Bulletin 285

DEPARTMENT OF COMMERCE
WILLIAM F. WHITING, SECRETARY
BUREAU OF MINES
SCOTT TURNER, DIRECTOR

COAL-MINE VENTILATION FACTORS

BY

H. P. GREENWALD and G. E. McELROY

PRICE 25 CENTS
Sold only by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1929

CONTENTS

Page
- Introduction 1
  - Scope of investigation 2
  - Acknowledgments 2
- Summary of results 3
  - Air measurement 3
  - Leakage at mine doors 3
  - Friction factors for straight airways 4
  - Resistance due to mine cars 4
  - Resistance due to bends 5
  - Resistance due to brattices 6
- Test methods 6
  - Experimental mine 6
  - Measurements of air velocity and volume 6
    - Determination of air velocity 6
    - Measurement of velocity pressure 8
    - Measurement of temperatures and barometric pressures 10
    - Methods of computation 11
  - Air-measuring station at 1B–100 12
    - Instruments 12
    - Differential static traverses 13
    - Velocity traverses 16
    - Center constants 17
    - Pressure loss due to air-measuring station 19
  - Air-measuring station at fan drift 22
    - Instruments 22
    - Differential static traverses 22
    - Center constants 24
  - Check air-measurement tests 25
  - Measurement of pressure losses 27
    - Theory 27
    - Static stations 27
    - Static tubes 28
    - Static-tubing connections 30
    - Tests of static tubes 30
    - Static differentials at static stations 30

Page
- Test methods—Continued.
  - Measurement of—Continued.
    - Effect of extended turbulence on pressure-loss measurements 32
  - Measurement of sections 33
  - Test procedure 34
  - Pressure-loss calculations 34
- Door-leakage tests 35
- Pressure losses in straight entries 38
  - Test sections used 38
  - Scope of test work 38
  - Resistance of clear straight entries 40
    - Effect of deflector brattices across cut-through dead ends 41
    - Effect of roughening of floor 42
    - Effect of shelter holes 42
    - Check tests in section *C–D* 43
  - Resistance of timbered straight entries 43
    - Split-timber sets on 5-foot centers 45
    - Split-timber sets on 10-foot centers 46
    - Effect of timber spacing on resistance 48
    - Crossbars only on 5-foot centers 48
    - Center posts only on 5-foot centers 50
- Pressure losses caused by mine cars 52
  - Tests in untimbered entry 53
    - Effect of number of cars in trip 53
    - Effect of different locations in test section 56
    - Effect of different spacings between cars 57
    - Effect of size of car 60
    - Loaded and empty cars 62
    - Cars opposite cut-through dead ends 62

Page
Pressure losses caused by mine cars—Continued.
  Tests in timbered entry 64
    Five-car trip with timbers on 5-foot centers 64
    Five-car trip with timbers on 10-foot centers 65
Pressure losses caused by right-angle bends 66
  Test section used 66
  Scope of test work 66
  Resistance of a single right-angle bend 67
    Effect of open dead end 68
    Effect of curves and bevel on inner corner 69
    Effect of curve on outer corner 71
    Effect of curves on both corners 72
    Effect of radial vanes 73
    Effect of straight extensions to radial vanes 77
    Effect of Venturi bends 77
  Resistance of two closely spaced right-angle bends 80
  Resistance of a double right-angle bend 80
    Effect of modifications of first bend on pressure losses at second bend 80
Pressure losses caused by right-angle bends—Continued.
  Resistance of a double right-angle bend—Continued.
    Relative effect of similar modifications of both bends 84
    Theory of air flow at a double right-angle bend 86
  Resistance of a reverse right-angle bend 86
Pressure losses and leakage of canvas brattices 89
  Check and line brattices in rooms 89
    Test section used 89
    Scope of test work 90
    Results of pressure-loss tests 92
    Results of leakage tests 94
  Line brattices in entry dead end 96
    Test section used 96
    Scope of test work 97
    Results of pressure-loss tests 97
    Results of leakage tests 100
    Efficiency of line brattices 103
Index 105

ILLUSTRATIONS

Fig. Page
1. Plan of experimental mine, showing location of test section and air-measuring and static stations 7
2. Wahlen gauge or Illinois differential micromanometer 9
3. Ellison gauge 10
4. Air-measuring station at 1B–100 12
5. Details of station side of 1B–100 air-measuring station 13
6. Close view of departure side of 1B–100 air-measuring station, showing center Pitot tube, cross wires, and piezometer plates in the foreground 14
7. General view of departure side of 1B–100 air-measuring station 15
8. Approach side of 1B–100 air-measuring station 16
9. Pitot tubes used at 1B–100 air-measuring station 17
10. Guide apparatus for traverse Pitot tube used at 1B–100 air-measuring station 18
11. Details of piezometer plates used at 1B–100 air-measuring station 19
12. Wahlen-gauge side of instrument chamber of 1B–100 air-measuring station 20
13. Inclined-gauge side of instrument chamber of 1B–100 air-measuring station 21
14. Pitot tubes used at fan-drift air-measuring station 23

Fig. Page
15. Interior of duct at fan-drift air-measuring station 24
16. Interior of instrument shelter at fan-drift air-measuring station 26
17. Static-pressure tube and holder 28
18. Static tube in place in the mine entry 29
19. Ventilation door between butt entries 36
20. Typical rib profile and cross sections along butt entries 39
21. Test section *A–B* with corresponding area graph 40
22. Split-timber sets used in pressure-loss tests 44
23. Area graph of No. 2 butt entry with split-timber sets erected on 5-foot centers 44
24. Area graph of No. 2 butt entry with split-timber sets erected on 10-foot centers 46
25. Variation of resistance with number of center posts 51
26. Mine car used in pressure-loss tests 52
27. Mine cars used in pressure-loss tests 53
28. Variation of pressure loss with number of cars 55
29. Variation of resistance of five cars with spacing of cars 59
30. Relation of single-car resistance and ratio of car area to entry area 63
31. Trip of cars used in timbered section in pressure-loss tests 64
32. Test section *B–C* with corresponding area graph 67
33. Modifications of inner corner of single right-angle bend 69
34. Modifications of both inner and outer corners of right-angle bend 72
35. Curves and radial vanes on the corner of No. 2 butt and the 475 cut-through 74
36. Radial vanes used in addition to curved surfaces of 3 and 12 foot radii 75
37. Radial vane used in addition to curved surfaces of 6 and 15 foot radii 75
38. First type of Venturi used on right-angle bends in pressure-loss tests 78
39. Second type of Venturi used on right-angle bends in pressure-loss tests 79
40. Relation of resistance of the two bends in test section *B–C* 82
41. Test sections *A–Z*, *Z–D*, and *Z–F* with corresponding area graphs 87
42. View of No. 6 room from the room neck 90
43. Last cut-through from No. 4 to No. 5 room 91
44. Single-thickness check brattice in place on No. 1 butt entry immediately outby No. 6 room 92
45. Double-thickness check brattice on No. 1 butt entry 92
46. Canvas door in place on No. 1 butt entry 93
47. Volume of air delivered to the face of an entry by line brattices 102

COAL-MINE VENTILATION FACTORS[1]

By H. P. Greenwald and G. E. McElroy

INTRODUCTION

Ventilation has been a primary problem in coal mining since mines were first worked under sufficient cover to encounter inflammable or other noxious gases. Quantitative requirements conforming to established safety standards are well known, so that the major problem that confronts the mine operator is: How can the necessary volumes of air be taken from the atmosphere outside the mine and efficiently distributed to the working faces?

The problem of coursing mine air divides naturally into two parts; the first concerns the fan and its prime mover, and the second concerns the mine through which the fan must force the air current.

The design and efficiency of fans have received much attention from manufacturers and others, but the resistances encountered by moving air underground and means of reducing the resistances have not received an equal amount of investigation. This is natural, because investigations of value could be made only in actual mine workings and then only with the aid of delicate and expensive measuring instruments. Furthermore, few operating mines could well consent to the interruptions that extended work of this kind would cause.

In coal-mine ventilation problems the works of Atkinson[2] and Murgue[3] have been the standard guide for many years. Later compilations have been made, such as that of Fitch.[4] However, though most of the experiments of these authorities were carefully conducted, their results are suspected of containing large errors. It was thought that such errors could be eliminated in new determinations by the use of more sensitive instruments and by the observance of certain details of technique essential to the correct measurement of air flow and the pressure differences causing it. It was also thought desirable to extend available data to cover conditions found in modern coal mines.

---

[1] Work on manuscript completed October, 1927.

[2] Atkinson, J. J., "On the theory of ventilation of collieries": Trans. North of England Inst. Min. Eng., vol. 3, 1854–5, pp. 73–222.

[3] Murgue, D., "Experimental investigations on the loss of head of air currents in underground workings": Trans. Am. Inst. Min. Eng., vol. 23, 1893, pp. 63–112.

[4] Fitch, Thomas W., jr., Mine Resistance: West Virginia Coal Min. Inst., June, 1910. Reprinted by American Blower Co. as pamphlet 297.

The Bureau of Mines is fortunate in owning an experimental mine.[5] This mine has been developed in the Pittsburgh coal bed at Bruceton, near Pittsburgh, Pa., and allowed this investigation to be conducted in actual mine workings. The test work which forms the basis of the present report was started in January, 1922; it was not completed until November, 1923, however, partly because of the necessity of developing methods and instruments, but mainly because of delays and interruptions occasioned by other test work. Concurrently, a similar investigation of metal-mine ventilation factors was conducted by the bureau in the metal mines of Butte, Mont., and a report[6] of this work has been published. Less extensive investigations of a similar precise nature have been conducted by the bureau in an Indiana coal mine[7] and by the University of Illinois Experiment Station[8] in Illinois coal mines.

Brief summaries of parts of the present report have been published at intervals by the bureau as Reports of Investigations, Serial Nos. 2602, 2621, 2647, 2671, and 2853.

SCOPE OF INVESTIGATION

Data on the pressure losses caused by the resistance of coal-mine entries to the flow of air were obtained under as many practical conditions as were available. One set of tests gave data on clear straight entries. Conditions were then modified by introducing mine cars in different numbers, spacings, and sizes; timbering of different kinds at different spacings; timbers and cars in combination; and side openings, such as shelter holes and cut-through dead ends. Another set of tests gave information on the resistance of right-angle bends and the reductions in resistance obtained by modifying them with curves or Venturi bends. A third set of tests determined the resistances caused by canvas brattices as used to deflect air to room and entry faces.

ACKNOWLEDGMENTS

This investigation forms part of a general program of ventilation research organized by G. S. Rice, chief mining engineer of the Bureau of Mines, and was conducted under the administrative direction of J. W. Paul, then chief of coal-mining investigations and in charge of the experimental mine. The work at its inception was in direct charge of G. E. McElroy, mining engineer, assisted by H. P. Greenwald, then assistant physicist; H. C. Howarth, coal-mine superin-

---

[5] A detailed description of the experimental mine and its equipment is given in Bureau of Mines Bulletin 167, Coal-dust Explosion Tests in the Experimental Mine, 1913 to 1918, Inclusive, by G. S. Rice and others, 1922. See pp. 33 to 58.

