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VENTILATION CHARACTERISTICS
OF SOME ILLINOIS MINES

BY

CLOYDE M. SMITH
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THE ENGINEERING EXPERIMENT STATION,
UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS
VENTILATION CHARACTERISTICS OF SOME ILLINOIS MINES

BY

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ENGINEERING EXPERIMENT STATION
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## CONTENTS

### I. INTRODUCTION
- 1. Object and Scope of Investigation
- 2. Acknowledgment

### II. METHODS AND EQUIPMENT USED

#### A. Anemometry
- 3. Use of Vane Anemometers
- 4. Calibration of Anemometers
- 5. Underground Calibration
- 6. Cross-sectional Measurements

#### B. Pressure Measurements
- 7. Pressure Differentials
- 8. Pressure-Measuring Equipment

### III. RESULTS OF SURVEY

#### A. Major Characteristics
- 9. Fans
- 10. Fan Deliveries
- 11. Stack Effect
- 12. Specific Mine Resistances
- 13. Zonal Specific Resistance
- 14. Power Consumption

#### B. Mine A
- 15. Fan Characteristics
- 16. Primary Currents
- 17. Proposed Alterations in High-Velocity Zone
- 18. Maintenance of Air Courses
- 19. Sealed Territories
## C. Other Mines

<table>
<thead>
<tr>
<th>Mine</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine B</td>
<td>34</td>
</tr>
<tr>
<td>Mine C</td>
<td>36</td>
</tr>
<tr>
<td>Mine D</td>
<td>38</td>
</tr>
<tr>
<td>Mine E</td>
<td>41</td>
</tr>
<tr>
<td>Mine F</td>
<td>43</td>
</tr>
<tr>
<td>Mine G</td>
<td>45</td>
</tr>
<tr>
<td>Mine H</td>
<td>47</td>
</tr>
<tr>
<td>Mine I</td>
<td>48</td>
</tr>
<tr>
<td>Mine J</td>
<td>49</td>
</tr>
<tr>
<td>Mine K</td>
<td>51</td>
</tr>
<tr>
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<td>52</td>
</tr>
<tr>
<td>Mine M</td>
<td>53</td>
</tr>
<tr>
<td>Mine N</td>
<td>54</td>
</tr>
</tbody>
</table>

## IV. Summary and Recommendations

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure</td>
<td>56</td>
</tr>
<tr>
<td>Quantities and Resistances</td>
<td>57</td>
</tr>
<tr>
<td>Potential Savings</td>
<td>58</td>
</tr>
<tr>
<td>Recommendations</td>
<td>59</td>
</tr>
<tr>
<td>Recirculation</td>
<td>59</td>
</tr>
<tr>
<td>Ventilation Standards</td>
<td>60</td>
</tr>
<tr>
<td>Ventilation Surveys</td>
<td>60</td>
</tr>
</tbody>
</table>

## Appendix

<table>
<thead>
<tr>
<th>Section</th>
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</tr>
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<tbody>
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<td>Recent Bibliography</td>
<td>61</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

NO. | PAGE |
--- | --- |
1. Traversing with Anemometer | 8 |
2. Cross-sectional Subdivision | 9 |
3. Laboratory Calibration of Anemometers | 10 |
4. Underground Calibration of Anemometers | 13 |
5. Underground Calibration Sections | 15 |
6. Ventilation Diagrams, Mine A | 24 |
7. Characteristics of Fan at Mine A | 27 |
8. Proposed Alterations, Mine A | 29 |
9. Primary Air Distribution, Mine B | 35 |
10. Primary Air Distribution, Mine C | 37 |
11. Primary Air Distribution, Mine D | 38 |
12. Primary Air Distribution, Mine E | 42 |
13. Primary Air Distribution, Mine F | 44 |
14. Primary Air Distribution, Mine G | 45 |
15. Primary Air Distribution, Mine H | 46 |
16. Primary Air Distribution, Mine I | 48 |
17. Primary Air Distribution, Mine J | 50 |
18. Primary Air Distribution, Mine K | 51 |
19. Primary Air Distribution, Mine L | 53 |
20. Primary Air Distribution, Mine M | 54 |

LIST OF TABLES

NO. | PAGE |
--- | --- |
1. Derivation of Rate of Flow | 18 |
2. Major Ventilation Characteristics of Mines | 22-23 |
3. Test of Fan at Mine A | 26 |
4. Estimated Power Cost of Air Transmission in High-Velocity Zone, Mine A | 28 |
5. Estimated Power Cost of Air Transmission in Intermediate-Velocity Zone, Mine A | 31 |
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VENTILATION CHARACTERISTICS OF
SOME ILLINOIS MINES

I. INTRODUCTION

1. Object and Scope of Investigation.—In view of the great importance of mine ventilation to both the workman and the operator the ventilation characteristics of typical Illinois mines should be of general interest. During the past year or two a survey of this kind has been made, covering several coal mines and a fluorspar mine.

In one case several days were devoted to an extensive survey of a very large mine. At other mines only a day or two could be spent in measuring the mine water gauge, the output of the fan, and the distribution of air among the primary splits, with attendant pressure losses. Geographically, the mines visited are well distributed throughout the state. They are room-and-pillar mines, with the exceptions of one long-wall mine and the fluorspar mine. Three coal seams are represented, and the capacities of the mines range from a few hundred to several thousand tons daily. All are shipping mines.

2. Acknowledgment.—This work was done as a part of the regular work of the Engineering Experiment Station of the University of Illinois, of which DEAN M. L. ENGER is Director, and of the Department of Mining and Metallurgical Engineering, of which PROF. A. C. CALLEN is the Head. The field work was facilitated by the full cooperation of the staff at each mine. This help is gratefully acknowledged.

II. METHODS AND EQUIPMENT USED

A. Anemometry

3. Use of Vane Anemometers.—In prior investigations of this series* a pitot tube with suitable pressure gauge was used as an anemometer for measuring rates of air flow underground, but in this survey, to expedite the work, a vane anemometer was used for this purpose. In making this choice it was realized that it might entail some sacrifice of accuracy, but it was felt that the greater speed and economy of the work would more than offset any loss in accuracy which might result.

In the customary underground use of the vane anemometer the operator stands in such a way that his body constricts the cross-section of the entry in which the instrument is held, with the result

*Univ. of Ill. Eng. Exp. Sta. Buls. 158, 170, 184, 190 and 249.
that the air speed is increased over its normal value. Furthermore, the instrument is usually held in a central position within the section, where the air speed is normally greater than the average speed, so that there is an accumulation of positive errors in the anemometer registration.

To overcome these errors in this survey the anemometer was suspended from the end of an easily-handled stick,* as shown in Fig. 1, and passed from point to point over the cross-sectional area of an entry, as indicated by Fig. 2. As a rule, the top and bottom points of each tier of traverse points were within 0.4 foot of the roof or floor, respectively, and the intermediate points were equally spaced from 0.8 to 1.5 ft. apart, according to the height of the tier, and the arbitrarily chosen number of traverse points therein. The vertical tiers of points were spaced from 1.0 to 1.5 ft. apart, according to the width of the section, and the number of tiers. Tier positions were marked on the roof or floor with chalk, and these chalk marks were used as guides in traversing, the position of each traverse point being gauged visually.

*A slotted billiard cue was used. Any similar device of comparable length which would keep the instrument hanging vertically in the measuring section would be suitable.
The anemometer was held for five seconds at each point, the total time required for a complete traverse ranging from less than a minute in unusually small cross sections to four or five minutes for very large sections.

Of the five seconds allotted to each anemometer position possibly as much as one second was spent, on the average, in moving the anemometer from one position to the next one, a process in which the instrument was, in many cases, subjected to a marked increase or decrease in speed. In such cases the inertia or momentum of the rotating vanes would be expected to decrease or increase the normal registration of the instrument, respectively. While the resulting errors might be compensating during the course of a complete traverse, an attempt was made to minimize them by retracing each initial traverse path in the opposite direction. Thus, traverses were always run in pairs, as indicated in Fig. 2.

As the majority of the reversed traverses gave results within two per cent of the corresponding initial traverse, and it was unusual for the discrepancy to exceed three per cent, it appears that any errors
resulting from the movement of the anemometer, and from the inertia or momentum of the rotating parts, were not critical.

To further reduce errors in anemometer registration, two or more calibrated instruments were ordinarily used successively in each traverse section.

An operator and a helper were used in this work. The operator read and manipulated the anemometers, while the helper recorded data and timed the traversing. A stop watch was used for timing, although an ordinary watch with second-hand could be used satisfactorily. Suspending the instruments from the end of the holder kept the operator about two feet downstream from the traverse section at all times, while the helper stayed in a recess within hearing distance.
The clutch of the anemometer was operated manually, which brought the operator's hand to the instrument for a second or two at the beginning and end of each traverse. As this time is small in comparison with the duration of most traverses, the resulting interference with the air flow is thought to be negligible.

4. Calibration of Anemometers.—The anemometers used in this investigation were all of the revolving vane type, like that shown in Fig. 1. One is a jewelled-bearing 3-in. imported instrument which was used at mean velocities less than 600 feet per min. while the other two are 4-in. instruments of domestic manufacture, which were used at higher velocities. One of the latter instruments has plain bearings, the other has jewelled bearings, and a zero-setting attachment which obviates the necessity of recording an initial reading for each traverse.*

The dials of an anemometer are graduated to indicate the linear feet of air flow through the instrument. The net dial registration for a period in which the clutch is engaged, divided by the duration of that period in minutes, is presumed to give the velocity of the air, in feet per minute. However, this indicated velocity is ordinarily subject to correction, which depends on the rate of air flow, the condition of the instrument, and the manner in which it is used. This makes it necessary to calibrate each instrument to provide for the proper conversion of its indications into true air speeds.

Two methods are in common use for the calibration of vane anemometers. In the whirling-arm method the instrument is mounted on the end of a long arm which can be rotated at various speeds. This has the effect of moving the instrument through still air at known linear speeds. By noting the indicated speed of the anemometer a calibration correction† can be established to equate air speed to anemometer speed.

The second method, which was used at the beginning of this work, is to place the anemometer in a stream of air which is flowing at a known rate past the instrument, and as nearly uniformly as possible throughout its cross section.

The apparatus used for this purpose is an adaptation of that previously described‡ as being used in investigations of mine ventilation by means of models.

*In the writer's opinion this slight advantage does not warrant the necessary additional complication of the instrument.
†A correction is commonly applied to the correction to allow for the motion of the air which results from the operation of the equipment.
‡Univ. of Ill. Eng. Exp. Sta. Buls. 265 and 279.
A nearly uniform velocity field, in which the anemometers were suspended, was obtained by inserting a 6-in. nozzle near the outlet of a 12-in. round duct, in simulation of the Moss nozzle.* To gauge the rate of flow past the anemometers, velocity-pressure readings at the center of an upstream section were correlated with a pitot-tube traverse of the nozzle outlet for each of several fan speeds. The anemometer was suspended at the outlet, and the fan set to run at constant speed. The net registrations of the anemometer for at least two 30-second periods were obtained, along with several readings of the center velocity-pressure from which the rate of air flow was calculated. These operations were repeated for several fan speeds, over a considerable range. From these data a comparison could be made of the anemometer registration and the calculated rate of flow for each fan speed, and from each set of data a calibration curve was drawn, as in Fig. 3.

The initial, and a recent, calibration for each of the three anemometers used in this investigation are represented in this figure.† The 3-in. anemometer (No. 1) showed very little change throughout the period of more than a year, whereas both of the 4-in. anemometers tightened appreciably. The result was that, when placed in a velocity field of 1000 feet per minute at the outlet of the nozzle, the plain-bearing instrument (No. 2) ran about four per cent slower in 1937 than it had a year earlier, and the jewelled-bearing instrument (No. 3) ran about eight per cent more slowly. This illustrates the necessity for making routine checks on the registration of a vane anemometer.

Changes in temperature and air density affect anemometer performance, but Ower$ states that changes in density of only a few per cent, such as were encountered in this work produce differences of less than one per cent in anemometer registration and may safely be neglected, so no attempt was made to determine their effect in this survey.

As underground work was done at temperatures ranging from about 50 deg. F. to nearly 100 deg. F. it was felt that characteristics of the anemometers might have been appreciably affected by this wide range in working temperature, so an attempt was made in the laboratory to evaluate the temperature effect.

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† Logarithmic ruling is used for compactness, and because it gives the same relative accuracy throughout the velocity range.
The three anemometers were calibrated one evening with the laboratory at 78 deg. F., then the calibrations were repeated the next morning at 52 deg. F. Each instrument ran more freely at the lower temperature, the maximum response (about three per cent) being shown by the jewelled-bearing 4-in. anemometer (No. 3). It thus appears that vane anemometers may be used within 30 deg. F. of calibration temperature without incurring errors due to temperature changes of more than a few per cent. No attempt was made to correct anemometer registrations for temperature in this work.
5. Underground Calibration.—During the course of the work it was found that the mean net* anemometer velocity for a given underground traverse was appreciably less than that obtained from a pitot-tube traverse† of the section. Furthermore, it was found that a velocity measured with a pitot tube held at a given traverse point was substantially higher than the net velocity obtained with an anemometer held in the same point, at velocities greater than about 500 ft. per min. This means that the vanes of an anemometer, held in an air stream of given velocity in a mine, rotate more slowly than if the instrument were held in a stream discharging at the same velocity from the 6-in. nozzle.

