</td>
</tr>
<tr>
<td>1/2</td>
<td>12.43</td>
<td>16.56</td>
<td>23.11</td>
<td>24.31</td>
</tr>
<tr>
<td>Orifice Dia. (in.)</td>
<td>33 psig</td>
<td>30 psig</td>
<td>20 psig</td>
<td>10 psig</td>
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<td>--------</td>
</tr>
<tr>
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<td>Under</td>
<td>Over</td>
<td>Over</td>
</tr>
<tr>
<td>3/16</td>
<td>27.91</td>
<td>32.11</td>
<td>27.91</td>
<td>32.11</td>
</tr>
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<td>27.91</td>
<td>32.11</td>
<td>27.91</td>
<td>32.11</td>
</tr>
<tr>
<td>5/16</td>
<td>27.91</td>
<td>32.11</td>
<td>27.91</td>
<td>32.11</td>
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<td>3/8</td>
<td>27.91</td>
<td>32.11</td>
<td>27.91</td>
<td>32.11</td>
</tr>
<tr>
<td>1/2</td>
<td>27.91</td>
<td>32.11</td>
<td>27.91</td>
<td>32.11</td>
</tr>
</tbody>
</table>

**Dependent Variables:**
- 5/8 Inch Inlet Sleeve and 7/8 Inch Vortex Finder Insert
- Without Vortex Finder Sleeve

**Maximum Pressure:** -35 psig

**Gallons Per Minute**
APPENDIX B

Detailed Data of River Sand Suspension Flow Through a Three Inch Cyclone
### TABLE B1

Dependent Variables: 1/4 inch Inlet Sleeve, 1/2 Inch Vortex Finder Insert, and 3/8 inch Underflow Orifice
Without Vortex Finder Sleeve
5-Per cent Solids by Weight

<table>
<thead>
<tr>
<th></th>
<th>10 psig</th>
<th>20 psig</th>
<th>40 psig</th>
<th>60 psig</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FEED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Rate (lb/hr)</td>
<td>94</td>
<td>121</td>
<td>182</td>
<td>364</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>4.3</td>
<td>4.0</td>
<td>3.9</td>
<td>6.4</td>
</tr>
<tr>
<td>-100-m, % (calculated)</td>
<td>19.3</td>
<td>54.5</td>
<td>21.7</td>
<td>14.7</td>
</tr>
<tr>
<td><strong>UNDERFLOW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield, %</td>
<td>98.2</td>
<td>96.8</td>
<td>96.9</td>
<td>97.9</td>
</tr>
<tr>
<td>Slurry Flow (gpm)</td>
<td>1.7</td>
<td>1.9</td>
<td>2.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>10.9</td>
<td>12.0</td>
<td>12.3</td>
<td>19.8</td>
</tr>
<tr>
<td>-100-m, %</td>
<td>17.6</td>
<td>19.2</td>
<td>19.2</td>
<td>12.8</td>
</tr>
<tr>
<td><strong>OVERFLOW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield, %</td>
<td>1.8</td>
<td>3.2</td>
<td>3.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Slurry Flow (gpm)</td>
<td>2.7</td>
<td>4.1</td>
<td>6.5</td>
<td>7.8</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>-100-m, %</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
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</table>

### TABLE B2

Dependent Variables: 1/4 Inch Inlet Sleeve, 1/2 Inch Vortex Finder Insert, and 3/8 Inch Underflow Orifice
With Vortex Finder Sleeve
5- Per cent Solids by Weight

<table>
<thead>
<tr>
<th></th>
<th>10 psig</th>
<th>20 psig</th>
<th>40 psig</th>
<th>60 psig</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FEED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Rate (lb/hr)</td>
<td>97</td>
<td>132</td>
<td>176</td>
<td>300</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>4.2</td>
<td>4.2</td>
<td>4.3</td>
<td>5.8</td>
</tr>
<tr>
<td>-100-m, % (calculated)</td>
<td>22.7</td>
<td>22.8</td>
<td>23.6</td>
<td>18.0</td>
</tr>
<tr>
<td><strong>UNDERFLOW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield, %</td>
<td>96.1</td>
<td>95.8</td>
<td>95.9</td>
<td>96.8</td>
</tr>
<tr>
<td>Slurry Flow (gpm)</td>
<td>1.8</td>
<td>2.1</td>
<td>2.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>9.8</td>
<td>11.7</td>
<td>13.4</td>
<td>17.9</td>
</tr>
<tr>
<td>-100-m, %</td>
<td>19.6</td>
<td>19.4</td>
<td>20.4</td>
<td>15.2</td>
</tr>
<tr>
<td><strong>OVERFLOW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield, %</td>
<td>3.9</td>
<td>4.2</td>
<td>4.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Slurry Flow (gpm)</td>
<td>2.7</td>
<td>4.1</td>
<td>5.8</td>
<td>7.2</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>-100-m, %</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
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</tbody>
</table>
**TABLE B3**