[6] McElroy, G. E., and Richardson, A. S., The Resistance of Metal-mine Airways: Bull. 261, Bureau of Mines, 1927, 149 pp.

[7] McElroy, G. E., Ventilation Tests in an Indiana Coal Mine: Bureau of Mines publication in preparation.

[8] Callen, A. C., and Smith, C. M., The Measurement of Air Quantities and Energy Losses in Mine Entries; Univ. of Illinois Exp. Sta. Bull. 158, 1926, 77 pp.; Part II, by the same authors, Bull. 170, 1927, 74 pp.

tendent; and V. C. Allison, assistant chemist. Mr. McElroy left Pittsburgh in July, 1922, to carry on similar test work at Butte, Mont., and Mr. Greenwald then assumed charge of the work. As the investigation progressed, additional observers were necessary, and W. J. Fene and C. W. Owings, assistant mining engineers, gave a considerable part of their time to the tests. Others of the experimental-mine staff who spent a large proportion of their time on this work were C. R. Wilson, physicist's helper; E. S. Hertzog, laboratory assistant; and P. L. Golden, laboratory aide.

Prof. A. C. Willard, of the University of Illinois Experiment Station, acted as consulting ventilation engineer during the development of test methods. The investigation was greatly aided by apparatus borrowed from the American Society of Heating and Ventilating Engineers, often at times when the society might well have used the apparatus in its own laboratory.

SUMMARY OF RESULTS

AIR MEASUREMENT

Since the value of all results of ventilation tests depends upon their accuracy, much time was spent in developing and testing equipment and methods. Air measurement was considered especially important; a series of tests was made in which the measurement of air at the rectangular section selected for test work was checked against simultaneous measurement of the same air flow in a circular section. These tests showed discrepancies of but ½ to 2 per cent in air quantities; and, as the errors seemed to center largely at the latter station, the former was considered sufficiently accurate for test purposes.

LEAKAGE AT MINE DOORS

Conditions in the check air-measurement tests were such that measurements of the leakage at two double-door air locks could be made with little extra trouble. The doors tested were 7 feet wide and 5 feet high and were made of two layers of 1 by 12 inch boards set at right angles to each other, with heavy building paper between the two layers. The frames were gunited tight and the doors closed flush with the door jambs. One set of doors had dry canvas flaps along the bottom, and the other had wet flaps. Test results were quite variable, but an analysis yielded the following approximate figures in cubic feet per minute for the leakage at 1-inch water pressure:

Air lock, wet flaps	1, 400
Single door, wet flaps	1, 700
Air lock, dry flaps	2, 000
Single door, dry flaps	3, 000 to 4, 000

FRICTION FACTORS FOR STRAIGHT AIRWAYS

Pressure-loss tests made to determine the resistance of the experimental-mine airways may be summarized as follows:

The friction factor K (defined under "Pressure-loss calculations," p. 34) for clean, straight, untimbered entry with fairly smooth floor, and for air velocities of 300 to 900 feet per minute averaged 0.0000000036 (abbreviated $0.0^{8}36$); this is probably as low a value as will be obtained for an airway in coal. For the entry just described, the friction factor is an inverse function of the air velocity; but above 300 feet per minute variation in velocity has no practical significance. A moderate increase in the roughness of the floor increased the friction factor about 5 per cent. For haulage entries with normal spillage of coal and dribbling from roof, the friction factor might safely be taken as $0.0^{8}40$. Closing cut-through dead ends, located on 100-foot centers, with deflector brattices decreased the friction factor 6 per cent. The addition of shallow shelter holes, cut in one rib midway of the cut-throughs, produced no appreciable change in the friction factor.

With split timbers placed in an otherwise clean straight entry friction factors and the resistance in terms of the normal resistance (untimbered) were determined, with the following results:

Friction factors and resistance

	K	Times normal resistance
3-piece sets on 5-foot centers	$0.0^{7}100$	6.5
3-piece sets on 10-foot centers	$.0^{8}84$	5.0
Crossbars only	$.0^{8}75$	3.5
Center posts only	$.0^{8}60$	3.3

For timbered entry conditions the friction factor was found to be practically independent of the velocity throughout the range investigated.

RESISTANCE DUE TO MINE CARS

The results of the tests with mine cars may be summarized as follows:

1. Resistance due to mine cars may be divided into end resistance and side resistance. The former is caused by surfaces at right angles to the direction of air flow and the latter by surfaces parallel to the air flow and by increased resistance in the zone of constriction due to increased velocities.

2. For one car occupying about 17.5 per cent of the clear area, the end resistance is about 75 per cent of the total.

3. For cars coupled together in trips, the end resistance is the same, irrespective of the number of cars; the side resistance is that for one car multiplied by the number of cars.

4. As the cars in a trip are separated, the resistance increases with the increase in distance between cars until a maximum is reached equal to the resistance of one car multiplied by the number of cars. The resistance is then constant for greater spacings. For test conditions the critical spacing was about 25 feet.

5. Tests of the effect of car size showed that resistance for both single cars and for trips increases approximately as the square of the ratio of end area of car to total area of airway.

6. The difference in resistance between loaded and empty cars has no practical significance.

7. The resistance caused by cars varies as the square of the velocity or volume of the air current.

8. For a car occupying 17.5 per cent of the total area of airway, the resistance is equivalent to approximately 100 feet of airway; in trips, each additional car after the first adds 25 feet to this value. For a car occupying 40 per cent of the total area, the equivalent in feet of airway was estimated to be about 400.

9. For airway conditions other than that tested, the expression of losses in equivalent feet will vary directly as the area and inversely as the perimeter and friction factor. For the test conditions the area was 57 square feet, the perimeter 31 feet, and the friction factor $0.0^{8}36$.

RESISTANCE DUE TO BENDS

Pressure-loss tests were made on right-angle bends in 6 by 9 foot entries, with the following results:

1. The normal loss with square inner and outer corners was 1.4 times the velocity pressure.

2. The greatest reduction of pressure loss considered practical was accomplished with the inner corner of the bend rounded on a 6-foot radius and with the outer rib lines joined by a 15-foot radius vane. These modifications reduced the loss to one-fifth normal.

3. A very marked reduction in the loss was obtained as the inner radius was enlarged.

4. A 45° bevel 5 feet long on the inner corner reduced the loss to about one-half normal.

5. A special Venturi bend installed without alteration of the existing square corner reduced the loss to about one-half normal. This construction effected a smooth reduction in area to two-thirds normal at the bend, with a gradual increase to normal area directly after the bend.

6. The loss at the second of two similar square-corner right-angle bends in series, 50 feet apart and with the air flow deflected in the

same direction, was less than half of that determined for the first bend. When the air flow at the second bend was deflected in the opposite direction the loss was approximately equal at both bends.

RESISTANCE DUE TO BRATTICES

Canvas brattices are extensively used in the ventilation of coal mines, and a series of tests was made to obtain some information on the pressure loss caused by them and the leakage of air through them. Two types were tested; the first were check and line brattices designed to conduct air to the face of rooms, and the second were line brattices used to conduct air to entry faces in advance of the last cut-through. The details of these tests can not readily be summarized, hence the reader is referred to data given in a later section (pp. 89 to 104).

TEST METHODS

EXPERIMENTAL MINE

The experimental mine, developed on the room-and-pillar system, is about 1 mile south of Bruceton and 13 miles south of Pittsburgh, in Allegheny County, Pa. The extent of the workings at the time of the ventilation tests and the names of the various entries are shown in Figure 1. The mine is ventilated by a fan about 200 feet from the pit mouth, rated at 80,000 cubic feet per minute at 2 inches water gauge.

The left butt entries provided in compact form all the conditions desired for resistance tests—straight entries, cut-throughs, right-angle bends, dead ends, and rooms—and it was decided that all work on resistance tests would be confined to these entries.

Normally all cut-throughs between the butt entries, except the last, were closed with air-tight stoppings, and the air travel was as shown in Figure 1.

MEASUREMENTS OF AIR VELOCITY AND VOLUME

DETERMINATION OF AIR VELOCITY

The determination of air velocities by velocity pressure is the most precise method applicable to mine conditions and was the method selected to be used. The velocity pressure at any point can be obtained as a differential pressure on a gauge by connecting the total pressure to one end and the static pressure to the other. Almost any type of uniform-bore tube, pointed directly against and parallel to the line of air flow, obtains the total pressure without appreciable error, even though the tube is slightly off line. It is more difficult to obtain true static pressure; the best method is that through capillary openings in a tube or plate parallel to the flow of air. The difficulty in obtaining a true static pressure arises from the fact that

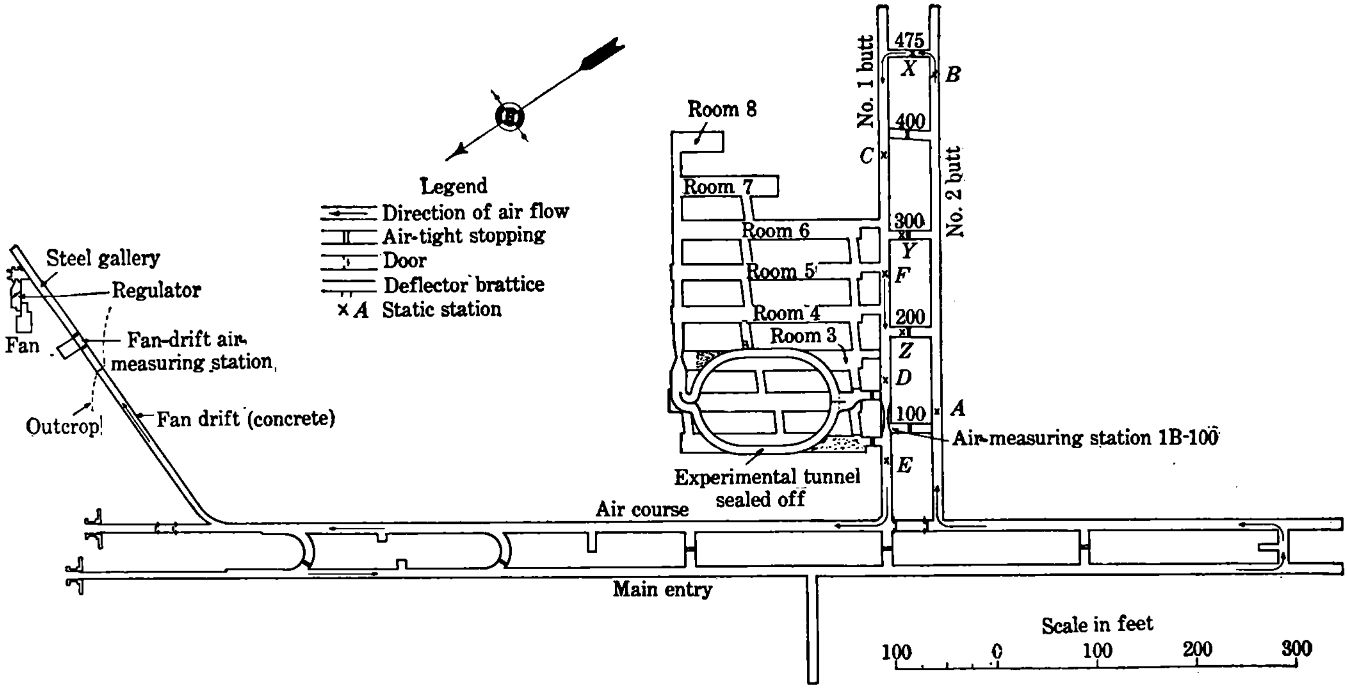


FIGURE 1.—Plan of experimental mine, showing location of test section and air-measuring and static stations

unless the air flow is absolutely streamline and free from turbulence velocity-pressure effects are exerted through the capillary static openings (the effect being greater the larger the opening) and increase or decrease the observed pressures above or below the true static pressures. Rowse[9] found that a piezometer ring, or capillary openings in the wall, was slightly more accurate for determining static pressures in a straight pipe than the static member of a Pitot tube, but that air quantities determined by the latter were accurate within 1 per cent when the static openings were very fine (0.02-inch) holes, as in the A. B. C. (American Blower Co.) design of Pitot tube.