It appears that the constricted nozzle stream is forced to flow through the anemometer with minimum evasion or retardation, whereas, in the mine, where the anemometer is small in comparison with the cross section, the stream, to an appreciable extent, flows around rather than through the anemometer, due to the instrument's resistance. This surmise is supported by the fact that the discrepancy is much less pronounced with the 3-in. than with the 4-in. anemometers. The 3-in. instrument is not only smaller but it also has much lighter rotating parts so that its resistance‡ to the flow of air is appreciably less than that of the 4-in. instruments. The result is that a given current in a mine will turn the vanes of the 3-in. anemometer much faster than those of the 4-in. anemometers. This is illustrated in the calibration curves of Fig. 4, to be discussed later. It follows that nozzle calibrations of vane anemometers are not applicable to underground usage in the higher velocity range, although they may serve as a routine check on the condition of an instrument.

It thus became necessary to resort to underground calibrations, and such calibrations were made at Mine A where it was possible to regulate currents from high to low velocity in a number of sections differing in size, shape, and conditions of approach and departure. These sections are shown in Fig. 5. They lie on the two main ventilating currents of the mine, each of which was provided with a temporary variable regulator, as indicated in the figure.

Pitot-tube traverses were made at one section (E76) in the east current, and at three sections in the west current.

The normal velocity distribution in each of the four pitot-tube traverse sections is shown in Fig. 5. The flattest velocity field was

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*By net anemometer velocity is meant the mean speed indicated directly by the anemometer traverse, subject to the appropriate calibration correction developed in the laboratory (Fig. 3).
†Univ. of Ill. Eng. Exp. Sta. Bul. 168, Chap. IV.
‡Preliminary laboratory tests indicate its resistance to be about 40 per cent of the resistance of the 4-in. anemometers.
VENTILATION CHARACTERISTICS OF SOME ILLINOIS MINES

Fig. 5. UNDERGROUND CALIBRATION SECTIONS

Sections Looking Upstream. Velocities on levels are in Feet per Minute.
found in section W44, which is just upstream from a 35-deg. bend. Although this section is only about two entry diameters downstream from section W31, the velocity distribution in section W44 is much better than that in section W31. The latter section is only four or five entry diameters below the T split, which accounts in part for its irregular velocity distribution.

The worst velocity distribution was found at section W58, which is less than two entry diameters below the 35-deg. bend, a condition which gives rise to a slight reversal of flow along the north rib of the section. The section was traversed to show what can be done under such adverse flow conditions.

With the mine idle, and normal air coursing, the results of pitot-tube traverses at these sections were as follows:

<table>
<thead>
<tr>
<th>Date</th>
<th>Section</th>
<th>Area sq. ft.</th>
<th>Mean Velocity ft. per min.</th>
<th>Quantity cu. ft. per min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 28, 1937</td>
<td>W31</td>
<td>53.6</td>
<td>1 620</td>
<td>86 800</td>
</tr>
<tr>
<td>June 1, 1937</td>
<td>W31</td>
<td>53.6</td>
<td>1 600</td>
<td>85 700</td>
</tr>
<tr>
<td>June 1, 1937</td>
<td>W44</td>
<td>47.9</td>
<td>1 760</td>
<td>84 200</td>
</tr>
<tr>
<td>June 3, 1937</td>
<td>W44</td>
<td>47.9</td>
<td>1 725</td>
<td>82 600</td>
</tr>
<tr>
<td>June 1, 1937</td>
<td>W58</td>
<td>64.4</td>
<td>1 355</td>
<td>87 400</td>
</tr>
</tbody>
</table>

The five quantities derived for the main west air course, which include traverses run on three different days, lie within a six per cent range, while the three traverses run on June 1 lie in a four per cent range, the upper limit of which is set by the traverse at section W58. This indicates that some dependence can be put on traverses run in sections as unfavorably situated as section W58, in which there is a slight reversal of air flow along the middle portion of one rib.

Pitot-tube traverses were run in the usual manner* beginning and ending at a central point to establish a center constant for each section, which was used, as previously,† to convert center velocities into mean velocities at rates of flow not traversed with the pitot tube. From the areas of the traverse sections it was possible to calculate the mean velocity in each, from a traverse or center velocity determination of any section in the same current.

Each pitot-tube traverse was preceded and followed by anemometer traverses at all of the sections in that current. Plotting the indicated sectional anemometer velocities against mean velocities as determined with the pitot tube over a suitable range in velocity gives a calibration curve for the anemometer. Such a curve, developed in a variety of underground sections, should approximate the calibration

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†Univ. of Ill. Eng. Exp. Sta. Bul. 249, p. 12 and Fig. 7.
of the anemometer in its place and manner of usage* with sufficient closeness to serve as a general calibration for underground traversing.

The alignment of the points in Fig. 4 for each instrument warrants the conclusion that, for the five traverse sections represented, differences in size, shape, and conditions of approach and departure did not affect anemometer performance beyond the limits of experimental error. This indicates that the methods of underground traversing and calibration used in this investigation are of general applicability, and that they afford a rapid and reasonably accurate means of measuring underground rates of flow at intermediate and higher velocities.

In addition to the underground-calibration curves, Fig. 4 shows the corresponding laboratory-calibration curve from Fig. 3 for each instrument. The discrepancy† between the two is not great for the 3-in. anemometer (No. 1), but both 4-in. instruments ran nearly 15 per cent faster in the laboratory than in the mine, in corresponding velocity fields. This is in accord with the previous discussion.

The underground-calibration curves of Fig. 4 formed the basis of quantity determinations throughout this survey.

6. Cross-sectional Measurements.—Having reduced the anemometer indication to mean air speed by means of the appropriate calibration curve, the area of the traversed cross section must be used to derive the volumetric rate of flow, or "quantity," which is expressed in cubic feet of air per minute.

The methods previously devised of plotting the perimeter of the section to scale, underground, requires rather bulky equipment, so it was replaced by a method which could be applied with a short steel tape and folding rule, each graduated in feet and decimals thereof. The tape was provided with a detachable weight‡ at its zero end.

In measuring a section, the uniformly-spaced tier marks were used as measuring points, and the weighted steel tape was held against the roof at each mark so that the bottom of the weight just cleared the floor. The tape reading thus gave the height of that tier of traverse points. At the two end tiers in each section offsets were taken from the tape to the rib with the rule at each foot above the floor, and at such additional points as might be indicated by irregularities in the rib. Additional overall measurements of the width were made for checking and to facilitate field estimation of areas. Field observations were

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*Such calibrations are held by some to be necessary for the dependable and satisfactory use of vane anemometers. A. P. Kratz, Research Professor of Mech. Eng., Univ. of Ill., in personal communication.

†Preliminary indications are that nozzle calibrations of the general kind represented by these laboratory-calibration curves could be applied directly to underground anemometer traverse data, if the nozzle diameter were three or more times the diameter of the anemometer.


‖An oil-gauger's innage tape and bob would be suited to this purpose.
TABLE 1
DERIVATION OF RATE OF FLOW
Mine L, Section N, North of Air Shaft*

<table>
<thead>
<tr>
<th>Number of traverse points</th>
<th>36</th>
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<td>Traversing time, sec.</td>
<td>180</td>
</tr>
</tbody>
</table>

<table>
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<th>3</th>
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</thead>
<tbody>
<tr>
<td>Starting point</td>
<td>ul.</td>
<td>lr.</td>
</tr>
</tbody>
</table>

| Initial anemometer reading, ft. | 12 204 | 14 274 | 86 791 | 88 757 |
| Final anemometer reading, ft.   | 14 274 | 16 328 | 88 757 | 90 784 |
| Net anemometer reading, ft.     | 2 070  | 2 034  | 1 966  | 2 027  |

| Mean anemometer reading, ft.   | 2 062 | 1 996 |
| True air speed, ft. per min. ¶ | 687  | 680  |

| Mean air speed, ft. per min.    | 687  |
| Cross-sectional area, sq. ft. § | 44.4 |
| Rate of flow, cu. ft. per min., 44.4 x 687 = | 30 500 |

*See Fig. 2.
†ul. = upper left; lr. = lower right.
‡One-third of mean net anemometer reading; traversing time, three minutes.
¶From Fig. 4.
§By planimetering Fig. 2.

entered on free-hand cross-sectional diagrams, which were later plotted to scale in the office and the area determined by planimeter. Table 1 shows the reduction of traverse data for the section of Fig. 2.

B. Pressure Measurements

7. Pressure Differentials.—The essential ventilation characteristics of a mine, or of a section thereof, are known when the coursing and quantity (cu. ft. per min.) of air being circulated therein, with the accompanying loss in total pressure experienced by each current, are known. The pressure loss for a current is determined by establishing the difference between the static pressure in a cross section at the beginning of the current and the static pressure in a cross section at its end, and properly combining with this difference the difference between the velocity pressures at the two sections. Ordinarily, the velocity pressures are not measured, but are calculated from the mean velocity of the air through each section.

The difference in static pressure must be brought to a common elevation, either by calculation or by instrumental means.

Two methods are in general use for measuring the difference in static pressure between any two cross sections of a current. One of
these is to gauge the absolute, or barometric pressure at each section, by means of an aneroid barometer, or suitable modification thereof. The difference between these two readings or settings, properly corrected for changes in atmospheric pressure with time, and brought to a common elevation, is the desired static pressure differential between the sections in question. In the other method the difference in static pressure between the two sections is measured directly on a differential gauge of suitable range and sensitivity. The pressure from each section is communicated directly to the gauge through a continuous line of rubber tubing which maintains an air tight connection between one side of the differential gauge and a static-pressure tube within the section.

The latter method was used in this survey. Static pressure differentials can be read directly on the gauge because the pressures from the two sections are brought to the gauge simultaneously, and at a common elevation, that of the gauge.*

8. Pressure-Measuring Equipment.—Two different pressure gauges were used successively in this work. Each combines a large pressure range, up to six inches of water, with high sensitivity at pressure differences of less than one inch of water. One of these was a homemade U tube patterned after similar instruments in use elsewhere. The other was an inclined-vertical draft gauge, in which the first inch of pressure is distributed over a 12-inch inclined scale, the remaining five inches of the pressure scale being vertical.

The inclination of the U tube could be varied from the vertical position, in which it had maximum range but minimum sensitivity, to a low inclination from the horizontal in which the pressure was magnified twelve times. In this position the range of the instrument was limited to about one-half inch of water, but its sensitivity was increased greatly over that in the vertical position. Although no index reading was necessary with the U tube this advantage over the draft gauge was offset by having to read both arms of the U tube for each pressure determination. As the U tube was found to be more fragile and less easily transported underground than the draft gauge it was soon discarded for the latter. In use, either was mounted on a light portable tripod.

For communicating pressures to the gauge, the heavy air hose previously used† was replaced with seamless, pure gum rubber tubing.

*The usual corrections for index and temperature of gauge, and density of air were applied. An aneroid barometer was used to measure the barometric pressure required to calculate the air density. See Univ. of Ill. Eng. Exp. Sta. Bul. 158, p. 32 and 50.
having a 3-mm. bore and a 2-mm. wall. Eight 50-ft. lengths of this tubing were carried,* making it possible to measure the pressure differential between sections nearly 400 feet apart. By repeating this in successive stages, setting the gauge first near the upstream end of the line of tubing and then near the downstream end of the next line, the pressure drop in a long current could be measured fairly rapidly, setting the gauge up about each 700 feet along the entry.

The pressure lines were checked against leakage and obstruction for each change in connections.

III. RESULTS OF SURVEY

A. Major Characteristics

9. Fans.—The major ventilation characteristics of the mines visited in this survey are shown in Table 2. The mines range from shallow slope mines to a shaft mine 730 feet deep.

While most of these mines are ventilated by centrifugal fans, axial-flow fans are also represented. All but two of the electrical motors used for driving the fans are of the three-phase, 60-cycle, induction type. Their current potential is about equally divided between 440 and 2200 volts, and the motors range in size from 5 to 150 h.p. One 500 h.p. synchronous and one d-c. motor are represented.

10. Fan Deliveries.—At nearly every mine visited the mine examiners had credited the fan with handling a considerably larger volume of air than was indicated by this survey. This condition is probably brought about by the cumulative effect of the plus errors previously mentioned (p. 8) which are involved in the ordinary procedure in measuring underground air currents. Since the procedure developed for this survey is intended to eliminate such errors, the quantities reported here are thought to represent the best data available on the delivery of the fans in question.

For an entire mine, the fan deliveries range from 17,000 to 155,000 cu. ft. per min. In each case this quantity was reduced by leakage in or about the air shaft, so that the total underground circulation ranged from 15,000 to 152,000 cu. ft. per min.†

11. Stack Effect.—At each mine the intake and return air currents were maintained at different densities within their respective shafts or

*Weight, 16 lbs.; each piece could be quickly rolled or unrolled and all were conveniently carried in a burlap bag.
†These include disc, and propeller fans, and a short-bladed fan of recent design, which is a modification of the propeller fan.
‡Either the total fan delivery or the underground circulation was estimated from a measurement of the other item at most mines. For details, see Table 2, lines 21 and 22.
slopes. This gave rise to a stack effect,* which usually opposed the fan, because most of the tests were made in the summer when the intake current was lighter than the return current. In tests made in cooler weather, the stack effect aided the fan (see Table 2, line 24).

As the water gauge against which the fan works combines the stack effect with normal mine resistance, it is necessary to allow for the stack effect in calculating the normal resistance of a mine; i.e. the resistance the mine would have if air of standard density (0.0750 lb. per cu. ft.) were being circulated throughout. The stack effect is affected by the depth of the shaft as well as by the difference between the densities of the intake and return currents, and is independent of the rate of flow.† For the tests represented in Table 2 the stack effect ranged from 0.03 to 0.27 inch of water.