Dependent Variables: 1/4 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert

<table>
<thead>
<tr>
<th>Underflow Orifice Diameter (in.)</th>
<th>3/16</th>
<th>1/4</th>
<th>5/16</th>
<th>3/8*</th>
<th>1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FEED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solids Rate (lb/hr)</td>
<td>180</td>
<td>178</td>
<td>182</td>
<td>182</td>
<td>196</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>4.1</td>
<td>4.1</td>
<td>4.1</td>
<td>3.9</td>
<td>4.4</td>
</tr>
<tr>
<td>-100-m, % (calculated)</td>
<td>19.8</td>
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<td>93.3</td>
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<td>95.6</td>
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*From Table B1

**TABLE B4**

Dependent Variables: 1/4 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert

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<th>Underflow Orifice Diameter (in.)</th>
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<th>5/16</th>
<th>3/8*</th>
<th>1/2</th>
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<td>Solids Rate (lb/hr)</td>
<td>193</td>
<td>177</td>
<td>195</td>
<td>176</td>
<td>191</td>
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<td>Solids, % (weight)</td>
<td>4.3</td>
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<td>4.6</td>
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<td>5.2</td>
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<td>-100-m, % (calculated)</td>
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<td>25.2</td>
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<td>93.9</td>
<td>95.9</td>
<td>95.8</td>
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<td>1.7</td>
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<td>5.3</td>
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<tr>
<td>Yield, %</td>
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<td>6.1</td>
<td>4.1</td>
<td>4.2</td>
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<td>Slurry Flow (gpm)</td>
<td>8.3</td>
<td>7.9</td>
<td>6.8</td>
<td>5.8</td>
<td>2.0</td>
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<tr>
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<td>0.3</td>
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*From Table B2
### TABLE B5

Dependent Variables: 1/4 Inch Inlet Sleeve, 1/2 Inch Vortex Finder Insert, and 3/8 Inch Underflow Orifice. Without Vortex Finder Sleeve

10-Percent Solids by Weight

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<tr>
<th>FEED</th>
<th>10 psig</th>
<th>20 psig</th>
<th>40 psig</th>
<th>60 psig</th>
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</thead>
<tbody>
<tr>
<td>Solids Rate (lb/hr)</td>
<td>244</td>
<td>315</td>
<td>424</td>
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<td>10.6</td>
<td>9.7</td>
<td>9.6</td>
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<td>-100-m, % (calculated)</td>
<td>24.1</td>
<td>25.3</td>
<td>25.6</td>
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<td>UNDERFLOW</td>
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<td>Yield, %</td>
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<td>94.0</td>
<td>93.6</td>
<td>95.3</td>
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<tr>
<td>Slurry Flow (gpm)</td>
<td>1.7</td>
<td>2.1</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Solids, % (weight)</td>
<td>24.3</td>
<td>25.3</td>
<td>27.8</td>
<td>36.5</td>
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<tr>
<td>Yield, %</td>
<td>5.8</td>
<td>6.0</td>
<td>6.4</td>
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<td>Slurry Flow (gpm)</td>
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<td>4.1</td>
<td>5.9</td>
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<td>-100-m, %</td>
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### TABLE B6

Dependent Variables: 1/4 Inch Inlet Sleeve, 1/2 Inch Vortex Finder Insert, and 3/8 Inch Underflow Orifice. With Vortex Finder Sleeve

10-Percent Solids by Weight

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<tr>
<th>FEED</th>
<th>10 psig</th>
<th>20 psig</th>
<th>40 psig</th>
<th>60 psig</th>
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<tbody>
<tr>
<td>Solids Rate (lb/hr)</td>
<td>242</td>
<td>309</td>
<td>442</td>
<td>735</td>
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<td>10.8</td>
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<td>-100-m, % (calculated)</td>
<td>19.6</td>
<td>20.4</td>
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<tr>
<td>Yield, %</td>
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<td>96.0</td>
<td>95.9</td>
<td>96.9</td>
</tr>
<tr>
<td>Slurry Flow (gpm)</td>
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### TABLE B7

**Dependent Variables:** 1/4 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert

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<td>Solids Rate (lb/hr)</td>
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<td>Solids, % (weight)</td>
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<td>-100-m, % (calculated)</td>
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*From Table B5

### TABLE B8

**Dependent Variables:** 1/4 Inch Inlet Sleeve and 1/2 Inch Vortex Finder Insert

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<td>Solids, % (weight)</td>
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*From Table B6