However, the condition of straight-line air flow does not obtain in mine airways. It is safe to assume that the greatest degree of turbulence exists along the periphery, because of rough walls, thus making doubtful the accuracy of piezometer static plates set in the walls. Furthermore, the installation and maintenance of piezometer plates in mine passages offer many difficulties. The standard method of traversing by a Pitot tube, in which the static pressure is determined by the static member of the tube at each point of measurement, also seems inapplicable to mine-air flow on account of the greater turbulence at points near the periphery. Consequently, the method of determining static pressures by the static member of a Pitot tube held at the center of the airway as a point of minimum turbulence was adopted as a tentative standard previous to test work, since it seemed to offer the least chance for error. Although this method required only an impact or single tube for traversing the section, another Pitot, or double, tube was provided so that comparisons could be made with observed static pressures obtained at all traverse points of the air-measuring section.

MEASUREMENT OF VELOCITY PRESSURE

Another difficulty in the pressure method of velocity determinations lies in the fact that for low air velocities the velocity pressures are so small that extreme care and very delicate instruments are necessary for accurate measurements. Below 400 feet per minute, even with the most delicate pressure-measuring instruments available. accuracy drops off rapidly under conditions of mine-air flow. On this account it was considered necessary to restrict the size of the airway at the point of measurement to obtain higher velocities and velocity pressures than would otherwise be obtained.

Wahlen gauge.—For the exact measurement of very small velocity pressures there was available a differential gauge, known as the Wahlen gauge, developed at the Engineering Experiment Station of the Uni-

---

[9] Rowse, W. C., "Pitot tubes for gas measurements": Trans. Am. Soc. Mech. Eng., vol. 35, April, 1913, p. 633.

versity of Illinois.[10] In this gauge (fig. 2) differential pressures are obtained by balancing the liquid displacement by raising or lowering the right-hand bulb with a micrometer screw. The distance moved is read directly on a vernier to 0.001 inch and is easily estimated to the nearest 0.0001 inch of gauge liquid.

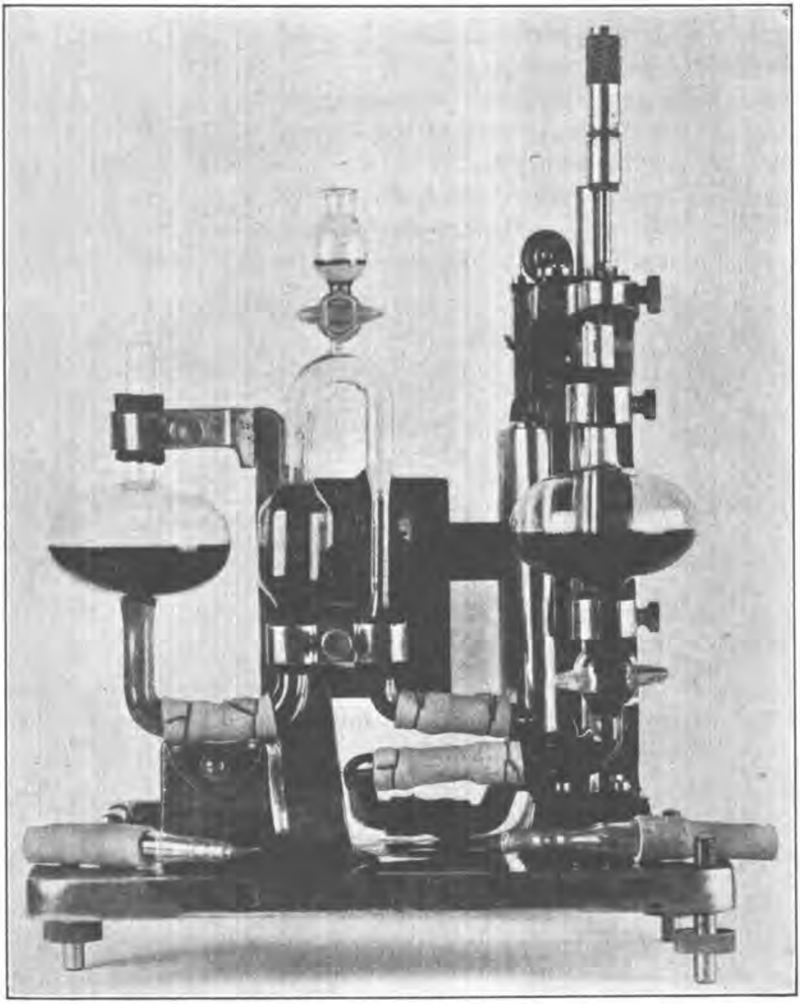


FIGURE 2.—Wahlen gauge or Illinois differential micromanometer

Use of the Wahlen gauge underground brought out many problems in its operation, which were solved as they arose. Among them may be cited the necessity of preventing the alcohol in the gauge from absorbing moisture from the damp mine air, and the heating of the instrument chamber to fairly constant temperature to insure proper operation at all times. Suitable illumination of the capillary tube

---

[10] Willard, A. C., Kratz, A. F., and Day, V. S., Investigations of Warm-air Furnaces and Heating Systems: Univ. of Illinois Exp. Sta. Bull. 120, 1921, pp. 91-98.

was also necessary. The gauge was sensitive to the small fluctuations occurring continuously in velocity and static pressures, and a scale was etched on the capillary tube so that such fluctuations could be read at regular intervals and a series of readings averaged. This system was the subject of careful mathematical and experimental investigation and was found to be correct and satisfactory. The question of parallax was considered but was found to have no serious influence on gauge readings.

Ellison gauge.—In some of the earlier work a commercial inclined draft gauge, known as the Ellison gauge, was used for measurements at the higher velocities. This gauge (fig. 3) had a 1-inch range on a 15-inch scale. Graduations were to 0.01 inch, and 0.001 inch was estimated. The graduations were calibrated against a Wahlen gauge on a closed-pressure system, and readings were corrected for change of gravity of the gauge liquid with temperature. Compared with the Wahlen gauges the Ellison gauges were sluggish, and frequent calibrations were required. After the scales were put on the capillary tubes of the Wahlen gauges the use of the Ellison gauge was discontinued.

FIGURE 3.—Ellison gauge

MEASUREMENT OF TEMPERATURES AND BAROMETRIC PRESSURES

The conversion of velocity pressures to air velocities involves the weight of air per cubic foot, which in turn involves air temperatures and absolute pressures. Air temperatures were obtained by a sling psychrometer of the Bureau of Mines type. It was found that air temperature varied considerably with the season of the year. The observed range was from 49° to 69° F. Absolute pressures were obtained by means of a small aneroid barometer at one point only, and these readings were corrected for other points according to the differential static pressures existing. The aneroid was corrected at intervals against a standard mercury barometer.

METHODS OF COMPUTATION

Weights of moist air per cubic foot were calculated according to the formula:[10]

$$\text{Weight of air} = \frac{1.3246}{459+t} \times (B - 0.378f)$$

where t = dry bulb temperature in degrees F.
B = barometric pressure in inches mercury.
f = vapor pressure at dew-point temperature.

Relative humidities were so close to 100 per cent that sufficiently accurate results were obtained by considering the air saturated and taking the air weights directly from a specially prepared table. Weights of air varied from 0.0718 to 0.0759 pound per cubic foot, the higher values being confined to the colder months.

At air-measuring stations the mean velocity was determined from the average of the traverse-point velocities. Velocities were determined from velocity pressures by the formula:

$$V = 1097.5\sqrt{\frac{VP}{d}}$$

where V = velocity in feet per minute.
VP = pressure in inches of water at 60° F.
d = weight of air in pounds per cubic foot.

This formula is derived from the basic formula for air flow:

$$v = \sqrt{2\,gh} = \sqrt{\frac{2\,gc\,VP}{12\,d}}$$

where v = velocity in feet per second.
g = 32.17 feet per second per second.
h = head in feet of air column.
c = weight of water, 62.366 pounds per cubic foot at 60° F.

To decrease the labor of calculation and to speed up the test work, the relation of the velocity at the center of the air-measuring sections to the mean velocity, termed the center constant, was determined before beginning the test work. This relation was expressed in ratios of the mean velocity; that is,

$$\text{Center constant} = \frac{\text{center velocity}}{\text{mean velocity}}.$$

The result, as used in this work, is the reciprocal of the result as expressed by certain other investigators. However, this form seems more rational and is better adapted to slide-rule computations of mean velocities from center-velocity pressures.

---

[10] Peele, Robert, Mining Engineers' Handbook: 1st ed., New York, 1918, p. 1036.

AIR-MEASURING STATION AT 1B-100

Only one station was required for air measurement for all of the pressure-loss tests; this station was erected at 1B–100 (fig. 1), where the adjoining cut-through dead end served as an instrument chamber. Details of construction are shown in Figures 4, 5, 6, 7, and 8.

INSTRUMENTS

Two special Pitot tubes and a guide apparatus, shown in Figures 9 and 10, were designed for this station. The tube designated as "center tube" was fixed, by means of the collar, permanently in place with its tip in the center of the air-measuring plane and with the shaft horizontal and at right angles to the center line of the straight section. The tube designated as the "traverse tube" was movable, and by means of the guide apparatus could be placed with its tip at the exact center of each of the twenty 1-foot squares into which the 4 by 5 foot air-measuring plane was divided. Owing to the sag and vibration in a tube of such length, the end of the tube was supported near the shaft on taut horizontal cross wires.