12. Specific Mine Resistances.—Corrected for stack effect, and converted to a basis of standard density (0.0750 lb. per cu. ft.) the pressure required to ventilate a mine, or section thereof served by a fan, varied between the limits of 0.24 inch and 4.35 inches of water (Table 2, line 26). The former item represents the fluorspar mine, and the latter Mine B, the largest mine visited.

To gain an idea of the comparative effectiveness of different mines and portions thereof as transmitters of air, the specific resistance‡ was calculated for each mine and certain portions thereof. This is the estimated water gauge which would be required for transmission of 100,000 cu. ft. per min. of air of standard density, through the mine, or resistance zone. In making this estimation it is assumed that resistance varies as the square of the rate of flow, so the specific resistance mounts rapidly where the quantity would have to be greatly increased over the actual quantity, to reach 100,000 cu. ft. per min. Not only does the specific resistance represent the total-pressure loss to be expected in transmitting 100,000 cu. ft. per min. through the mine, or portion thereof, but it affords a ready means of comparing the water gauge and power required to transmit air at any given rate of flow through two or more mines or other resistance zones. For example, if Mine Y has a specific resistance of one and Mine Z a specific resistance of two, a total pressure of one inch of water will be required

*Sometimes called natural ventilating pressure, although this term is strictly applicable only in the absence of ventilating devices, such as fans or furnaces. The stack effect reported here could not exist without the assistance of a fan, and hence is not wholly a natural effect.
†It may be approximated with sufficient accuracy by multiplying the difference between the mean of the air density in the intake shaft and of that in the return shaft by the depth of the shafts, in feet, and dividing this pressure, in lb. per sq. ft., by 5.2 to convert it into inches of water.
‡The "resistance factor" of McElroy and Richardson; see "Resistance of Metal-Mine Airways" by G. E. McElroy and A. S. Richardson, U. S. Bureau of Mines Bul. 261, p. 139, 1927. Since their factor $R$ relates to a specific rate of flow (100,000 cu. ft. per min.) the term "specific resistance" seems preferable to "resistance factor."
| I. Mine | A | B | C | D | E* | F | G | H | I | J | K | L | M | N* |
|--------|---|---|---|---|----|---|---|---|---|---|---|---|---|---|----|
| 1. Coal seam No. | 6 | 6 | 6 | 6 | 2 | 0 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 2. Approximate depth of shaft, ft. | 210 | 500 | 460 | 730 | 350 | 110 | 50* | 50* | 260 | 260 | 610 | 250 | 320 | 370 | 210 | 650 |
| 3. Daily production | 5+ | 5+ | 3 | 1 | 1 | 1 | 3 | 3 | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 1- |

II. Fan Location.

<table>
<thead>
<tr>
<th>II. Fan</th>
<th>Main</th>
<th>Main</th>
<th>Main</th>
<th>Main</th>
<th>North</th>
<th>West</th>
<th>North</th>
<th>South</th>
<th>Main</th>
<th>Main</th>
<th>Main</th>
<th>Main</th>
<th>Main</th>
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</tr>
</thead>
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<tr>
<td>7. Width, ft.</td>
<td>3</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td>8. Diameter, ft.</td>
<td>12</td>
<td>12</td>
<td>8</td>
<td>6</td>
<td>5.2</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>11. Mounting</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
<td>under.</td>
</tr>
<tr>
<td>12. Housing</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
<td>fixed</td>
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III. Driving units.

<table>
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<tr>
<th>III. Driving units</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>elec.</th>
<th>steam</th>
<th>steam</th>
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<tbody>
<tr>
<td>17. Voltage</td>
<td>440</td>
<td>440</td>
<td>440</td>
<td>440</td>
<td>440</td>
<td>440</td>
<td>440</td>
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<td>440</td>
<td>440</td>
<td>440</td>
<td>440</td>
<td></td>
</tr>
<tr>
<td>18. Speed</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
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</tr>
<tr>
<td>19. Full-load speed, r.p.m.</td>
<td>315</td>
<td>600</td>
<td>575</td>
<td>850</td>
<td>1 160</td>
<td>1 160</td>
<td>1 160</td>
<td>1 160</td>
<td>1 160</td>
<td>1 160</td>
<td>1 160</td>
<td>1 160</td>
<td>1 160</td>
<td></td>
</tr>
<tr>
<td>20. Connection</td>
<td>chain</td>
<td>V</td>
<td>flat</td>
<td>V</td>
<td>flat</td>
<td>V</td>
<td>flat</td>
<td>V</td>
<td>flat</td>
<td>flat</td>
<td>flat</td>
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IV. Ventilation characteristics.

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<tr>
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<th></th>
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</thead>
<tbody>
<tr>
<td>21. Fan delivery</td>
<td>115 200</td>
<td>21 000</td>
<td>60 800</td>
<td>21 000</td>
<td>17 000</td>
<td>21 000</td>
<td>45 500</td>
<td>36 700</td>
<td>51 700</td>
<td>42 300</td>
<td>71 400</td>
<td>38 050</td>
<td>71 400</td>
<td></td>
</tr>
<tr>
<td>22. Underground circulation</td>
<td>115 000</td>
<td>147 000</td>
<td>55 050</td>
<td>15 000</td>
<td>21 000</td>
<td>45 500</td>
<td>36 700</td>
<td>51 700</td>
<td>42 300</td>
<td>71 400</td>
<td>38 050</td>
<td>71 400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23. Total pressure, in. of water</td>
<td>2.29</td>
<td>3.63</td>
<td>3.54</td>
<td>2.68</td>
<td>1.61</td>
<td>0.78</td>
<td>0.25</td>
<td>3.15</td>
<td>3.36</td>
<td>2.26</td>
<td>3.37</td>
<td>1.06</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>24. Stack effect,</td>
<td>-1.05</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td>-0.95</td>
<td></td>
</tr>
<tr>
<td>25. Net ventilating pressure,</td>
<td>2.16</td>
<td>3.76</td>
<td>3.76</td>
<td>2.25</td>
<td>1.46</td>
<td>0.73</td>
<td>0.91</td>
<td>3.48</td>
<td>3.48</td>
<td>2.35</td>
<td>2.06</td>
<td>0.74</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>26. Net</td>
<td>2.24</td>
<td>4.35</td>
<td>3.61</td>
<td>2.54</td>
<td>2.14</td>
<td>1.65</td>
<td>0.77</td>
<td>2.24</td>
<td>1.37</td>
<td>3.13</td>
<td>3.26</td>
<td>2.27</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>27. Month of test</td>
<td>July</td>
<td>May</td>
<td>May</td>
<td>March</td>
<td>March</td>
<td>July</td>
<td>July</td>
<td>July</td>
<td>July</td>
<td>April</td>
<td>April</td>
<td>July</td>
<td>Aug.</td>
<td>July</td>
</tr>
<tr>
<td>28. Air h.p.,</td>
<td>55.8</td>
<td>103.5</td>
<td>51.5</td>
<td>22.8</td>
<td>15.7</td>
<td>6.0</td>
<td>4.4</td>
<td>1.2</td>
<td>7.4</td>
<td>10.2</td>
<td>26.6</td>
<td>37.0</td>
<td>15.1</td>
<td>27.6</td>
</tr>
<tr>
<td>V. Specific resistances at standard air conditions</td>
<td>0.03</td>
<td>1.9</td>
<td>4.6</td>
<td>4.1</td>
<td>6.9</td>
<td>9.4</td>
<td>26</td>
<td>57</td>
<td>77</td>
<td>51*</td>
<td>6.6*</td>
<td>11*</td>
<td>6.4</td>
<td>13*</td>
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<tr>
<td>-----------------------------------------------</td>
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<td>----</td>
<td>-----</td>
<td>-----</td>
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<td>-----</td>
</tr>
<tr>
<td>29. Mine or section</td>
<td>0.87</td>
<td>1.04</td>
<td>0.7</td>
<td>0.58</td>
<td>1.9</td>
<td>4.0</td>
<td>3.1</td>
<td>0.42</td>
<td>0.5</td>
<td>1.4</td>
<td>0.5</td>
<td>0.8</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>30. Underground circulation</td>
<td>0.05</td>
<td>0.046</td>
<td>0.13</td>
<td>0.056</td>
<td>0.69</td>
<td>6.12</td>
<td>0.03</td>
<td>0.33</td>
<td>1.2</td>
<td>0.10</td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total air courses per 100 ft.</td>
<td>0.092</td>
<td>0.0484</td>
<td>0.142</td>
<td>0.05</td>
<td>2.2</td>
<td>1.4</td>
<td>0.72</td>
<td>0.2</td>
<td>0.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Longwall mine, other coal mines are room and pillar mines. †Fluor spar mine, others are coal mines. ‡Applies to section of mine served by this fan. §Quantity measured underground only; difference between fan delivery and underground delivery is estimated leakage in and around air shaft. ¶Difference in elevation between top and bottom of return slope. ©Calculated to depth of 250-ft. level only. †‡Allowing 1000 cu. ft. per min. for shaft leakage. #Estimated, or by estimation. ‡Direct-current motor. §Reported by mine management. °Synchronous motor. ¶With hoisting shaft partly blocked for repairs. Based on an estimated quantity for this section of mine.

Section pressure differential measured at bottom of air shaft as 0.10 inches of water. Combined shaft resistance estimated as 0.20 in. and velocity pressure at fan outlet 0.11 in. Total mine water gauge 4.22 in. water. *§Short-bladed modification of propeller fan. +Average of 3. †A five-way split, see Fig. 9. ‡At top of downstream compartment of air shaft. §See text p. 51. ¶Specific resistance of entire mine, 2.4. °Estimated from the combined resistances of the 90-deg. bend at the top of the air shaft, the intake compartment of the air shaft, and the 90-deg. bend at the bottom of that compartment.

**Notes**

Line 3. Figures give approximate daily production in thousands of tons; 1 = less than 1000, 5+ = more than 5000.
Line 4. sur. = surface; und. = underground.
Line 5. centr. = centrifugal; n.f. = axial flow.
Line 10. for. = forward; back. = backward; str. = straight.
Line 11. under. = underfract; over. = overfract.
Line 12. rev. = reversible.
Line 13. blow. = blowing; exh. = exhausting.
Line 16. elec. = electricity; all electric motors were of the 3-phase, 60-cycle, induction-motor type, unless otherwise noted.
Lines 17-19. Manufacturer’s rating.
Line 20. V = V belt; flat = flat belt.
Line 21. Measured near fan unless otherwise noted.
Line 22. Measured near bottom of air shaft.
Line 23. Fun static pressure as measured, plus velocity pressure in section at or near fan outlet.
Line 24. Stack effect regarded as positive when it acted with the fan. For derivation see p. 21.

Line 25. The pressure which would be required if air in both shafts were at mean density, which is taken as the mean of the densities of the intake and return currents. Line 23 = line 25 + line 24.
Line 26. Adjusts the resistance of the mine itself to the value it would have if the air were of standard density (0.0750 lb. per cu. ft.) throughout the system.
Line 27. Illustrates influence of season on stack effect (line 24).
Line 28. Energy in the air delivered by the fan at the time of test.

Line 28 = 5.2 × line 23 × line 21
33 000

Line 29. Estimates the resistance of each mine to the flow of 100 000 cu. ft. per min. (see p. 24).
Line 29 = line 28 × (100 000)². Section here refers to those portions of a mine ventilated by a given fan.
Lines 34, 35, and 36. Units referred to are single unless otherwise designated.
to transmit 100,000 cu. ft. per min. through Mine Y, and a pressure of two inches of water to transmit this quantity through Mine Z, the energy output being 15.75 and 31.5 air h.p. respectively. If the quantity be cut in half (to 50,000 cu. ft. per min.) at each mine the water gauge and the air h.p. at Mine Y would be reduced to 0.25 inch of water and 1.97 air h.p., and at Mine Z to 0.50 inch of water and 3.94 air h.p. Thus, since the specific resistance of Mine Z is twice that of Mine Y the water gauge and air h.p. for Mine Z will be twice the corresponding items for Mine Y when transmitting any given quantity through both mines. This illustrates the usefulness of the specific resistance for comparing water gauges and power consumptions to be expected in ventilating different mines, or portions thereof.

The values of the specific resistance for an entire mine shown in Table 2 (line 29) lie between 0.93 (Mine A) and 57 (Mine F). This means that, for like overall efficiencies, about sixty times as much pressure and power would be required to force a given quantity of air through Mine F as to force the same quantity through Mine A. Nearly one-third of the fans represented in Table 2 were working against a specific resistance greater than ten, an excessively high value.

13. Zonal Specific Resistance.—As a means of comparing like portions of different mines as air transmitters, the specific resistances of major zones within each mine were computed and tabulated in lines 30-35 of Table 2.

Line 30 gives the specific resistance of the underground circulation, an item which is determined by the quantity flowing into the mine from the bottom of the intake shaft, and the water gauge between the intake and return currents, at the shaft bottom. It thus excludes the leakage currents in and around the shafts, and the resistance of the shafts and their approaches and departures.

For example, Diagram E of Fig. 6 shows that 155,000 cu. ft. per min. enter Mine A against a water gauge of 2.24 inches, giving this mine a specific resistance of 0.93 (line 29, Table 2). However, only 152,000 cu. ft. per min. actually enter the mine, and the total pressure differential between the air-shaft drift and the nearby return airway is 2.00 inches of water. This gives a specific resistance of 0.87 for the underground circulation at Mine A, which is a little less than the specific resistance for the entire mine.

Line 30, Table 2, shows the specific resistance of underground circulation to range from 0.87 at Mine A to 62 at Mine F. It was not determined at every mine, but in several cases it was found to be higher than the specific resistance of the entire mine. This is possible
Diagram D - 37th & 38th Entries South

Returns

0 /00 200 300 400 500 600 700

Rates of flow in cu. ft per min.
Total pressures in inches of water
Pressures based on atmospheric datum and adjusted to standard air density, 0.075 lb per cu. ft.