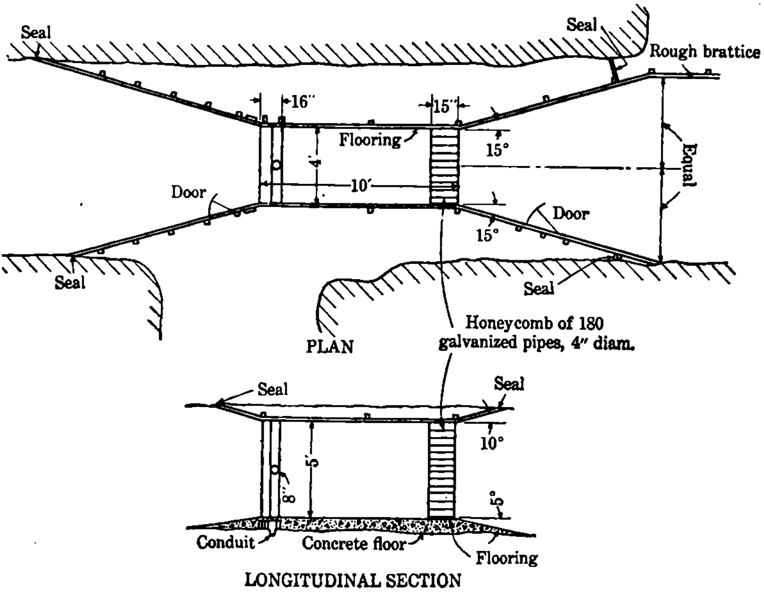


FIGURE 4.—Air-measuring station at 1B–100

For comparative determinations of static pressures a piezometer ring was installed at the air-measuring plane. The ring consisted of four brass plates, one centered in each wall of the air-measuring plane, connected by a ring of tubing outside the section; the static pressure was taken from a point on the station side of this ring. The design of these plates is shown in Figure 11, and the installation is shown in Figure 6.

Rigid table supports were constructed along one wall of the instrument chamber for the Wahlen gauges (fig. 12), and a rigid framework was placed against the opposite wall for mounting the inclined gauges (fig. 13). In the illustrations the gauge connections are arranged for pressure-loss tests. Use of the capillary scales on the Wahlen gauges made the use of inclined gauges unnecessary and they were subsequently removed.

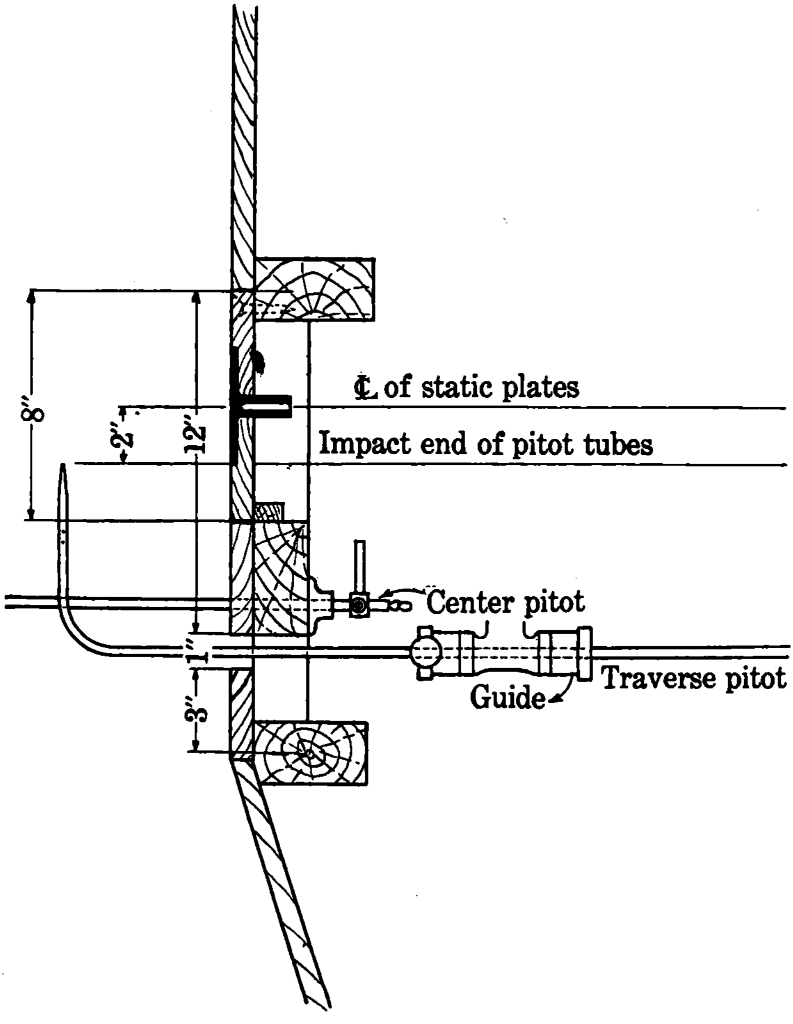


FIGURE 5.—Details of station side of 1B-100 air-measuring station

DIFFERENTIAL STATIC TRAVERSES

Before the pipe honeycomb was installed at the approach end of the straight section of the 1B-100 air-measuring station, a series of tests was made to find the differences in static pressures as determined

(1) by Pitot tube at traverse points, (2) by Pitot tube at center point, (3) by piezometer ring, and (4) by pressure in the instrument chamber.

With a center velocity of 400 feet per minute the difference between the traverse-tube statics and the other static pressures ranged from 0 to 25 per cent of the velocity pressures, with an average of approximately 8 to 10 per cent. At 2,000 feet per minute these differences were just about halved, except for the instrument-chamber static, which gave maximum differences from traverse-point statics of close to 30 per cent and average differences of about 15 per cent; this exception was possibly due to greater leakage, but it was probably also caused by velocity-pressure effects on the slot opening. Direct comparisons were also obtained between the three base statics—center Pitot-tube, piezometer, and instrument-chamber static. The results showed that the statics obtained by the center Pitot were

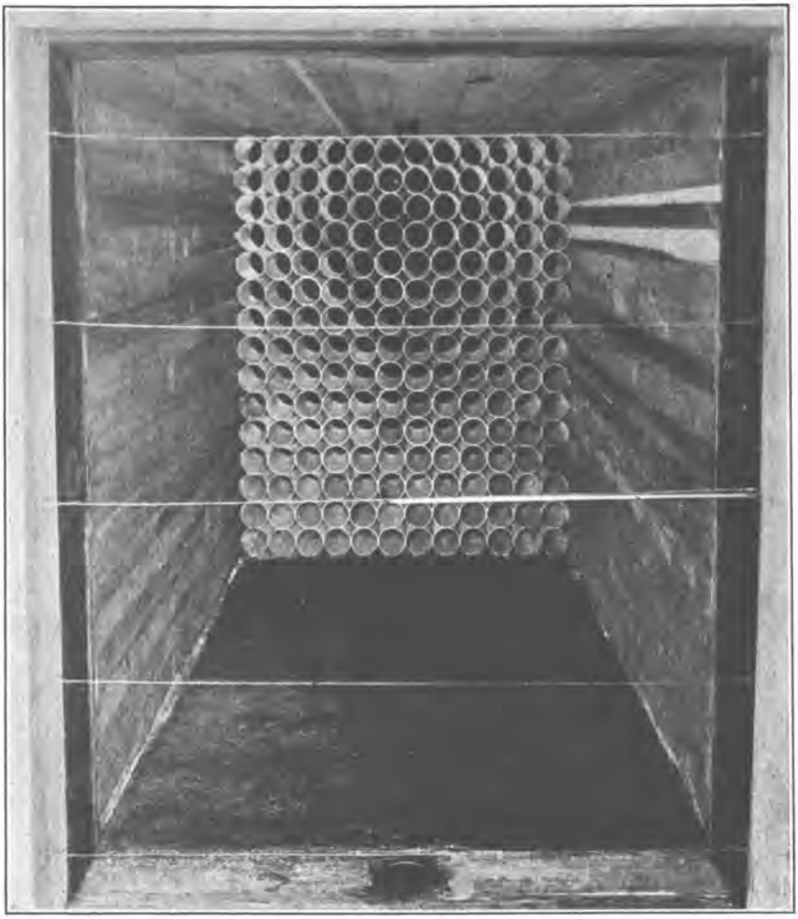


Figure 6.—Close view of departure side of 1B-100 air-measuring station, showing center Pitot tube, cross wires, and piezometer plates in the foreground

somewhat less than those obtained by piezometer (2 to 3 per cent of the velocity pressure at 2,000 feet per minute). The instrument-chamber statics were much higher than those obtained by either piezometer plates or center tube, with differences from the latter of 12 to 15 per cent of the velocity pressure at 2,000 feet per minute.

Although the average agreement of center-tube and piezometer statics under the described conditions appeared good, yet individual static differentials for traverse points were quite erratic; therefore, in an attempt to produce more uniform air flow conditions, a honeycomb of 4-inch tubes was installed at the approach end of the straight section. With the honeycomb installed, static-pressure differentials were again determined between traverse tube and center tube, piezometer ring and instrument chamber, respectively. The results roughly checked the preceding series on a quantitative basis, but they were more constant in duplicate tests; general observations during these tests indicated more constant conditions of air flow but without very much change in the degree of turbulence.

FIGURE 7.—General view of departure side of 1B-100 air-measuring station

VELOCITY TRAVERSES

Determinations were made of traverse-point velocity pressures, using each of the four statics as bases. In addition, the set determined on traverse-tube statics was corrected to the other three by means of the differential statics previously determined. The mean velocities computed from seven sets of 20-point traverse readings for two extreme quantities of air flow were compared with the mean velocity based on center-Pitot statics. The results are shown in Table 1.

FIGURE 8.—Approach side of 1B-100 air-measuring station

TABLE 1.—*Comparative results of velocity traverses at 1B–100 air-measuring station*

Approximate center velocity, feet per minute	Mean velocity in per cent of base velocity						
	Velocity pressure direct from—				Calculated traverse-velocity pressures, using static differentials from—		
	Center-Pitot static (base)	Piezometer static	Instrument-chamber static	Traverse-Pitot static	Center-Pitot static	Piezometer static	Instrument-chamber static
400	100.0	99.4	94.1	97.7	98.2	98.3	94.3
2,000	100.0	98.8	82.0	98.9	100.0	98.4	91.7

These tests showed close enough agreement between mean velocities based on center-tube and piezometer statics to warrant going ahead with the test work. The low results by instrument-chamber statics indicate that there was some leakage, even with all the precautions taken to secure air-tightness, and they also show that instrument-station statics should not be used in conjunction with such restricted passageways.

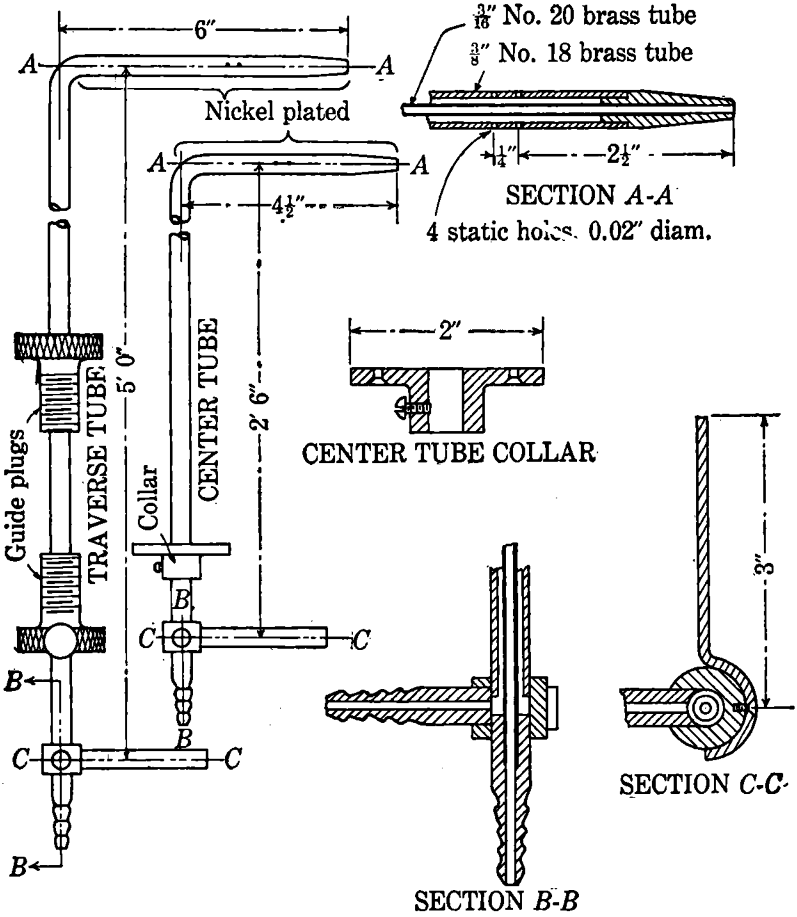


Figure 9.—Pitot tubes used at 1B–100 air-measuring station

CENTER CONSTANTS

The center constant, or ratio of center velocity to mean velocity, was very close to unity at the 1B–100 air-measuring station. The values obtained in the final determination and used in this work are given in the following table:

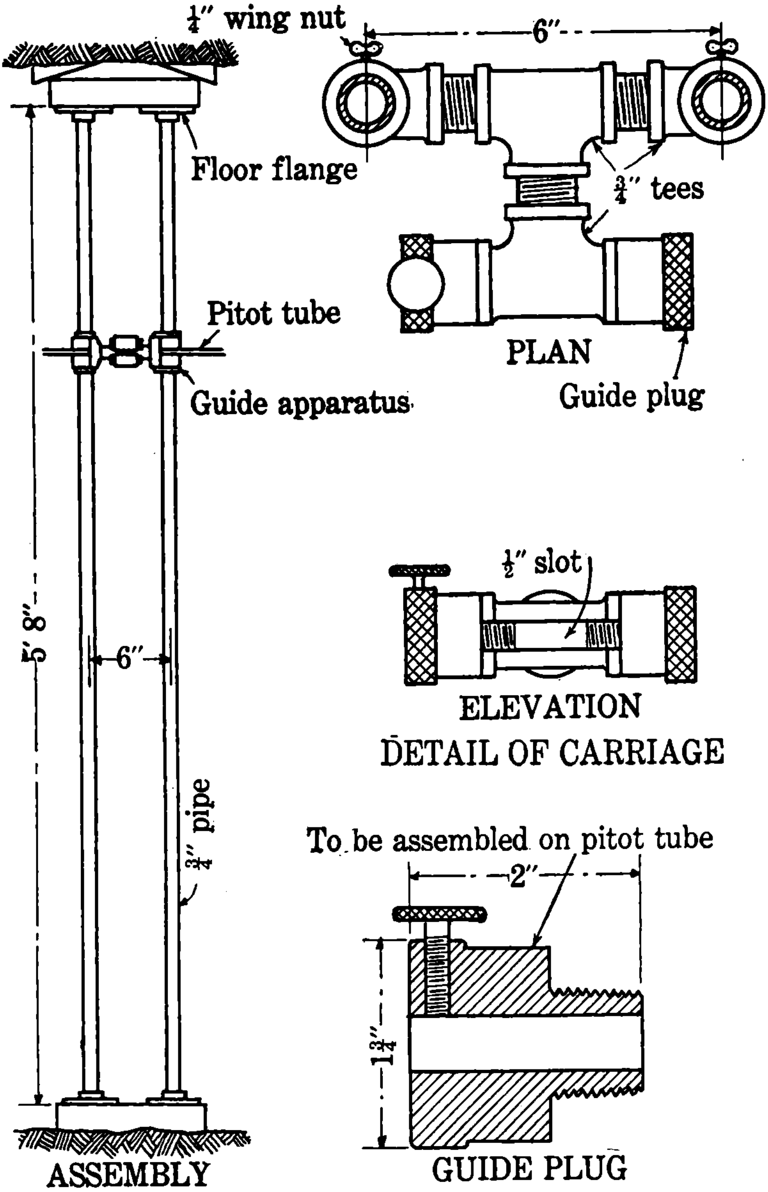


FIGURE 10.—Guide apparatus for traverse Pitot tube used at 1B-100 air-measuring station

Table 2.—*Center constants at 1B–100 air-measuring station*

Mean velocity, feet per minute	Center constant
450	1.016
825	1.009
1,375	1.006
1,960	1.002

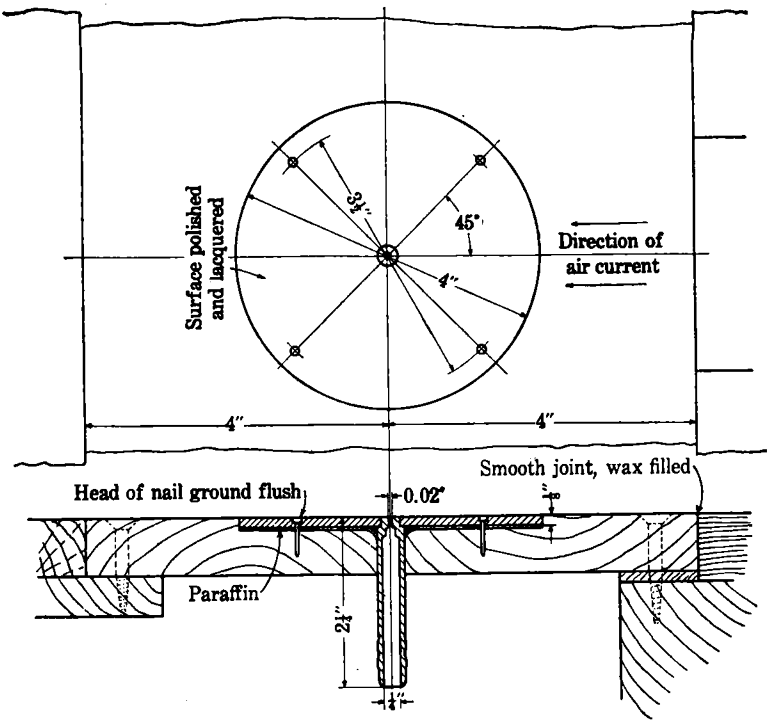


Figure 11.—Details of piezometer plates used at 1B–100 air-measuring station

PRESSURE LOSS DUE TO AIR-MEASURING STATION

As a matter of interest, the pressure loss due to the installation of the constriction and honeycomb at the 1B–100 air-measuring station was determined and found to be equivalent to one-sixth of the total mine resistance, one-third of the total resistance of the butt entries, 5.4 times the velocity pressure in the unconstricted entry, 0.75 times the difference in velocity pressures as between the constriction and the clear entry, and 900 feet of similar clear entry.

The division of the loss as between the constriction and the honeycomb was not determined, but comparison of these data with those available on similar constrictions indicates that the honeycomb was responsible for the major part of the pressure loss, possibly for as much as 80 per cent or more.

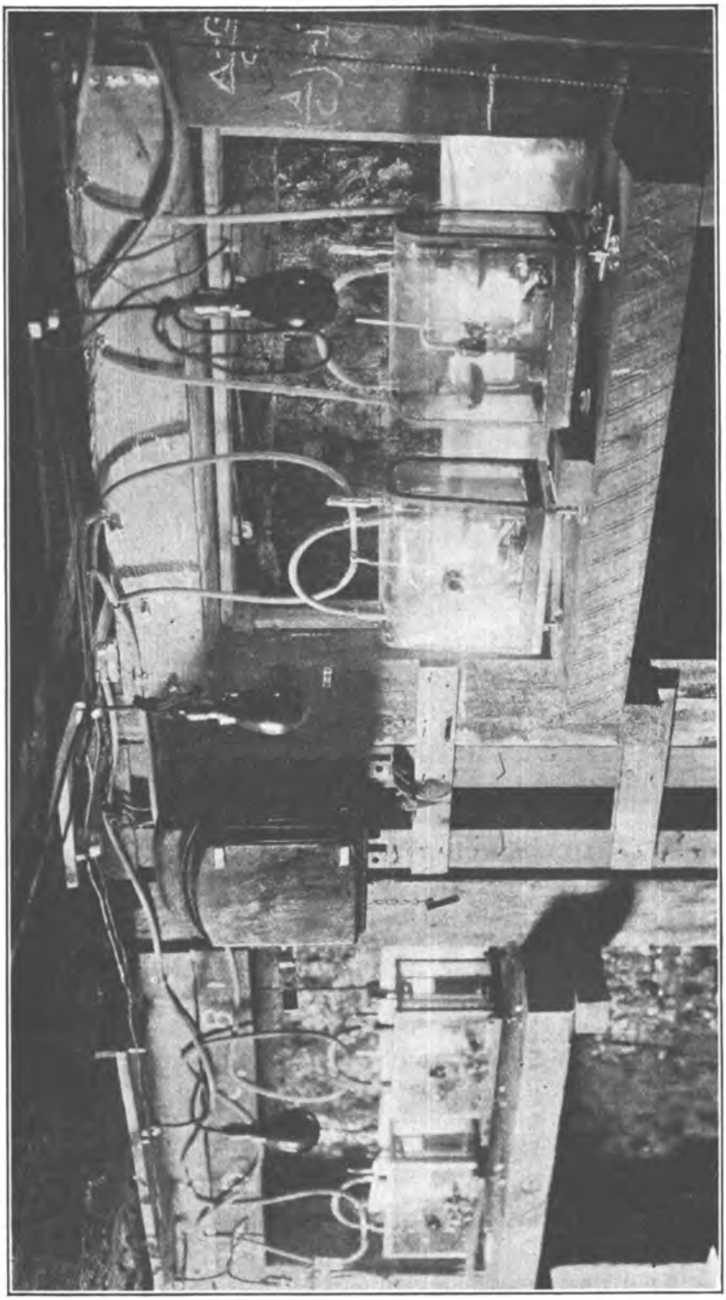


FIGURE 12.—Wahlen-gauge side of instrument chamber of 1B-100 air-measuring station