Fig. 6. Ventilation Diagrams, Mine A
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where shaft leakage is so large that a fan could deliver 100,000 cu. ft. per min. to the entire mine, short circuiting much of it in shaft leakage, at a lower pressure than it could force that quantity through the underground system only. Were there no shaft leakage, the specific resistance of the underground circulation would necessarily be less than that of the entire mine, and the difference would represent the specific resistance of the shafts (line 31, Table 2). The combined specific resistance of the intake and return shafts ranged from 0.10 at Mine A to 4.0 at Mine E.

The estimated specific resistance of either 90-deg. bend at the top or bottom of the intake compartment of the air shaft at Mine A is only 0.03. Several 90-deg. bends were surveyed during the course of the work, most of them being shaft-bottom bends. Their specific resistances varied from 0.046 at Mine B to 2.7 at Mine E. Much of this variation is due to differences in cross-sectional dimensions, rather than to differences in such characteristics as freedom from obstructions and easement of corners. Thus, the mean linear dimension of the cross section of the Mine B bend is more than twice that of the Mine E bend so that the mean velocity required for the transmission of 100,000 cu. ft. per min. around the former bend would be less than one-fourth as great as the mean velocity with 100,000 cu. ft. per min. flowing around the smaller bend. As the resistance varies about as the square of the mean velocity, perhaps one-twentieth as much pressure would be required to maintain a flow of 100,000 cu. ft. per min. around the larger bend as around the smaller (Mine E) bend, were the two bends geometrically similar. Actually, the larger bend had much better configuration than the smaller, which was so irregular and badly obstructed that its resistance was disproportionately high.

This illustrates a disadvantage of specific resistance as a criterion of flow conditions. It is so sensitive to absolute size that it often fails to reflect the other conditions of the passageway, such as alignment and smoothness of surfaces. A criterion involving the linear speed of air flow such as \( k \) in the standard formula \( 5.2ia = ksv^2 \) must be used to reflect such features.

The commonest form of split found underground is the T split like that at Mine A (Diag. A, Fig. 6). The specific resistance of the simple two-way splits surveyed ranged from 0.03 at Mine H to 0.69 at Mine D.

Single overcasts varied in specific resistance from 0.22 (Mine M) to 1.2 (Mine J), while two double overcasts had specific resistances of 0.80 and 6.1 (line 34, Table 2).
### Table 3

#### Test of Fan at Mine A

<table>
<thead>
<tr>
<th>Resistance added</th>
<th>None</th>
<th>Minimum</th>
<th>Medium</th>
<th>Maximum</th>
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</thead>
<tbody>
<tr>
<td>Underground circulation, cu. ft. per min.</td>
<td>152 000</td>
<td>103 000</td>
<td>73 600</td>
<td>29 400</td>
</tr>
<tr>
<td>Estimated leakage, cu. ft. per min.</td>
<td>3 000</td>
<td>3 200</td>
<td>3 300</td>
<td>3 400</td>
</tr>
<tr>
<td>Fan delivery, cu. ft. per min.</td>
<td>155 000</td>
<td>106 200</td>
<td>76 000</td>
<td>32 300</td>
</tr>
<tr>
<td>Velocity in fan drift, ft. per min.</td>
<td>1 710</td>
<td>1 070</td>
<td>847</td>
<td>351</td>
</tr>
<tr>
<td>Velocity pressure in fan drift, in. water</td>
<td>0.18</td>
<td>0.07</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Static pressure in fan drift, in. waterb</td>
<td>2.39</td>
<td>2.35</td>
<td>2.59</td>
<td>2.67</td>
</tr>
<tr>
<td>Total pressure in fan drift, in. water</td>
<td>2.59</td>
<td>2.55</td>
<td>2.84</td>
<td>2.88</td>
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<tr>
<td>Air h.p.</td>
<td>55.9</td>
<td>52.3</td>
<td>31.4</td>
<td>13.8</td>
</tr>
<tr>
<td>Electrical h.p.</td>
<td>109.5</td>
<td>84.9</td>
<td>73.5</td>
<td>50.0</td>
</tr>
<tr>
<td>Overall efficiency, per cent</td>
<td>31.4</td>
<td>43.7</td>
<td>23.0</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Fan Data:
- Centrifugal type, with forward-curved blades; diameter 12 ft., width 6 ft., speed 114 r.p.m.
- *Measured in single main east and west air courses, see Fig. 6.
- **Between surface fan and measuring sections in mine; proportional to square root of static pressure.
- Cross-sectional area, 90.8 sq. ft.
- **By measurement.
- **By interpolation.

In the case of air courses, a length of 100 feet is taken as a standard resistance zone, and specific resistances are expressed on this basis. Other things being equal, double air courses would have only one-fourth the specific resistance of a comparable single air course, and quadruple entries only one-fourth the specific resistance of double ones, but this is by no means borne out in line 35, Table 2, where the lowest specific resistance per 100 feet of air course (0.036, Mine I) is for a single air course. The specific resistance of the quadruple air course at Mine B was one-third greater than this, and the maximum specific resistance per 100 feet was 2.2 for the single air course at Mine E. This range in the specific resistance of straight air courses not only reflects differences in the cross-sectional dimensions of the entries, but differences in configuration as well. The low resistance of the single air course at Mine I is attributable to a combination of large cross-sectional area (nearly 100 sq. ft.) and unusual freedom from debris, as the entry had just been thoroughly cleaned shortly before the test.

The manifold range of specific resistance for the various zones represented in section V of Table 2 shows, on one hand, that comparatively low specific resistances can be attained, and, on the other, that in many instances resistances many times higher than necessary are being tolerated.

14. **Power Consumption.**—The energy being put into the air by the fans ranged from 1.2 to 103.5 air h.p., the greatest amount of energy going into the largest mine (Mine B).

No attempt was made to measure the power input into any of the
fan driving units, except where meters had been permanently installed with electrical driving motors. Where watt-meter or watt-hour-meter readings were available for the driving motor it was possible to calculate the overall efficiency of the motor, drive, and fan, assuming the meter to be accurate. Five values so obtained ranged from 21 to 51 per cent, the highest value representing the ventilating unit at Mine A.

B. Mine A

15. Fan Characteristics.—By far the most extensive survey was made at Mine A, where much of the surveying technique was developed and tested. By regulating the two primary splits it was possible to make a partial test of the fan, with the results shown in Table 3 and Fig. 7. The normal operation of this fan was apparently near its point of maximum efficiency, the overall efficiency of the motor, drive, and fan being 51.1 per cent. Circumstances did not permit a test to be made at a delivery greater than that of normal operation.

16. Primary Currents.—All of the air entering the mine from the fan makes a 90-deg. turn at the top of the downcast compartment of the air shaft, and another such turn at the bottom. The total loss in pressure from the fan to the air course was 0.16 in. of water, with an energy loss of 3.9 air h.p. At an overall efficiency of 50 per cent and
<table>
<thead>
<tr>
<th>Zone (see Fig. 8)</th>
<th>Under Present Conditions</th>
<th>After Proposed Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SD-E</td>
<td>SD-1SW</td>
</tr>
<tr>
<td>1. Approximate distance, ft.</td>
<td>170</td>
<td>70</td>
</tr>
<tr>
<td>2. Quantity, cu. ft. per min.</td>
<td>61 000</td>
<td>30 500</td>
</tr>
<tr>
<td>3. Velocity, ft. per min.*</td>
<td>1 000</td>
<td>1 500</td>
</tr>
<tr>
<td>4. Total pressure loss, in. water</td>
<td>0.48</td>
<td>0.26</td>
</tr>
<tr>
<td>5. Air h.p.</td>
<td>4.6</td>
<td>1.2</td>
</tr>
<tr>
<td>6. Electrical h.p.</td>
<td>0.2</td>
<td>2.4</td>
</tr>
<tr>
<td>7. Annual cost</td>
<td>$920</td>
<td>$240</td>
</tr>
<tr>
<td>8. Estimated annual saving in power cost of ventilation</td>
<td>$1400</td>
<td></td>
</tr>
</tbody>
</table>

Line 5 = $\frac{5.2 \times \text{line 2} \times \text{line 4}}{33 000}$

Line 6 = $\frac{\text{line 5} \times 100}{\text{overall efficiency (50 per cent)}}$

Line 7. Estimated annual power cost of ventilating the zones represented in Fig. 8 assuming cost of power at $100 per h.p.-yr.*

*Approximate values based on estimated mean cross-sectional areas.

†Approximate mean rate of air transmission in high-velocity zone.

aEquivalent total pressure loss for all currents from Sect. SD (Fig. 8) through designated sections.

an estimated cost of $100 per h.p. year* for electrical energy this represents an annual expenditure for power of nearly $800. This is seven or eight per cent of the total estimated power cost of ventilating the mine, which is about $11 000 annually.

The underground distribution of the air is shown in Fig. 6. Diagram A of this figure shows that the air is transmitted as a single current for about 30 feet from the air shaft, to the main east and west air courses, where it forms two primary splits of 61 000 (east) and 91 000 (west) cu. ft. per min. The drift between the shaft and the air courses has a concrete-lined arch section which is more than 100 square feet in cross-sectional area, so that the air moves through it at about 1500 ft. per min. The air courses tributary to this drift are unlined and untimbered, and each has a highly variable cross-sectional area averaging about 60 sq. ft. with the result that, after splitting, the west current is transmitted at about 1500 ft. per min. for nearly 100 feet, and the east current at approximately 1000 ft. per min. for about 150 feet. Beyond this, the high velocities are reduced by splitting and/or dividing the current between two parallel intercommunicating entries in both cases.

*Assuming year-round operation of the fan, this is equivalent to 1.53 cents per kw.-hr.
The pressure and energy losses in this high-velocity zone are analyzed in Table 4, which shows an estimated annual cost of over $1900 for power consumed in splitting and transmitting the incoming current of air within 200 feet of the air shaft.

17. Proposed Alterations in High-Velocity Zone.—If the main east and west air courses were doubled to their junction with the shaft drift as indicated in Fig. 8, the mean air speed would be cut at least in half, and the pressure losses and power consumption in this zone would accordingly be reduced to about one-fourth of their present values, assuming the maintenance of the present rate of flow. As indicated in Table 4, this should result in an annual saving in ventilation costs of more than $1400.

No power saving would follow directly from the improvement, however, because, operating at its test speed (114 r.p.m.), the fan would respond to the lowered mine resistance by delivering more air at a lower water gauge than before, but at higher power consumption, as is characteristic of centrifugal fans with forward-curved blades. This is illustrated in Fig. 7, where point A represents the intersection of the pressure curves of the fan and the mine for the normal operating condition at the time of test. Were the resistance of the mine to a fan delivery of 155 000 cu. ft. per min. to be reduced by the proposed alterations in the high-velocity zone from 2.29 to 1.99 in. of water (point B, Fig. 7), a new mine-pressure curve would be developed which would intersect the fan-pressure curve at point C (Fig. 7). Under these circumstances, with the fan still running at 114 r.p.m. it would deliver 164 000 cu. ft. per min. against 2.23 in. of water, and would consume 113 electrical h.p. (point D) in doing so. This is an increase of 3.5 h.p. for a gain of 9000 cu. ft. per min. in fan delivery.

If it were desired to restore the former fan delivery, the fan speed should be reduced in the ratio of 155 000 to 164 000, or to 108 r.p.m.
It would then deliver 155,000 cu. ft. per min. at 1.99 in. water (point B) at a power consumption of 95 h.p., or 14.5 h.p. less than its normal consumption at the time of test. In general, the full benefit in power savings to be had from reducing the resistance of the passageways of a mine can be had only by reducing the fan speed to restore its pre-alteration delivery.

It is interesting to note that the effective resistance (0.41 in. water) of the proposed zone of alterations is nearly one-fifth of the resistance of the entire mine. The main east current is transmitted nearly 2000 ft. (Diagram B, Fig. 6) and the main west current 1000 ft. (Diagram C) before another drop of 0.4 inch of water gauge is encountered. This means that the resistance per unit length of the single entries in the primary splitting zone is roughly ten times that of the double air courses further inbye.