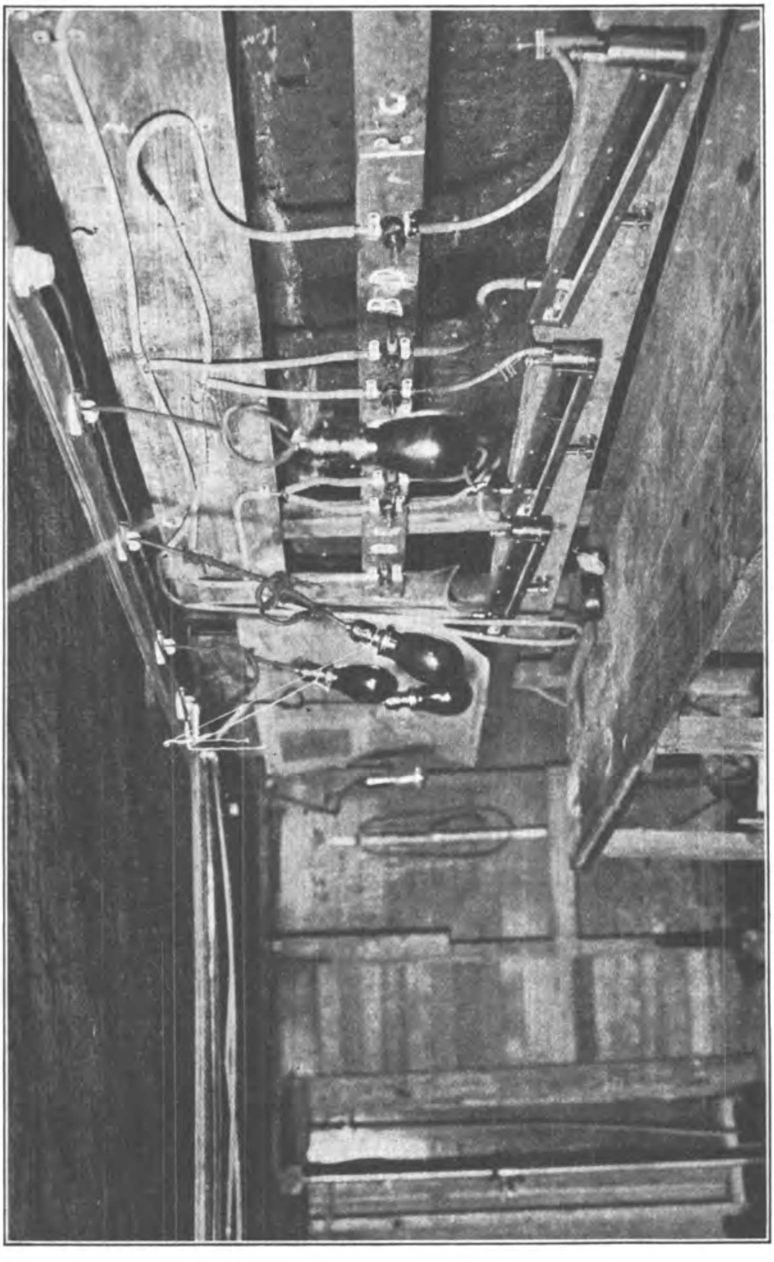


FIGURE 13.—Inclined-gauge side of instrument chamber of 1B-100 air-measuring station

AIR-MEASURING STATION AT FAN DRIFT

As a further check on the accuracy of air measurement at the 1B–100 air-measuring station, it was decided to install another station and make simultaneous measurements at both. The location selected for the second station was close to the departure end of a 6-foot-diameter concrete tube 20 feet long connecting the fan drift to the surface steel gallery. (Fig. 1.) This location offered many advantages, including an entirely different type of section without constriction; uniform straight sections for approach and departure, although rather short; and an opportunity to work with atmospheric pressure as a base. For traversing, the circular area was divided into five annular rings of equal area; traverse points were located at the intersection of the vertical and horizontal diameters with the mean radii of these areas, giving 20 traverse points for the area of 28.3 square feet.

INSTRUMENTS

Special Pitot tubes, as shown in Figure 14, were designed for traversing the large area of the fan-drift station, not only because it was desired to use center-tube static pressures—a method that requires two tubes—but also because the thickness of the concrete walls and the great length of the tubes prevented interchange of tubes. The horizontal tube was supported on both sides, whereas the vertical tube passed through a stuffing box set in the roof and carried a sleeve engaging a rigid vertical rod. Figure 15 (a photograph of the interior of the duct) shows the latter as the downward continuation of the vertical tube. Both tubes were equipped with guide levers on their exterior ends which were parallel to their interior impact ends.

To protect instruments and operators from weather conditions, a small instrument house was erected over the duct. Interior arrangements of tubes, gauges, and connections are shown in Figure 16.

DIFFERENTIAL STATIC TRAVERSES

To determine the degree of turbulence at the air-measuring plane in the fan-drift station, two sets of differential static traverses, comparing traverse Pitot-tube statics with center Pitot-tube statics, were made on two different days. The results, though somewhat variable, indicated no appreciable increase in the static differentials with increase in velocity, hence the error in velocity determinations due to this cause should decrease with increasing velocity.

Comparison of these static differentials with those for the 1B–100 station showed a greater degree of turbulence at the lower velocities but a much less degree of turbulence at the higher velocities, indicating that the use of a constriction at the 1B–100 air-measuring station was not without its disadvantage.

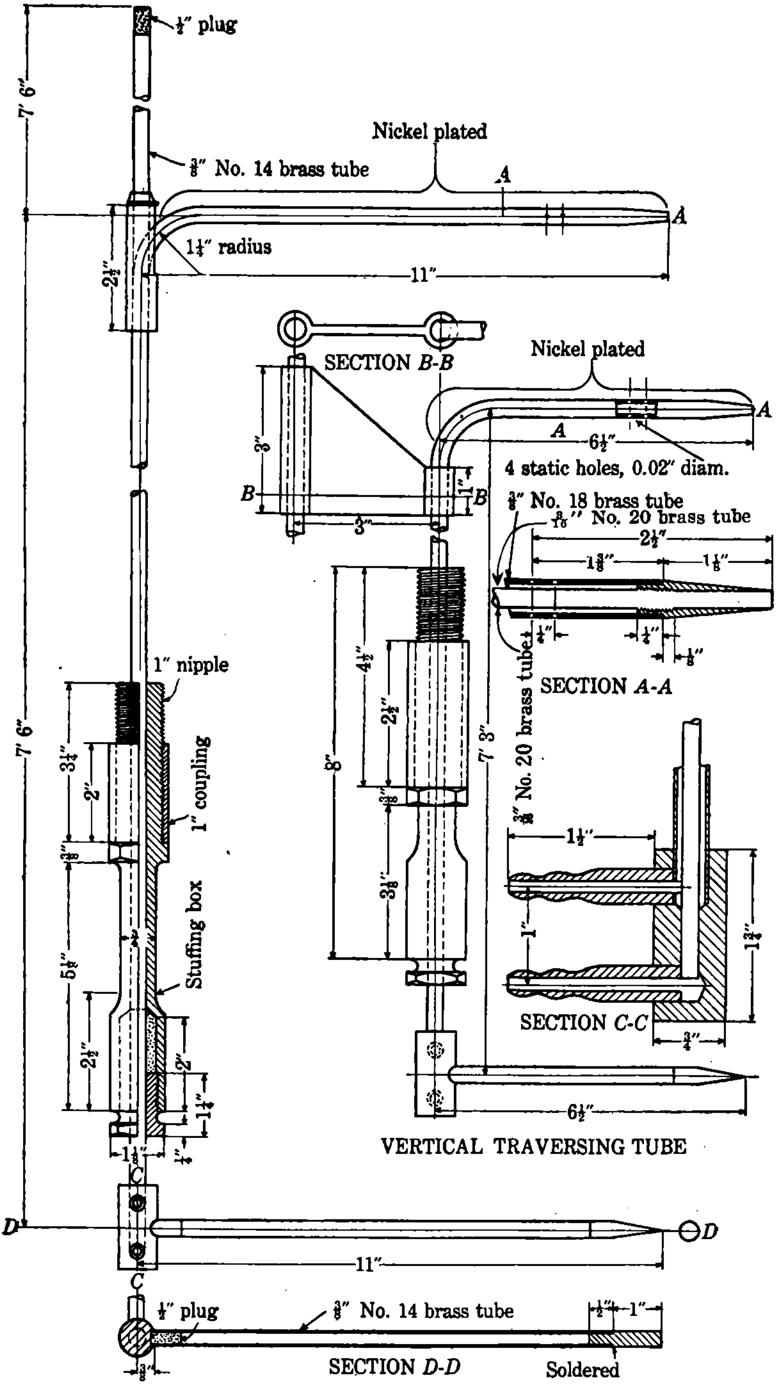


FIGURE 14.—Pitot tubes used at fan-drift air-measuring station

CENTER CONSTANTS

In determining center constants at the fan-drift station it was apparent at the start that outside wind conditions, as determined by simultaneously observing gauge readings and smoke issuing from a nearby smokestack, had an important effect on velocity distributions within the air-measuring section. However, the check air-measurement tests, for which this station was installed, were run on comparatively quiet days, and a series of center-constant traverses was therefore made under the same conditions. These results are shown in Table 3.

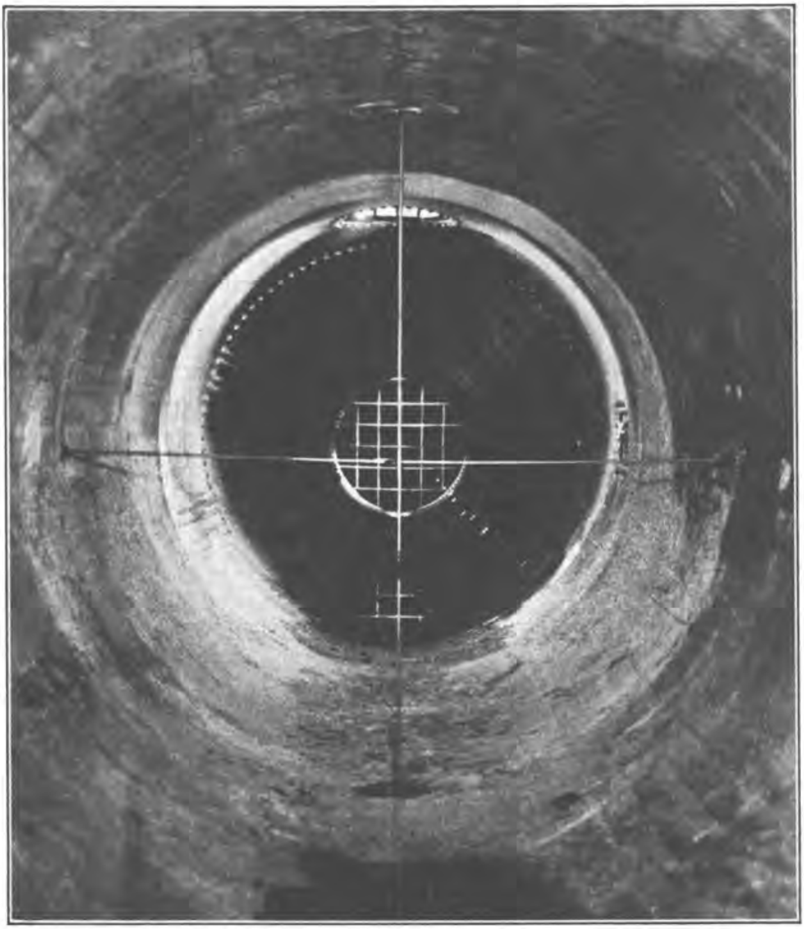


FIGURE 15.—Interior of duct at fan-drift air-measuring station

TABLE 3.—*Center constants at fan-drift air-measuring station*

Mean velocity, feet per minute	Center constant	Outside wind conditions
1,400	1.132	Very light south to southwest breeze.
1,405	1.122	Do.
855	1.064	Very light steady south breeze.
825	1.109	Very light to very steady south breeze.
325	1.114	Practically quiet.
325	1.094	Do.