18. Maintenance of Air Courses.—Although each entry of the double air courses was driven wider and higher than the single entries near the air shaft, fallen roof material has so obstructed the main air courses that, on the average, the cross-sectional area of each is roughly equal to that of the single air courses. This is shown as follows:

<table>
<thead>
<tr>
<th></th>
<th>Number of Sections Measured</th>
<th>Mean Cross-sectional Area of Each Entry sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main east air courses, single</td>
<td>3</td>
<td>53</td>
</tr>
<tr>
<td>Main east air courses, double</td>
<td>13</td>
<td>56</td>
</tr>
<tr>
<td>Main west air courses, single</td>
<td>3</td>
<td>47</td>
</tr>
<tr>
<td>Main west air courses, double</td>
<td>12</td>
<td>46</td>
</tr>
</tbody>
</table>

On the east side of the mine, each of the double air courses has a slightly larger cross-sectional area, on the average, than the single air courses, but on the west side there is a slight difference in favor of the single air courses. However, cross-sectional areas throughout the west air courses averaged appreciably less than those on the east side of the mine. This is reflected in column 5 of Table 5 which shows the specific resistance per 100 ft. of the double main air courses. In general the resistance of the main air courses is nearly twice as high on the west as on the east side of the mine, an approximate average specific resistance for the east double air course being 0.09, and for the west double air course 0.17 per 100 ft. Either figure is much lower than the specific resistance of 0.5, or more, per 100 ft. in the single east main air course.
<table>
<thead>
<tr>
<th>Approximate Distance</th>
<th>Quantity</th>
<th>Estimated Velocity</th>
<th>Total Pressure Loss</th>
<th>Specific Resistance per 100 ft.</th>
<th>Air h.p. 5.25</th>
<th>Annual Power Cost*</th>
<th>Estimated Reduction in Pressure Loss</th>
<th>Estimated Annual Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft.</td>
<td>cu. ft. per min.</td>
<td>ft. per min.</td>
<td>in. water</td>
<td>per 100 ft.</td>
<td>33 000</td>
<td>dollars</td>
<td>in. water</td>
<td>Dollars</td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
<td>(8)</td>
<td>(9)</td>
</tr>
<tr>
<td>I. Main east air courses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from single entry to stable split</td>
<td>300</td>
<td>61 000</td>
<td>560</td>
<td>0.10</td>
<td>0.090</td>
<td>1.0</td>
<td>200</td>
<td>0.05</td>
</tr>
<tr>
<td>from stable split to overcast 1SE</td>
<td>600</td>
<td>51 000</td>
<td>470</td>
<td>0.17</td>
<td>0.107</td>
<td>1.4</td>
<td>280</td>
<td>0.09</td>
</tr>
<tr>
<td>across overcast 1SE to 2SE</td>
<td>100</td>
<td>51 000</td>
<td>900</td>
<td>0.11</td>
<td>0.42</td>
<td>0.9</td>
<td>180</td>
<td>0.08</td>
</tr>
<tr>
<td>from 2SE to 3SE</td>
<td>2 100</td>
<td>35 000</td>
<td>260</td>
<td>0.29</td>
<td>0.11</td>
<td>1.6</td>
<td>320</td>
<td>0.15</td>
</tr>
<tr>
<td>II. Main east return entries from 1SE to shaft bottom</td>
<td>800</td>
<td>73 600</td>
<td>400</td>
<td>0.16</td>
<td>0.037</td>
<td>1.0</td>
<td>380</td>
<td>0.05</td>
</tr>
<tr>
<td>III. Main west air courses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from single entry to 1NW</td>
<td>500</td>
<td>69 500</td>
<td>660</td>
<td>0.14</td>
<td>0.076</td>
<td>1.3</td>
<td>260</td>
<td>0.07</td>
</tr>
<tr>
<td>from 1NW to 3SW overcast</td>
<td>400</td>
<td>48 500</td>
<td>330</td>
<td>0.333</td>
<td>0.34</td>
<td>2.6</td>
<td>520</td>
<td>0.17</td>
</tr>
<tr>
<td>from 3SW to 4SW, across overcast</td>
<td>100</td>
<td>48 500</td>
<td>900</td>
<td>0.11</td>
<td>0.46</td>
<td>0.8</td>
<td>160</td>
<td>0.06</td>
</tr>
<tr>
<td>from 4SW to 6SW</td>
<td>1 000</td>
<td>48 500</td>
<td>500</td>
<td>0.32</td>
<td>0.14</td>
<td>2.4</td>
<td>480</td>
<td>0.10</td>
</tr>
<tr>
<td>from 6SW to 8SW</td>
<td>600</td>
<td>31 000</td>
<td>340</td>
<td>0.06</td>
<td>0.10</td>
<td>0.3</td>
<td>60</td>
<td>0.03</td>
</tr>
<tr>
<td>from 8SW to 10SW</td>
<td>1 500</td>
<td>20 500</td>
<td>230</td>
<td>0.11</td>
<td>0.17</td>
<td>0.4</td>
<td>80</td>
<td>0.06</td>
</tr>
<tr>
<td>IV. Main west return entries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>from 7SW to 8SW</td>
<td>2 100</td>
<td>42 500</td>
<td>390</td>
<td>0.22</td>
<td>0.058</td>
<td>1.5</td>
<td>300</td>
<td>0.07</td>
</tr>
<tr>
<td>from 3SW to shaft bottom</td>
<td>1 200</td>
<td>67 500</td>
<td>550</td>
<td>0.12</td>
<td>0.022</td>
<td>1.3</td>
<td>260</td>
<td>0.04</td>
</tr>
<tr>
<td>Total...</td>
<td>$1570</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Estimating overall efficiency of ventilating unit at 50 per cent and cost of electrical energy at $100 per h.p.-yr.; col. 7 = 200 $ \times \text{col. 6}.

**An average increase of 50 per cent in net cross-sectional area in the main east and west air courses would give \( \frac{5}{6} \) the present velocity and \( \frac{5}{4} \) or about 50 per cent of the present total pressure loss.

†Estimating average increase of 20 per cent in net cross-sectional area of combined return airways would give 83 per cent of present velocity and about \( \frac{5}{4} \) of present total pressure loss, saving about \( \frac{5}{4} \) of present loss.

*An approximate value based on cross-sectional areas of measured sections.

A Single current; currents not so designated flow in two parallel intercommunicating entries.

C Single entry across overcast.
If the fallen debris were removed from the double air courses throughout the mine, their cross-sectional areas would be increased about 50 per cent, which would cut their resistance to the present air currents to about one-half the present figure. The resultant savings in the power cost of ventilation are shown in columns 9 and 10 of Table 5, the total annual saving being estimated at nearly $1600. This is a little greater than the saving to be expected from doubling the outbye ends of the main east and west air courses (Table 4) which would entail the driving of about 300 feet of single entry, with crosscuts, in coal. However, to effect the total savings indicated in Table 5 it would be necessary to clean about four linear miles of entry.* Three factors combine to bring about this disparity in the linear effect of alterations. The foremost of these is that the mean air speed in the intermediate-velocity zone represented by Table 5 is roughly one-third of that in the high-velocity zone represented by Table 4, so that the resistance offered to, and the power consumption required for, the transmission of a given quantity of air per minute a specified distance in the intermediate-velocity zone are of the order of one-ninth of the corresponding resistance and power consumption in the high-velocity zone. Thus, the opportunities for economy are much lower in the intermediate- than in the high-velocity zone. Furthermore, splitting reduces the amount of air to be handled in the main air courses. This has the double effect of reducing the speed of the air and also the amount of air to be moved at the reduced speed. Finally, two parallel entries must be cleaned throughout their length to effect the 50-per-cent increase in cross-sectional area postulated here. The result is that the overall economies to be expected from a general cleaning of air courses at Mine A are low in comparison with the probable cost of effecting and maintaining the improvements.

The present practice at this mine is to keep a small crew of men at work in the air courses, trimming the roof and ribs, and leveling the fallen debris, to avoid local constrictions and obstructions. The importance of work of this kind, where velocities are about average, is illustrated by alterations which were made at the first southeast overcast (Diagram B, Fig. 6). The alteration consisted in enlarging the cross-sectional area over the overcast by blasting down roof and rib rock and by smoothing the approach to and departure from the overcast in disposing of the debris. In evaluating the results of this improvement the slight change in rate of flow has been allowed for, and

*One of the return entries in part II and another in part IV of Table 5 are haulage entries which are now kept clean. Except for the two overcasts the remaining distances of column 1, Table 5, must be doubled to get the lineal distance to be cleaned.
the following data are presented as for the rate of flow (51 000 cu. ft. per min.) shown in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Before Alterations</th>
<th>After Alterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-sectional area over overcast, sq. ft.</td>
<td>28.3</td>
<td>50.4</td>
</tr>
<tr>
<td>Mean air speed over overcast, ft. per min.</td>
<td>1800</td>
<td>1010</td>
</tr>
<tr>
<td>Total-pressure loss in 100 ft. of single entry across overcast, in. water</td>
<td>0.34</td>
<td>0.11</td>
</tr>
<tr>
<td>Specific resistance</td>
<td>1.31</td>
<td>0.42</td>
</tr>
<tr>
<td>Estimated annual power cost of transmitting air through this zone</td>
<td>$550</td>
<td>$160</td>
</tr>
<tr>
<td>Estimated annual saving resulting from alterations</td>
<td></td>
<td>$390</td>
</tr>
</tbody>
</table>

As the estimated annual saving is well in excess of the cost of making the improvement this alteration was worth-while from every point of view.

The further distribution of the major air currents within Mine A is indicated in Diagrams B and C, Fig. 6, with total pressures expressed in inches of water above atmospheric pressure. The data are self-explanatory and need not be discussed in detail.

19. Sealed Territories.—Diagram D, Fig. 6, represents some worked-out room territories which are typical of such territories throughout the mine, except that here the room entries (37th and 38th east and west) are being kept open for communication rather than being sealed off. This explains the presence of doors in an old territory. While working, the territory was ventilated with fresh air from the first and second southwest air courses. Part of this air returned through the third and fourth southwest entries and the remainder through the first and second southeast entries. The remainder of the intake air flows further inbye along the first and second southwest air courses to ventilate territories which are now productive (49th and 50th east and west entries).

Air measurements made just outbye the 37th east and west entries showed that only 15 900 cu. ft. per min. of fresh air were being delivered through the first and second southwest air courses, whereas these air courses were receiving 30 500 cu. ft. per min. from the main west air courses (Diagram A, Fig. 6). Thus half of the air delivered to this pair of air courses was lost in passing 18 double pairs of room entries, all of which are stopped at both ends. Dirt stoppings are installed at the air-course end of each room entry, and a concrete stopping at the haulage-road end, when a territory is worked out.

Inasmuch as 13 additional double pairs of abandoned room entries lie between the measuring sections of Diagram D and the working
territories being ventilated through the first and second southwest air courses, it is probable that substantially less than one-half the initial air supply is reaching the working room panels (49th and 50th east and west entries).

Many concrete stoppings were examined along the return entries, outbye the territory shown in Diagram D. They were found to be well-constructed and apparently tightly sealed into the strata, as there was no audible leakage. While stoppings not examined may have been largely responsible for the loss of 15 000 cu. ft. per min. out of the first and second southwest air courses, between their source and the 37th and 38th east-west entries, it is probable that there is continuous and inaudible seepage of air past and through any stopping which is exposed to a higher pressure on one side than on the other, so that every stopping involved probably contributes to the leakage.

In this case it may be assumed that the dirt stoppings in the room entries along the first and second-southwest air courses leak freely, and that the full static pressure differential between the air courses and the return entries, at each (east-west) room entry is borne by the concrete stopping at the haulage-road end of the room entry. There are 72 of these concrete stoppings in question. As each may be assumed to be 60 sq. ft. in area, more than 4000 sq. ft. of concrete stoppings are exposed to pressure differentials which maintain continuous leakage through the pore spaces in the concrete, and past each stopping wherever it is not perfectly sealed into air-tight strata of rock or coal. A mean rate of flow of three or four feet per minute throughout the area of the stoppings in question would account for the leakage noted. This situation in a small part of Mine A illustrates the great importance of leakage in mine ventilation. While it is not possible to prevent all leakage, a determined effort should be made to stop all leaks which are of sufficient velocity and volume to produce sound. Particular attention should be paid to the older stoppings near the mine bottom, as they are not only ordinarily subject to higher pressure differentials, but are also more liable to gross leakage due to failure, than are newer stoppings farther inbye.

C. Other Mines

20. Mine B.—This is the largest mine surveyed. It is ventilated by a 5x12-ft. centrifugal fan which was delivering 147 000 cu. ft. per min. at the bottom of the downcast air chamber at the time of test. There was a total-pressure difference of 3.96 in. of water between the main intake and the main return currents at the shaft bottom. As it
was not feasible to measure the mine water gauge it is estimated at 4.35 in. under standard conditions, as indicated in Table 2. Estimating leakage in and around the air shaft at 5000 cu. ft. per min. the total estimated fan delivery was 152,000 cu. ft. per min.

According to an electric meter at the mine the fan motor was con-
suming 228 h.p. With the fan putting 103.5 h.p. into the air, the overall efficiency of the ventilating unit was 45.4 per cent.

All of the incoming air makes a 90-deg. bend at the bottom of the air shaft, the specific resistance of this bend being 0.045. On leaving the shaft drift the incoming current is split five ways, as shown in Fig. 9. The specific resistance of this split is 0.03.

More than 90 per cent of the incoming current is taken to a major split, about 800 ft. inside the mine, through four intercommunicating entries, as shown in Fig. 9. These entries average about 6 ft. high by 11 ft. wide, the roof being supported by cross bars on about 6-ft. centers. Each cross bar is set on four props, the outer two of which are near the ribs, the inner two being about two feet nearer the center line of the entry.

The presence of the inner props in the air stream sets up high resistance to the flow of air,* and though the mean rate of transmission is only about 600 ft. per min. there is a total-pressure loss of 0.66 in. of water between the source of the four main air courses and the major split (Fig. 9). This corresponds with a specific resistance of 0.048 per 100 ft. of quadruple entry, which is a little more than half the corresponding resistance of the double main east air courses of Mine A. As the total cross-sectional area of the quadruple air courses in Mine B is more than twice that of the double air courses in Mine A, the Mine B specific resistance per 100 ft. would be expected to be less than one-fourth that for Mine A. The excess resistance at Mine B could no doubt be eliminated by retimbering the air courses so as to remove all props from the interior of the entry cross sections.

At the major split in Mine B, 85 000 cu. ft. per min. go north, and the remainder, 46 100 cu. ft. per min., west. The latter current crosses a double overcast with a total-pressure loss of nearly 0.2 in. water, the specific resistance of this unit being 0.9.

21. Mine C.—This mine is ventilated by a modern centrifugal fan, having backward-curved blades. It is housed to permit access to the drift which connects the fan with the downcast compartment of the air shaft, so that it was possible to measure the fan delivery directly. This was done on two different occasions, in July with the fan running at 238 r.p.m., and in the following May, after the fan had been speeded up to 313 r.p.m.