CHECK AIR-MEASUREMENT TESTS

In order to conduct check air-measurement tests by measuring the same air flow at the 1B–100 station inside the mine and at the fan-drift station outside the mine it was necessary to use special care to prevent leakage of air either into or from the air current between these two points. The stoppings between the main entry and air course were of concrete, well hitched into the ribs, and required only the sealing of a few small pipe openings. Air-tight stoppings were made at each of the two double-door air locks by nailing one door of each lock shut and applying a heavy coat of gunite to the frame.

The results of simultaneous measurement of volumes at the two stations, determined by 20 center velocity-pressure readings at 15-second intervals, are given in Table 4.

TABLE 4.—*Check air-measurement tests*

Test No.	Volume, cubic feet per minute		Difference	
	Fan-drift station	1B–100 station	Cubic feet per minute	Per cent [1]
162	10,260	10,480	220	2.1
161	10,200	10,750	550	5.1
160	17,680	18,050	370	2.0
159	17,750	18,020	270	1.5
158	23,700	23,830	130	.5
157	23,570	23,760	190	.8
156	35,070	35,470	400	1.1
155	35,220	35,520	300	.8
154	44,200	45,000	800	1.8
153	44,200	45,050	850	1.9

[1] Based on volumes at 1B–100.

These data show discrepancies of 1 to 2 per cent. The differences are slightly greater at lower and higher velocities than at intermediate velocities, and larger quantities are indicated at the inside station than at the outside station. Since any leakage would have reversed the latter condition, it was concluded that the airway was air-tight and that the discrepancies were due to errors in measurement.

Also, it seemed probable, because of the less constant conditions of air flow at the outside station, that the larger percentage of the differences noted was due to unavoidable errors at that station rather than at the 1B–100 station. This statement of regularity of air flow is based not only on general observations made during test work, but also on a study of simultaneous center velocity-pressure records made during these tests. This study shows variations of center velocities of 1 to 10 per cent at the fan-drift station, above or below the average of 20 observations, coincident with similar variations of but 0.5 to 2.5 per cent at the 1B–100 station. At each station the limits of variation decreased progressively as the average velocities increased. The range of mean velocities at the fan-drift station was 350 to 1,500 feet per minute, and at the 1B–100 station it was 550 to 2,250 feet per minute.

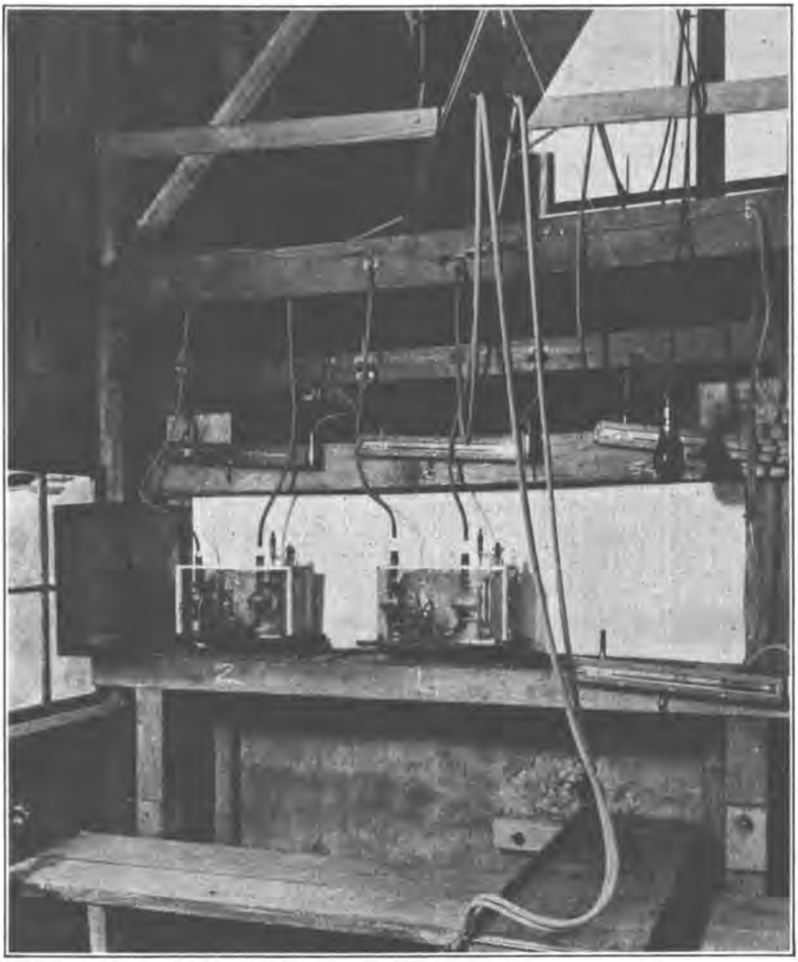


FIGURE 16.—Interior of instrument shelter at fan-drift air-measuring station

MEASUREMENT OF PRESSURE LOSSES

THEORY

The total pressure at any point in an airway has two components, which may be designated "velocity pressure" and "static pressure." For any cross section at right angles to the flow the static pressure is assumed to be constant, but velocity pressure varies from point to point, and therefore the total pressure varies also. The actual loss of pressure in any given length of an airway is a loss of mean total pressure and involves both components. Under ordinary conditions this loss can not be determined directly without laborious traversing. If, however, the cross sections of the airway at the points of measurement have equal areas, the mean velocity-pressure component becomes a constant, and hence the difference between static-pressure components at the two stations corresponds to the mean total pressure loss. This fact was made use of in measuring the pressure losses at the four most important stations in the present work.

Static stations of different areas can, however, be used, provided a correction is made for differences in velocity pressures as calculated from volume and area measurements. When a standard set of velocities is used for all conditions only a single correction to the differential static pressure is needed for each velocity, irrespective of test conditions. A general rule for this correction, applicable to either pressure or exhaust systems, may be stated thus: When the area of the station toward which the air is flowing is the larger of the two, the differential total pressure is greater than the observed differential static pressure, and the correction is positive; conversely, if the second station is the smaller, the correction will be negative.

STATIC STATIONS

Nine stations, as shown in Figure 1, were constructed for the measurement of static pressure; four of these stations were designated as primary and the remaining five as secondary. The primary stations, named *A*, *B*, *C*, and *D*, were located at 2B–115, 2B–450, 1B–390, and 1B–140. At these places sections 10 feet long were carefully trimmed to equivalent areas. Subsequent measurements showed a maximum variation of less than 2 per cent in area. It should be kept in mind that the term "static station" as used in this report refers to the plane of cross section in which the static measurement is taken. This plane was located near the departure end of the 10-foot trimmed section in each station.

The secondary static stations, named *E*, *F*, *X*, *Y*, and *Z*, were located in smooth-trimmed sections, but they were not made any particular size; the observed differential static pressures were corrected by the computed differential velocity pressures as outlined in the preceding paragraph.

STATIC TUBES

Static tubes, patterned after the static member of the Pitot tubes used in air measurement, were installed at the static stations. This design is shown in Figure 17, and a tube in place is shown in Figure 18.

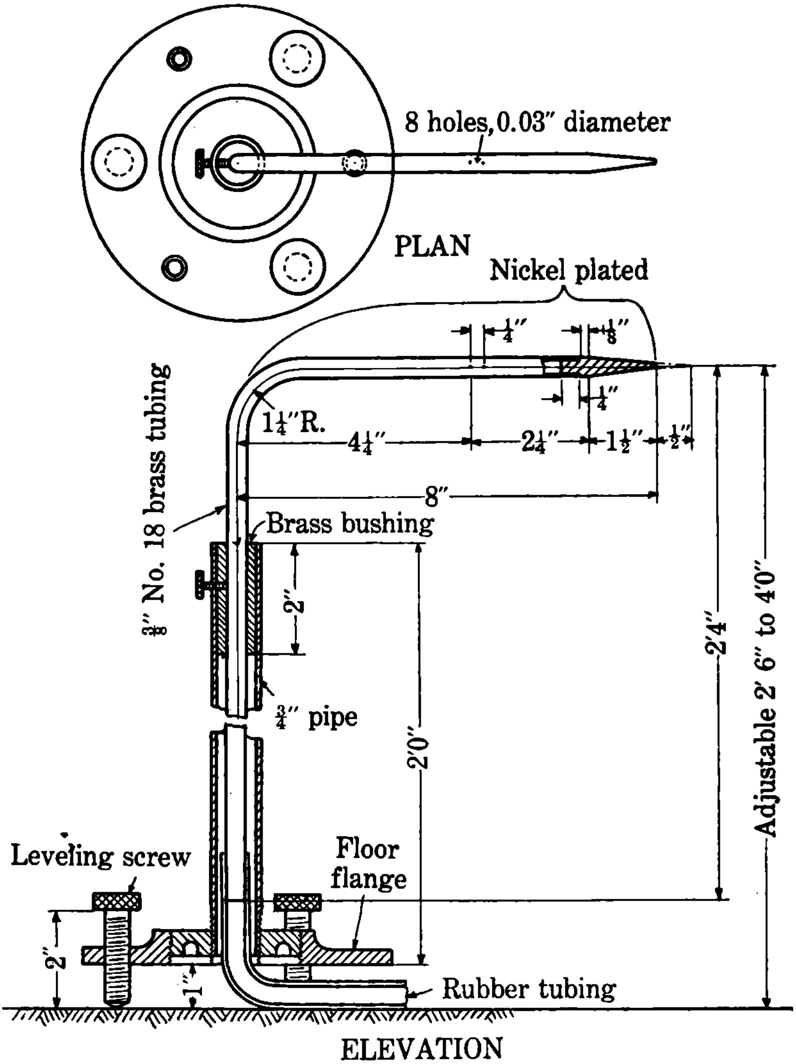


FIGURE 17.—Static-pressure tube and holder

In order to reduce to a minimum the turbulence effects on the static openings, the tubes were installed on the center line of the entry with their ends as nearly parallel as possible to the air flow. The floor of the static-station sections was tamped level, and the tube ends were also leveled.