In the first case, it delivered 62 600 cu. ft. per min. against a total pressure of 1.98 inch of water, and in the second case its delivery was 92 400 cu. ft. per min. against a water gauge of 3.54 inches, the

*Univ. of Ill. Eng. Exp. Sta. Bul. 279, p. 43.
specific resistance of the mine having decreased from 4.6 to 4.1 (Table 2) in the meantime.

Although the fan housing, air-shaft top structure, and shaft lining were of good steel and concrete construction in good repair, a delivery of only 55,000 cu. ft. per min. was measured underground, at the time of the first survey; when the fan was delivering 62,600 cu. ft. per min. This indicates a leakage of about one-eighth of the fan delivery, which is larger than was to be expected at a well-constructed installation of this kind.

The primary distribution of the incoming air with appropriate indications of total pressures and quantities at the time of the first survey are shown in Fig. 10. As the resistance of neither the air (intake) shaft nor the hoisting (return) shaft was measured, it was necessary to use a pressure datum for Fig. 10 which approximates atmospheric pressure as nearly as possible.

The figure shows that most of the air goes into the east split, the remainder going west. The east current is served by a double air course, the north entry of which is badly obstructed by falls, while the south entry presents a high resistance to the flow of air, due to the presence of center props, much as at Mine B. Although the combined cross-sectional area of the two entries in this air course where unobstructed is more than 100 square feet, the specific resistance of the double air course was 0.14 per 100 feet of length. At Mine A, the corresponding figure was 0.09 for the double air course on the east side of the mine.

The pressure drop across the man doors (Fig. 10) leading from the intake to the return entries near the air shaft was 1.55 inch, and there was audible leakage past these double doors. Comparison of the measurement (34,000 cu. ft. per min.) of the entire east current

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**Fig. 10. Primary Air Distribution, Mine C**
before it passed these doors, with the total (32,300 cu. ft. per min.) at the two sections just after it passed the doors, indicates that this leakage was 1700 cu. ft. per min., less than was anticipated from the sound. This suggests that noisy leakages through small apertures frequently do not account for as much loss of air as silent seepages through large areas of porous concrete curtain walls, stoppings, or coal pillars, which are exposed to pressure differentials.

Opportunities for reducing the power consumption of the fan motor at Mine C lie principally in reducing shaft leakage, and in cleaning and retimbering the air courses adjacent to the air shaft. As shown in a previous bulletin* cross bars supported in rib hitches are preferable to center props in timbering air courses, from the standpoint of air resistance. This change might well be made in the east air course at this mine.

22. Mine D.—At Mine D it was possible to measure the normal performance of the fan both exhausting and blowing, with the results shown in Table 2. The fan is a 4x6-ft. centrifugal unit, with forward-curved blades. It is set in a reversible housing, and is usually operated exhausting, but during freezing weather the air flow is reversed for a few hours each day.

As shown in Fig. 11 the mine is ventilated through a three-com-
partment shaft, the smallest compartment of which serves as an air chamber, the other two being hoisting compartments. The fan is nearly 200 ft. from the shaft, and is connected with it by a drift in which the rate of flow and static pressure against which the fan worked were measured. Exhausting, the fan's delivery was 60 800 cu. ft. per min. against a total pressure of 2.38 inches of water, whereas, blowing, its delivery was 47 800 cu. ft. per min. against 2.08 inches of water at the drift measuring section. The air horsepowers were 22.8 and 15.7, respectively.

It is difficult to explain the decreases in both pressure and quantity which resulted from the reversal of air flow, for a relatively large decrease in the pressure against which a fan operates is normally accompanied by an increase in the amount of air it delivers per unit of time. In this case, however, both the pressure and the quantity were lower at the measuring section when the fan was blowing than when it was exhausting. A decrease in delivery of a fan of this type is accompanied by a decrease in its power consumption, or load, and in this case the fan was driven four per cent faster by its motor in response to the lightened load while blowing.

A variation of the specific resistance to air transmission with direction of flow has been reported before.* It probably results largely from a difference in the number, or sequence and severity of expansions and contractions. While a difference of one-third in the specific resistance of an entire mine under blowing and exhausting conditions is larger than might be expected, a relative difference as large as this was found in the model of a mine shaft and shaft bottom bend previously investigated.*

An outstanding feature of the ventilation at Mine D is the excessive leakage which prevails in the shaft and around the top and bottom of its air chamber, both under exhausting and blowing conditions. In each case it is about one-third of the fan delivery. Most of this leakage is thought to take place through the 2-inch-board partition, or curtain wall, which separates the air chamber from the hoisting compartments in the shaft. There is audible leakage at many places along this wall.

The distribution of air currents and pressures, near the shaft bottom, is shown in Fig. 11 for both exhausting and blowing conditions.

The main current is turned through a vertical 90-deg. bend at the bottom of the air chamber. The specific resistance of this bend, under

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blowing conditions, is 0.78, as compared with a specific resistance of 0.045 for the corresponding shaft bottom bend at Mine B.

The air chamber of the shaft is connected with the two main air courses (east and west) by a short drift, which is timbered with three-piece sets. The west ventilating current serves a large producing territory, and carries the stable split. The east current turns south to ventilate the south side of the mine. It also carries a split to the north side of the mine. The main air courses are single entries which have become highly irregular and locally obstructed due to falls, with the result that they have high specific resistances. This is illustrated in the main west air course, where the specific resistance was 0.8 per 100 feet of entry between the stable split and the T junction near the shaft. This is more than twenty times the corresponding specific resistance of the opposite haulage road which has a very large cross section near the shaft bottom. The specific resistance of the Mine D air course is 50 per cent greater than that of the single air courses near the bottom of the air shaft at Mine A.

The characteristics of the T split-junction where the main air course joins the drift to the shaft are as follows:

<table>
<thead>
<tr>
<th>Normal rates of flow, cu. ft. per min.:</th>
<th>Exhausting</th>
<th>Blowing</th>
<th>Per Cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>In shaft drift</td>
<td>40 000</td>
<td>34 000</td>
<td>100</td>
</tr>
<tr>
<td>In east air course</td>
<td>18 500</td>
<td>15 500</td>
<td>46</td>
</tr>
<tr>
<td>In west air course</td>
<td>21 500</td>
<td>18 500</td>
<td>54</td>
</tr>
</tbody>
</table>

Losses:

- Between east and main currents: 0.09 in. water (0.26 air h.p.)
- Between west and main currents: 0.07 in. water (0.30 air h.p.)
- For split-junction: 0.08 in. water (0.56 air h.p.)

Specific resistance of split-junction: 0.56 0.69

The specific resistance of the T split in the high-velocity zone at Mine A could be determined under blowing conditions only. It was 0.043, in comparison with 0.69 at Mine D. This large difference arises mainly from the presence of a very large cross section in the shaft drift at Mine A, and from the absence of timbering at that mine.

Potential savings in the ventilation of Mine D lie primarily in eliminating the excessive shaft leakage, in enlarging and improving the 90-deg. bend at the bottom of the air chamber, and in cleaning and enlarging the shaft drift and main east and west air courses. As the fan normally exhausts air from the mine, estimates of potential
VENTILATION CHARACTERISTICS OF SOME ILLINOIS MINES

savings will be based on that coursing. At present nearly 21,000 cu. ft. per min. of leakage air are being handled at a pressure of 2.4 inches of water. This is equivalent to more than 15 electrical h.p., assuming the overall drive-fan efficiency to be 50 per cent. At $100 per h.p.-year, there would be a saving of $1,500 annually* in the power cost of ventilation from stopping the leakage in and around the shaft.

Underground, it is safe to assume that the resistance to the transmission of air at a given rate of flow could be cut in half by properly cleaning and enlarging the passageways, as previously indicated. Estimating the pressure loss around the shaft bottom bend at 0.12 inch of water, there is now a loss of more than 0.3 inch in the air course within 500 feet of the shaft. At the underground rate of flow of 40,000 cu. ft. per min. and loss in total pressure of 0.3 inch of water this is equivalent to nearly four electrical h.p. Assuming that this could be cut in half, an estimated annual saving of $200 would result from clearing less than 1000 feet of air course, and easing the bend at the bottom of the air chamber.

23. Mine E.—This was the only longwall mine visited. Its ventilation is similar to that of Mine D in that both the intake and return currents are handled through the same shaft, by an exhausting fan. Although each fan is driven by a 75-h.p. motor, the fan at Mine E delivers less than one-half as much air as that at Mine D.

The Mine E fan is a small single-inlet centrifugal unit, which was exhausting 23,500 cu. ft. per min. from the mine against a total water gauge of 1.61 inch of water. This is an output of 6.0 air h.p. On the day of the test the watthour meter serving the fan motor indicated an average power consumption of 22.4 h.p. Thus the actual overall efficiency of the ventilating equipment was 27 per cent, a little more than one-half that at Mine A.

The specific resistance of Mine E is 26 as compared with 6.9 for Mine D, exhausting, and 0.93 for Mine A. This means that the resistance of Mine E is so high, due principally to constricted and tortuous passageways, that nearly thirty times as much pressure and power would be required to deliver a given quantity of air, per minute, through Mine E, as through Mine A. Although this surface fan was handling 23,500 cu. ft. per min., only 15,000 cu. ft. per min. were entering the air chamber of the shaft, from the mine. The remainder (8,500 cu. ft. per min.) was leaking into the return air from the incoming air around the shaft bottom, through the wooden curtain.

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*This and the following estimate for Mine E are based on a full year's operation. As it is now customary to operate the mine only about seven months of the year, actual savings would be reduced proportionately, under present operating conditions.
wall in the shaft (Fig. 12) and around the shaft top, just as at Mine D. Thus more than one-third of the fan's delivery was being wasted in shaft leakage. If the present underground circulation is adequate, more than one-third of the present power cost of ventilation would be saved by eliminating this shaft leakage. Not only would the amount of air handled by the fan be reduced one-third, but the water gauge would also be reduced through the reduction in shaft resistance incident to the reduction in the rate of flow in both shaft compartments. As nearly two air h.p. are involved, the saving in the power cost of ventilation should be about $800 annually, at the present efficiency of the ventilating unit.

The average cross-sectional area of the eight measured sections at Mine E was 34.4 square feet, which is in contrast with the situation at Mine D, where the average cross-sectional area of the air-course sections was 43.3 square feet, and at Mine A, where the double air courses provide about three times as much cross-sectional area as do the single entries at Mine E. Roughly, this means that nine times as much energy must be applied to air at Mine E to transmit a given quantity of it, per minute, a given distance through the air courses as at Mine A.

The coursing of the air, rates of flow, and pressure distribution which prevailed near the shaft bottom at Mine E, at the time of the survey, are shown in Fig. 12.
The first pressure loss is encountered by the incoming air in entering, traversing, and leaving the hoisting compartments of the shaft. That portion which escapes leakage into the return shaft compartment then flows into the mine workings along the haulage roads. As shown by measurement there was a pressure loss of 0.05 inch of water in the intake compartments of the shaft. The corresponding loss in total pressure suffered by the return current in the 8x3-ft. air chamber of the shaft was 0.11 inch of water. As the net cross-sectional area of the two hoisting compartments is more than three times that of the air chamber, the total pressure loss in the latter could be expected to be fully ten times that in the hoisting compartments. The greater relative loss in the hoisting compartments is attributed to the resistance of the buntons which separate the two compartments, at intervals of a few feet.

At the bottom of the air chamber the mine current is deflected through an abrupt 90-deg. bend which is partly obstructed by fallen timbers and other debris. The total pressure loss around this bend was 0.06 in., which indicates a specific resistance of 2.7. This is an excessively high resistance, as shown by comparison with the specific resistance (0.046) of the shaft-bottom bend at Mine B. Furthermore, at Mine E, there was a total pressure loss of 0.12 inch of water in transmitting the major return current from the T junction to the shaft bottom, a distance of about 300 feet. This corresponds with a mean specific resistance of about 2.2 per 100 feet of entry, as compared with the specific resistances at Mine A of 0.5 per 100 feet of single main air course, and less than 0.1 per 100 feet in some of the double main air courses.

It is evident that the air courses at Mine E would have to be considerably enlarged and straightened, and the shaft leakage very much reduced, if the economy of the mine's ventilation, and its effectiveness at the working face were to be materially improved. Following such improvements in the mine, attention could properly be given to increasing the efficiency of the fan installation.

24. Mine F.—This mine is ventilated by a small single-inlet fan which was designed primarily for industrial purposes. It is operated blowing, and was delivering 17 000 cu. ft. per min. against a water gauge of 1.65 inch at the time of the test. This represents 4.4 air h.p. The fan is driven by a 20-h.p. motor.

As the test was made on a cold day, the stack effect (0.08 inch of water) was with the fan, so that the actual mine resistance to air of mean density (0.0771 lb. per cu. ft.) was 1.73 inch of water. This
corresponds with a mine water gauge of 1.65 inch for air of standard density (0.0750 lb. per cu. ft.), and a specific resistance for the mine of 57, which is an excessively high value.

The intake current enters the mine from the air chamber of a two-compartment air shaft, which is concrete lined throughout. The second compartment, an escapeway, is separated from the air chamber by a thick concrete wall which prevents audible leakage. However, there is considerable leakage at the top of the shaft.

The intake current was measured in the main air course which joins the air chamber of the shaft in a right-angle bend, the measured underground circulation being 15 900 cu. ft. per min. Its immediate distribution is indicated in Fig. 13. The entire current is transmitted about 700 feet through a constricted air course (of about 40 sq. ft. cross-sectional area) which is heavily timbered with three-piece sets. As the current loses 0.22 inch of water in total pressure in this distance, the specific resistance of the air course is 1.4 per 100 feet, an excessively high value.

The current is split at the junction of the north and west entries as shown in the figure, most of the air going north into the main producing territory of the mine. The other split is severely regulated so that only about 1000 cu. ft. per min. go west to ventilate development work. The north current crosses a double overcast immediately after splitting from the main current, encountering a specific resistance of 6.1 in doing so. This is in contrast with the specific resistance of 0.8 for the double overcast surveyed at Mine B.

At Mine F, the combined return current from the two primary splits is brought under the two overcasts and to the shaft bottom through two intercommunicating entries, one of which is a haulage
road, which is kept clean. The specific resistance of this passageway is 0.3 per 100 feet, in contrast with 1.4 per 100 feet for the adjacent single air course.

So long as the present circulation is adequate to ventilate this mine, the opportunity for reducing the power cost of ventilation is very limited, save at the top of the air shaft, where the leakage could be eliminated at negligible cost. Elsewhere in the mine, the cost of improvements would be high in comparison with the potential savings, unless it were desired to increase the quantity appreciably. In that event, the high specific resistances in the main air course would cause the ventilation cost to mount very rapidly with increased quantity, and underground alterations would be indicated for any considerable increase in the mine quantity.

25. Mine G.—This is a shallow slope mine, which is served by two independent fans.

The north side of the mine is ventilated by a small, electrically-driven centrifugal blowing fan which was delivering only 10 000 cu. ft. per min. against a water gauge of 0.78 inch. The current delivered by the fan is passed to the working territory through 1600 feet of irregular single air course, which averages less than 40 square feet in cross-sectional area. As a return current it traverses about 8800 feet of haulage road before it discharges into the atmosphere. The result is that this section of Mine F has the extremely high specific resistance of 77.

The remainder of the mine is ventilated by a single-stage propeller fan, installed inside the mine, just outbye the first working territory.
This fan draws air into the mine through a shallow shaft, then along the main west air course, forcing it into working territories, then out along the main west haulage road, whence it discharges through the slope. This is illustrated in Fig. 14. The fan was delivering 21,000 cu. ft. per min. against a total pressure of 2.25 inches of water, at the time of the test. This represents 7.4 air h.p. The fan is driven by a 20-h.p. motor, through V-belt connection.

Although the intake air current is split shortly after it leaves the fan, thereafter moving at low speeds, the specific resistance (51) of this second section of Mine F is also very high. This is largely due to the fact that the total current circulated by the fan is drawn into the mine through 4200 feet of single air course, at a mean speed of roughly 600 or 700 feet per minute. While this is not an excessive speed, the air course is very irregular in cross section, and in many places is partly obstructed with fallen debris.

As at Mines E and F, net savings to be effected in the power cost of ventilation at Mine G would probably hinge on the necessity of circulating more air underground. Were it desired to double the
quantity, for example, it would be imperative at least to clean the air courses, which are the principal sources of resistance at present.

26. **Mine H.**—At the time of the test this mine was ventilated by two propeller fans, blowing in parallel. Both drew air from a common intake current, and, after forcing it through working territories, returned it to common return currents. The fans were located underground, near the air shaft, as shown in Fig. 15. Both fans were 5 ft. in diameter and were run at about 900 r.p.m.

The north fan was a single-stage fan driven by a 40-h.p. motor. At the time of the test it was delivering 45 500 cu. ft. per min. against a water gauge of 1.42 inch. This represents 10.2 air h.p. The overall efficiency, using the power indication of the permanent wattmeter serving this fan's driving motor, was 33 per cent. This section of the mine had a specific resistance of 6.6.

The south fan was a two-stage unit, driven by a 75-h.p. motor. It was delivering 53 600 cu. ft. per min. against 3.15 inches of water, against a rather high specific resistance (11), for this section of the mine. The fan's output was 26.6 air h.p. and the overall efficiency was 43 per cent.

The location of the fans, the coursing of the air, and the quantities and pressure distribution near the bottom of the air shaft are shown in Fig. 15. Since the resistance of either an intake or return shaft was not measured at this mine it was necessary to express the pressures in Fig. 15 on an arbitrary datum which is thought to represent atmospheric pressure rather closely.

The mine's total intake current makes a 90-deg. bend at the bottom of the downcast air chamber, encountering a specific resistance of 0.17, which is about four times that at Mine B.

After leaving the shaft, the current is divided in two at a T split which is equipped with a splitting device, as shown in Fig. 15. The specific resistance of the T split is only 0.03, about one-third less than that at Mine A. Not all of this low specific resistance is due to the air splitter, however, because at Mine H the cross-sectional area of each air course is quite large, averaging more than 80 square feet near the shaft bottom.

Accepting the assumption that the pressure datum of Fig. 15 is atmospheric, the specific resistance of Mine H, as a whole, is 2.3, which is very much less than the specific resistance of either circuit alone. This low overall resistance results from a combination of two favorable factors. The first is the benefit naturally to be expected from splitting, whereby the mean speed of air transmission is greatly re-
duced, with consequent material reduction in pressure losses. The second is unique to a dual- or multiple-fan* installation, in that a fan in each split other than that of highest resistance replaces a regulator. The north fan at Mine H replaced a regulator, when the two fans were installed underground.

Prior to the installation of these fans the mine was ventilated by a centrifugal fan at the top of the air shaft, which necessitated the maintenance of a regulator in the north split. In 1931† this regulator had a specific resistance of 6.5, which would represent an energy loss of 9.7 air h.p. in the transmission of the surveyed quantity. At the overall efficiency (44 per cent) at which the centrifugal fan was then operating this represented an expenditure of about $2200 annually for electrical energy, wasted in forcing air through the regulator. At the time of this survey, the power cost of ventilating the north split was $2900 annually, only one-third more than was formerly wasted by the regulator.

This illustrates the large savings which can be made by multiple fan installations where two or more major splits are to be ventilated against widely differing pressures.

27. Mine I.—The propeller fan has recently been modified principally by decreasing the length of blades and increasing their cross-sectional dimensions, to give a single-stage axial-flow fan which can operate at higher duties and capacities than an unmodified propeller fan. Mine I is ventilated by a fan of this type which is set in the main east air course of the mine, about 400 ft. from the air shaft.

The fan is 6 feet in diameter and is run at 1135 r.p.m. by a 75-h.p. motor. At the time of the survey it was blowing 71 500 cu. ft. per min. against 3.36 inches of water, an output of 37.9 air h.p. The mine has a specific resistance of 6.4.

The location of the fan and the coursing of the air to the first split are shown in Fig. 16. The incoming current enters the mine through a 90-deg. bend at the bottom of the downcast compartment of the air shaft. The specific resistance of this bend is 0.18, four times the specific resistance of the corresponding unit at Mine B. However, the main east air course in Mine I is untimbered, and it has recently been cleaned to a large cross-sectional area (nearly 100 sq. ft.) with the result that its specific resistance is only 0.036 per 100 ft. This is the lowest specific resistance found in this survey for any air course, whether single or multiple. An overcast just outbye the first split has a specific resistance of 0.35, which is less than that of the overcast at Mine A after alterations.

The underground fan at Mine I supplants an old centrifugal fan on the surface, which now serves as a standby unit. The new fan draws the intake current for the mine through the old fan housing, then around a 90-deg. bend into the downcast chamber of the air shaft, against a specific resistance of 0.52. This is more than ten times the specific resistance of the right-angle bend at Mine B, but of course the two resistance zones are hardly comparable, as the shaft-top bend at Mine I includes the old fan and fan housing.

28. Mine J.—The only underground centrifugal fan installation examined was at Mine J, where a fan with backward-curved blades was installed near the foot of the air shaft. The fan is set in a fire-proof housing, and operates blowing. At the time of the test it was delivering 42 300 cu. ft. per min. against a total pressure differential of 2.26 inches of water.

The location of the fan with respect to the air shaft is shown in Fig. 17, which also shows the primary distribution of the air, and ventilating pressures. The discharge current splits at a T split on leaving the fan, 24 300 cu. ft. per min. going south, and 16 000 cu. ft. per min. going north over an overcast, then east to ventilate a working territory. There is audible leakage at the two sets of doors shown near the fan. This leakage is estimated at 2000 cu. ft. per min.

Another source of leakage, which represents recirculation of return air, is the wooden man doors between the bottom of the air shaft and the haulage road north of it. Although this leakage is not large,
its existence illustrates a potential recirculation hazard attending underground fan installations which is discussed more fully later.

In spite of a "splitter" (Fig. 17) at the T split the specific resistance (0.53) of this unit was very high, being about 12 times that of the T split at Mine A. This excessive resistance is due in part, at least, to the fact that the air issued from the fan outlet at rather high velocity (about 1100 ft. per min.), and most of its velocity pressure is lost in the splitting process.

The north current encounters a very restricted passage at the overcast, whose specific resistance is 1.2. This is followed by a right-angle bend whose specific resistance is 0.8. It is clear that this split could not be economically ventilated with much larger currents of air without enlarging the cross section of the entry and reducing the resistance of the overcast and adjacent bend.

The air is drawn into the fan through a nearby shaft, which serves only as an intake, the 90-deg. bend between the shaft and the fan inlet having a specific resistance of 0.36, about eight times that at Mine B.

After ventilating the mine the air returns along the main east haulage road to either the hoisting shaft, or the escape shaft, both of which serve as return shafts. At the time of the survey the hoisting shaft was partly blocked for repairs. As this forced the fan to work against an abnormally high resistance, it is not possible to gauge the normal fan performance, or the usual mine resistance.
29. *Mine K.*—This mine is ventilated by a huge steam-driven centrifugal fan, rather than by a smaller electrically-driven unit, as is the case at the mines previously discussed. Mine K fan is typical of the fans which were installed at coal mines a few decades ago. They were straight-bladed, and many of them were home-made. However, few are still in use, most of them having been replaced with more modern installations.

This fan has an overshot mounting in a fixed concrete housing. It operates as a blowing fan, and has double inlets. The fan wheel is 15 feet in diameter and five feet wide. Running at 122 r.p.m. it has the highest rotational and peripheral speeds of the three steam-driven fans which were examined in this work.

In Table 2 it is credited with a delivery of 74 000 cu. ft. per min. against a water gauge of 2.37 inches. This is equivalent to 27.6 air h.p. As no attempt was made to measure the power input into any of the steam-driven fans examined in this investigation, there is no indication of the efficiency of this installation. The specific resistance of the mine was 4.1.

On reaching the bottom of the air shaft the incoming air makes a right-angle bend from the air chamber into an irregular single entry which terminates in a T split at its intersection with the main east-west air course (Fig. 18). The specific resistance of the combined 90-deg. bend and T split was 1.35. Dividing this equally between the two units gives the excessively high specific resistance of 0.68 for each.
The air courses in the high-velocity zone are not only very irregular in cross section and alignment, but they are also heavily timbered with 3-piece sets. There is also a considerable amount of fallen debris on the floor, but the worst single feature of the main east and west air courses is their small cross-sectional area (about 40 sq. ft.) which makes it necessary to transmit the moderate split currents at rather high velocities (800-900 ft. per min.). The result is that the west current suffered a loss in total pressure of 0.16 inch water in traveling only 200 feet. This corresponds with a specific resistance of 0.72 per 100 feet which is many times too high for economical ventilation. Appreciable savings could be made in the cost of ventilating this mine by enlarging and smooth-lining the air courses between the air shaft and the first secondary split on each of the primary (east and west) splits.

As there was a pressure drop of 1.59 inch of water across the doors which separate the air shaft from the main bottom, the specific resistance to the underground circulation was 3.3, that of the entire mine being 4.1.

30. Mine L.—The fan at Mine L is also steam-driven. Although it is operated at only 64 r.p.m., due to its large diameter (24 ft.) its peripheral speed of 3830 ft. per min. is comparable with that of many electrically-driven fans which are driven at two or three times this rotational speed. At the time of the test this fan was delivering 58,000 cu. ft. per min. against a water gauge of 1.01 inch. This is equivalent to 9.2 air h.p.

The specific resistance of Mine L was only 2.3, which is the lowest value determined in this survey for an old mine. This comparatively low resistance is partly attributable to the fact that the intake air splits into two currents at the bottom of the downcast air chamber of the air shaft. This reduces the speed of underground transmission below the value it would have if a single entry were used to conduct the air from the shaft. In fact, the specific resistance of the T split at the shaft bottom of this mine is but 0.10. This may be compared with the specific resistance (1.36) encountered at Mine K in getting the air from the shaft into the two primary shafts.

The air courses in Mine L are quite large and of a cross-sectional shape that approaches semi-circularity in many places, as is characteristic of the air courses of many mines of this field where a strong limestone cap rock lies close to the coal. However, such a cross section presents more rubbing surface per square foot of cross section
than does a more nearly equidimensional cross section, with consequent increase in the frictional resistance to the flow of air. The result is that the mean specific resistance encountered in transmitting the south current (Fig. 19) 1300 ft. from the air shaft to and over the overcast at the third east south entry was 0.14 per 100 ft., while the specific resistance between the 4th east south entry and the 9th east south air course was 0.25 per 100 ft.

The specific resistance of the total underground circulation from the bottom of the air (intake) shaft to the bottom of the hoisting (return) shaft was 2.0 as compared with an estimated specific resistance of 2.3 for the mine as a whole. The specific resistance of the combined shafts, including entrance and departure losses, was 0.5, nearly one-half of which is encountered in the main or hoisting shaft.

On the whole, the major ventilation characteristics of this mine are much better than the average for this survey, with the possible exception of the overall ventilating efficiency and cost, which were undetermined.

31. Mine M.—The fan at Mine M is also an old steam-driven unit, operated at a little more than 60 r.p.m. It was delivering 55 000 cu. ft. per min. against a water gauge of 1.27 inch at the time of the survey. This is equivalent to 11.0 air h.p.

The specific resistance (4.0) of Mine M is nearly 70 per cent higher than that of Mine L. Contributing to this increase is the fact that all of the incoming air makes a right-angle bend at the shaft bottom. The specific resistance of this bend is 0.24, which is more than five times the specific resistance of the bend at the bottom of the air shaft at
Mine B. As shown in Fig. 20, the main current at Mine M is split into two currents (north and south) close to the air shaft.

The north split was throttled to 20,600 cu. ft. per min. by a regulator whose specific resistance was 3.3. The south current was transmitted through the main south air course at about 400 ft. per min. for the first several hundred feet. From the air shaft to the first overcast, the specific resistance of this air course was 0.29 per 100 ft. That of the entire underground ventilating system was 3.6, and that of the shafts 0.8.

The overcast in the south air course has a specific resistance of 0.22, half the specific resistance of the one at Mine A, after alterations.

The principal opportunity for economy in the ventilation of Mine M lies in stopping audible leakage in and around the air shaft, in enlarging and rounding the shaft bottom bend, and in cleaning the air courses within a few hundred feet of the air shaft.

32. Mine N.—This is a fluor spar mine, which is ventilated by an 8-ft. disc fan. It was exhausting 26,500 cu. ft. per min. from the mine at the time of the test. Most of this air entered the air shaft from the 250-ft. level of the mine, and an underground measuring station was established in the crosscut leading from this level to the shaft. The water gauge (0.38 in.) was low at this mine, one-third
of it being required to overcome the adverse stack effect which existed between the shafts at the time of the test. The fan is driven by a 20-h.p. motor, its output being 1.6 air h.p. The specific resistance of the mine was 3.6. Underground pressure differentials were low, due to limited circulation through large passageways. The specific resistance of a right-angle bend at the bottom of the air shaft was 0.30, a very high value.

33. Work of Others.—Interest in the development and application of techniques of ventilation surveying has been active in recent years, particularly in Europe. Some workers advocate the use of pressure measurements only, and others the use of quantity measurements only. However, most workers feel it to be desirable, if not necessary, to have both criteria measured concurrently, as was done in this work.

A mention of some unpublished descriptions of surveying technique may add to the information represented in the bibliography.

One large coal company which operates several mines in the United States has evolved a technique for making routine ventilation surveys of its mines. Pressure differentials are obtained from altimeter readings, which have to be corrected for altitude and changes in atmospheric pressure. Rates of flow are measured with vane anemometers under the following specifications:

"The best results are obtained by moving the anemometer about so as to cover the full section of the airway. Better volume balances are obtained by deducting the assumed section of the observer's body (usually three to four square feet) from the measured section of the airway. Readings of the anemometer are corrected from the characteristic curve of the instrument."

From the anemometer and pressure data and corollary information obtained in the underground work, maps of the surveyed mine are prepared under the following titles:

Present Ventilating Pressures
Present Ventilating Volumes
Mine Conditions and Structures Affecting Ventilation

This gives the operating staff of the mine an adequate basis for improving the ventilation of the mine, and sets a standard for future maintenance.

In measuring fan deliveries underground one engineer fixes a vane anemometer on the end of a 6-ft. stick, and stands in a central position in the entry, at arm's length downstream from the measuring

*See appended Bibliography, p. 61.
†Saxe, reference 7, Bibliography.
‡Cowan, reference 17, Bibliography.
*Personal communication.
§Essentially an aneroid barometer.
section. Keeping the anemometer holder in the measuring section, he then traverses the cross section in a network of points at five-second intervals, as was done in this survey, moving from his fixed position only to start and stop the instrument at the beginning and end of the traverse. A single attempt to follow this procedure at Mine H gave a mean velocity ten per cent greater than that obtained by the technique of this survey, but no adequate comparison between the two techniques has yet been made.

A possible advantage of such a procedure is that it should reduce the effects of any disturbance which might be communicated upstream from the observer's body to the measuring section. With the observer standing as nearly as possible in one position throughout a traverse, any upstream disturbances would remain uniform, rather than shifting with the observer and the anemometer, as might be expected under the technique followed in this survey. However, where the observer keeps at least two feet downstream from the measuring section, it is doubtful whether any disturbances in the air flow are communicated from his body to the measuring section.*

A more elaborate procedure for measuring the delivery of mine fans has been proposed† involving the physical indication of traverse points by means of stretched wires, and an anemometer traverse of this network at ten-second intervals, by an operator standing in fixed position at least four feet downstream from the section. It seems probable that this method should give uncorrected results concordant with those of this survey, and that the same calibration correction could be applied to results from both methods. The verification of this assumption awaits further work.

IV. SUMMARY AND RECOMMENDATIONS

34. Procedure.—The major ventilation characteristics of several mines were measured by using vane anemometers to determine rates of flow, and differential pressure gauges to measure the pressures maintained by the fan at various points in each mine. Static pressures from each of two cross sections in the mine, or from a single cross section and the atmosphere, were brought separately to the high- and low-pressure sides of the gauge through continuous lines of rubber tubing. The net registration of the gauge was the static pressure differential between the sections. The velocity pressure dif-

ferential was combined, algebraically, with this to give the difference in total pressure between the two sections.

Successive combinations of such determinations of differentials in total pressure resulted in the determination of the total pressure at any section in a given current of air.

The mean velocity of flow through a cross section of a mine entry was measured with calibrated vane anemometers. Each was held about two feet ahead of the operator, in the chosen cross section, at each of several points within the section, for five seconds, anemometer registration being continuous from the first traverse point to the last. The traverse points were arranged in a grid (Fig. 2), and were from one to two feet apart. The net registration of the anemometer was divided by the traversing time in minutes to give the indicated anemometer speed. This was converted to air speed in feet per minute by the application of a calibration correction for the anemometer used, at the indicated mean speed.

Anemometers were calibrated in the laboratory, as a routine check on their condition, but it was found necessary to calibrate them underground, against pitot-tube traverses, of the kind formerly used* in this investigation. Such calibrations were made at Mine A over a wide range in velocities, and at a number of traverse sections differing in size, shape and conditions of approach and departure.

To convert mean air speeds underground into rates of flow in cubic feet per minute the area of each traversed cross section was obtained by measuring its height at frequent intervals across the section, and its width at the roof, floor, and suitable intermediate heights. In measuring heights a plumbed steel tape was used, and horizontal offsets were taken from this tape to the rib, each foot above the floor, when the tape was held in either end position. Sketch notes were taken and from these data the outline of the section was plotted to scale on coordinate paper. The cross-sectional area was then determined by planimeter.

35. Quantities and Resistances.—The fan deliveries to or from the surveyed mines ranged from 17 000 cu. ft. per min. for one of the smaller mines, to 155 000 cu. ft. per min. for one of the larger mines. Underground circulation was always less than the fan delivery, due to leakage in fan housings, shaft curtain walls, and about the shaft bottoms. The greatest measured discrepancy between fan delivery and total underground circulation was 20 100 cu. ft. per min. at Mine

*Univ. of Ill. Eng. Exp. Sta. Bul. 158, Chap. IV.
D. This shaft leakage was nearly one-third of the fan delivery, as was the shaft leakage at Mine E.

The resistance which entire mines and portions thereof offer to the transmission of air are compared in Table 2 by means of the specific resistance which is the estimated water gauge which would be required to course 100,000 cu. ft. per min. through the mine or designated portion thereof. The estimation is based on the total pressure which was required to course the measured rate of flow through the resistance zone, at the time of the survey, assuming the resistance to vary as the square of the rate of flow. It is also assumed that the air coursing and physical conditions within the mine or portion thereof remain unchanged.

The specific resistance for an entire mine ranged from 0.93 to 57, and for every type of resistance examined, (overcast, T split, etc.) a similar relatively wide range in specific resistances was found. The minimum value shows that low resistances are attainable, while the maximum values show that excessive resistances are frequently tolerated. They act as a continuous drain on the power supply to the mine.

36. Potential Savings.—It is safe to say that every mine represented in this survey could effect considerable annual savings in the power cost of ventilation by stopping leaks and by enlarging, straightening, and smoothing air courses and other passageways where air speeds are more than a very few hundred feet per minute. In many cases further savings could be made by modernizing the fan installation.

An outstanding example of the potential saving from underground alterations is at Mine A, where it is estimated that more than $1400 could be saved annually by driving about 300 feet of single entry in coal with cross cuts. At Mine D nearly as great a saving* could be made by stopping the leakage through the curtain wall in the shaft. At Mine H, about $2700 is being saved annually in the power cost of ventilation, through having provided each main split with a fan, one of which replaces a regulator. Very considerable savings could be made at Mine K by enlarging and smooth-lining the main air courses, which are now highly constricted and irregular. Each mine presents its own problems of this kind, and a balance must be maintained between the cost of making and maintaining the improvements, and the anticipated savings over a period of years.

*Assuming year-round fan operation.
37. Recommendations.—In striving for economy in ventilation, the principal consideration is to minimize leakages and velocities. Every effort should be made to stop all audible leakage, for every cubic foot of leaking air is a needless load on the fan and a direct monetary loss. As the audible leakages are readily detected, and frequently easily stopped, they should be given prompt attention. Even without audible leakage, there will still be considerable seepage of air through and past concrete walls and stoppings, and possibly through coal pillars, particularly in the zone of higher pressure differentials near the shafts.

Throughout the mine, the mean speed of air transmission should be kept as low as possible, air speeds less than 500 feet per minute being highly desirable. Where it is not feasible to get the rate of flow down to a very few hundred feet per minute, the entries should be as nearly straight and smooth-lined as possible, with rounded corners at bends. Otherwise money will be wasted with every revolution of the fan, whether the mine is working or idle, in forcing air to move against unnecessary resistance.

A further reason for cleaning air courses and maintaining them in good repair is that they serve as escapeways, and so should always be kept in a safe and easily-traveled condition, as a safety precaution.

Having leakages, velocities, and resistances at a minimum throughout the ventilating system of a mine, the next step in economical ventilation is to see that the fan is fitted to the duty it is called on to perform, and that it is driven by a motor of proper size. The fan should operate at or near the peak of its efficiency, and its drive motor should operate nearly at full load, to gain full benefit from the ventilating unit.

38. Recirculation.—There has been a recent increase in the number of underground fans in the state, and it seems desirable to call attention to a hazard in such installations which is almost lacking in surface installations. That is the danger of recirculation, which arises at all doors, stoppings, curtain walls or other structures which separate an intake current from a return current at higher pressure. In general, this is the case with all such partitions outbye an underground fan, as leakage at such a partition dilutes the fresh incoming air with return air. Such recirculation is a matter of particular concern in a gassy mine, where dangerously high concentrations of explosive gas may be built up by long-continued recirculation.

At every underground fan installation, all such separators (stoppings, doors, etc.) should be carefully examined for leakage daily, and
the intake air should be tested for methane, just ahead of the fan. Only in this manner can a reasonable assurance against the development of a serious hazard be sustained.

39. Ventilation Standards.—Since, as is well known, most of the fresh air which enters a mine leaks into the return currents without reaching the working face, the fan delivery is not a criterion of the adequacy and quality of a mine’s ventilation. It is intimately related to the cost of ventilation, but only remotely to the quality thereof. The adequacy of mine ventilation should be gauged primarily by the character of the air at the working face, and the air at every such face should be tested at least once during each shift for such characteristics as temperature, humidity, content of methane, oxygen, and dust in addition to the regular pre-shift examination as now carried out. Visibility should also be reported, as more active ventilation might be needed to clear the air of dust and fog which tend to obscure the workmen’s vision. Similar tests should be made at selected points in the haulage roads and the main shaft bottom, and at any other points in the mine where an adverse ventilation condition might be indicated.

Were these daily reports uniformly favorable, it could safely be said that the mine was being properly ventilated, regardless of the amount of air the fan delivered. It is felt that, in many instances, the adoption of ventilation standards of this kind coupled with an analysis of air transmission and fan performance, as in this survey of Mine A, would lead to improvement in working conditions, at a lower cost for ventilation.

40. Ventilation Surveys.—To maintain a check on the performance of the fan and the economy of ventilation, it is recommended that the engineer at each mine be provided with equipment* like that used in this work, including two vane anemometers, and that he establish one or more underground air-measuring stations in the high-velocity zone of the mine, where the anemometers may be calibrated against pitot-tube traverses, and that periodic surveys be made to indicate fan performance, mine resistance, and the distribution of the fan’s delivery and water gauge among the major working territories of the mine. Such surveys, made at least annually, and coupled with routine daily surveys of air conditions at the working faces should provide a dependable means of keeping the power cost of ventilation at a minimum, while providing ventilation of maximum effectiveness throughout the mine.

*Estimated purchase cost less than $300. Much of it can be made in a well-equipped machine shop at lower cost.
### Recent Bibliography of Mine-Ventilation Surveys

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RECENT PUBLICATIONS OF
THE ENGINEERING EXPERIMENT STATION†


Circular No. 23. Repeated-Stress (Fatigue) Testing Machines Used in the Materials Testing Laboratory of the University of Illinois, by Herbert F. Moore and Glen N. Krouse. 1934. Forty cents.


Reprint No. 3. Chemical Engineering Problems, by Donald B. Keyes. 1935. Fifteen cents.


†Copies of the complete list of publications can be obtained without charge by addressing the Engineering Experiment Station, Urbana, Ill.


Reprint No. 7. Papers Presented at the Second Annual Short Course in Coal Utilization, Held at the University of Illinois, June 11, 12, and 13, 1935. None available.


*A limited number of copies of bulletins starred are available for free distribution.
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