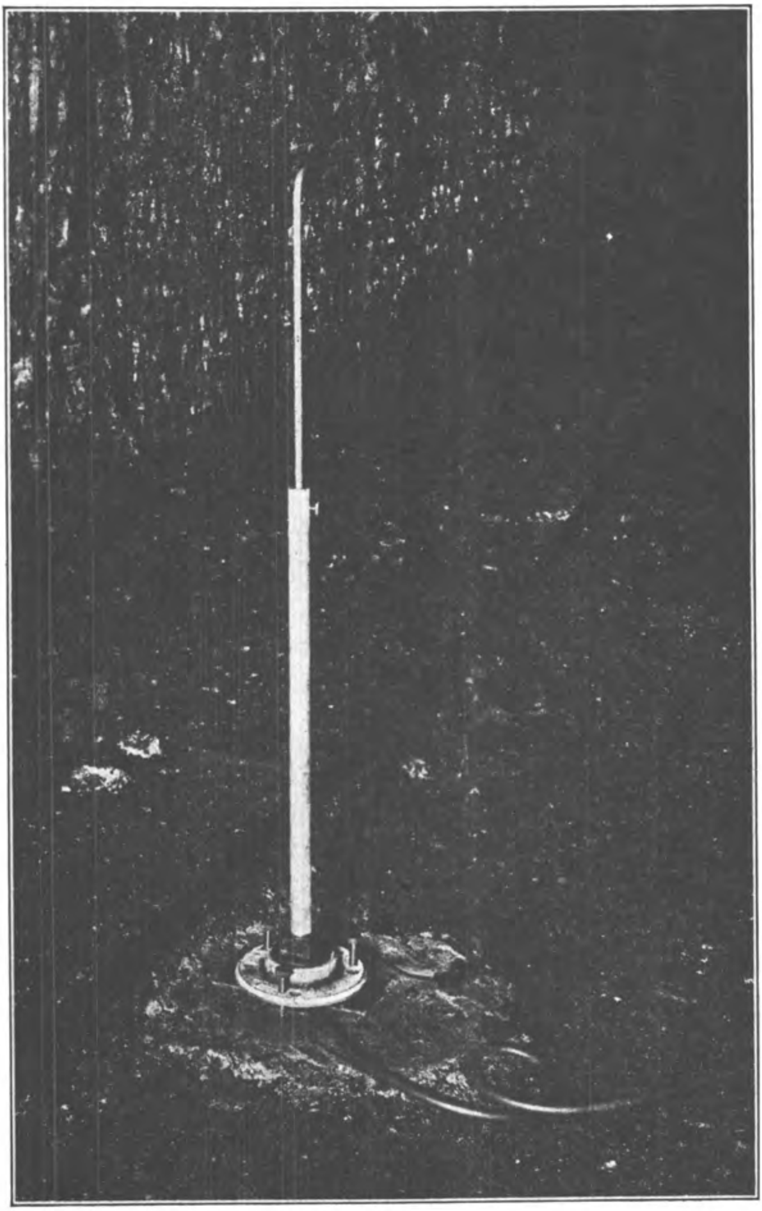


FIGURE 18.—Static tube in place in the mine entry

STATIC-TUBING CONNECTIONS

All static tubes were connected to the 1B–100 instrument station through lead tubing of ¼-inch inside diameter, using equal lengths of tubing for connections to any two tubes, regardless of their distances from the instrument to which they were connected; this was necessary because tests showed that an appreciable period of time was required to transmit pressures through long lengths (up to 400 feet) of such small-diameter tubing. Exact data on this point were masked to some extent by the sluggishness of the liquids in the Ellison gauges used for the tests, but for a 250-foot length the time was determined to be somewhat less than 8 seconds. This determination was made by connecting the same pressure to both sides of a gauge through 10-foot and 250-foot leads, respectively. A considerable amount of difficulty was experienced with this tubing because of water films and leaks, and for later work pneumatic hose of ⅜-inch inside diameter was used with much better results.

TESTS OF STATIC TUBES

The preceding paragraph describes the static-pressure measuring arrangements as they were used in pressure-loss tests. The static tubes were made the subject of several tests to determine how variations in adjustment affected the readings obtained. Tests were made in September, 1923, at static stations *A* and *B*, in which the pressure loss obtained with both static tubes on line was taken as standard. When the tube at station *A* was turned 10° off line, the differential static pressures averaged 1.5 per cent low. When the divergence was increased to 15° the results were about 4 per cent low with an increase to 6 per cent when the angle of divergence was increased to 30°. Finally both tubes were turned 30° off line, and under this condition the differential static-pressure measurement averaged 1.5 per cent low. When employed in pressure measurements, however, the tubes were never more than a degree or two out of line; hence no appreciable error in pressure-loss measurements can be traced to this source.

STATIC DIFFERENTIALS AT STATIC STATIONS

In order to get some idea of the degree of turbulence at the main static stations observations were made on the differences in static pressures as determined with three tubes set at different points in the same plane on the horizontal center line. Tests of this kind were made at stations *A*, *D*, and *X*.

The air had a clear straight approach to station *A* after entering No. 2 butt. The approach to station *D* was also straight, but there were a few cross timbers left in No. 1 butt that might cause some turbulence. At both stations comparative readings were taken between a center tube and tubes 1 foot distant on either side. At station *A* readings were also taken with a center tube and tubes 18 inches from each rib.

The results of the tests indicated about the same degree of turbulence as was shown by the central portion of the fan-drift air-measuring station and a much lower degree of turbulence than the average for the 1B–100 air-measuring station. Quantitatively the differences were of negligible importance at velocities over 500 feet per minute, but for low velocities they may have caused some errors in differential static-pressure measurements, even though plus and minus effects probably balanced each other to some extent.

The readings on the tubes showed that the distribution of air was somewhat different at different velocities. At station *A* the differential static pressure between the center and 1 foot from center averaged 0.0009 inch at a velocity of 150 feet per minute but was reduced to 0.0001 inch at 750 feet per minute. Differential static pressures between the center and points 18 inches from the ribs were 0 at the lower velocity and 0.0013 inch at the higher. At station *D* the static differentials near the center of the entry increased with the velocity. It is possible that the air distribution at station *D* was affected by the proximity of the restriction at the 1B–100 air-measuring station. It was thought that a deflector brattice erected in No. 3 room neck just ahead of station *D* would improve conditions at the station, but the brattice apparently had little or no effect in reducing turbulence.

Conditions at station *X* were liable to be less uniform than at stations *A*, *B*, *C*, or *D*. The static tube was only 25 feet distant from right-angle bends on both approach and departure sides, and it might be expected that the air flow through the static-station plane would be turbulent; when the square corners were not modified this was actually true. Static pressures were taken between a tube in the center and tubes 18 inches from either rib. The former was the regular location of the *X* tube, and for convenience the latter locations were designated *X′*. The differential static pressure between the center and the sides was 10 per cent of the velocity pressure at velocities of 500 and 900 feet per minute. This was the worst condition observed. When vanes were erected on the corners to reduce turbulence, conditions were greatly improved, and the differences varied from 0 to 3 per cent of the velocity pressure, with an average under 2 per cent.

Conditions were also checked by simultaneous observation of the differential static pressures between tubes at *B* and *X* and *B* and *X′*. The differences found were of the same order as those between tubes *X* and *X′*, as might be expected.

Readings taken with the *X* tube were consequently reliable except when the corners were square, under which condition errors up to

10 per cent of the velocity pressure may have been present. It would appear that any such error in pressure measurement for the section *B–X* would be accompanied by a similar error of opposite sign in the measurement for section *X–C*. The total pressure loss for the section *B–C* would not be affected.

EFFECT OF EXTENDED TURBULENCE ON PRESSURE-LOSS MEASUREMENTS

Moving air whose degree of turbulence has been increased by an obstruction will continue in that condition until friction uses up the energy stored in the cross currents and brings the degree of turbulence back to the normal. This action is termed "extended turbulence" and is of the same nature as the disturbances observed in running water on the downstream side of bridge piers or other obstructions. Extended turbulence will cause an increased pressure loss in the section through which the turbulent air is flowing. It may also cause errors in differential static-pressure measurements because of velocity-pressure effects exerted through the capillary openings of static-pressure tubes.

Data on extended turbulence effects were obtained by noting differences in differential static pressures *B–C* or *B–X* corresponding to changes in conditions in the preceding section *A–B* (fig. 1), taking as a base values determined with *A–B* clear. Tests were made at the four standard velocities. The presence of one to seven cars 245 feet from static tube *B* caused no appreciable increase in the pressure loss of section *B–C;* a trip of five empty cars 195 feet from static tube *B* caused an increased loss in *B–C* of about 2 per cent; with the trip 145 feet from *B* an additional loss of 5 to 6 per cent was observed; but when the trip was but 95 feet from *B* the pressure loss *B–C* showed a decrease, due probably to turbulence effects on static tube *B*.

When the nearest car was 95 feet from *B* and the other four were separated by successively increasing distances, there were no changes in the pressure loss *B–C;* this result shows that in all the tests of this kind the air had approximately the same distribution and turbulence after passing the last car.

The pressure losses *B–C* and *B–X* were not materially different when there were 5, 10, 15, and 20 timber sets on 5-foot centers in section *A–B*, as the inner set was 95 feet from *B* in all tests. Placing five empty cars in the timbered section caused no changes in pressure loss *B–C* except a decrease at the highest velocity. This decrease was accompanied by an increase in the pressure loss *B–X*, ascribed to turbulence effects on static tubes *B* and *X*.

When timber collars or crossbars only were present in section *A–B*, the pressure loss *B–X* was the same as when full timber sets were present in *A–B*. The loss *B–X* was less, however, when center posts were present in section *A–B*, which indicates that the posts caused less turbulence than the timber sets; such a condition might be predicted from the fact that lower friction factors were determined for the section *A–B* with the posts only than with either the crossbars only or the full timber sets.

The accuracy of tests with timber sets with and without cars in section *A–B* must suffer from errors due to extended turbulence effects, but the agreement of the derived friction factors with those obtained under entirely different test conditions at Butte, Mont., makes it appear that the errors involved were small—that is, less than 5 per cent.

MEASUREMENT OF SECTIONS

Before proceeding with the actual test work a careful survey was made of the roof, floor, and rib lines of the entries in the test section. Major irregularities of ribs and floor disclosed during this survey were eliminated by slabbing and filling, especially at the 475 cut-through, which was the location of projected tests of losses at bends.

In obtaining the average area of the entries for the section between static stations, cross sections were measured at 5-foot intervals along the entry. Heights and widths were measured at 1-foot intervals from a 5 by 7 foot frame. These measurements were taken to the nearest 0.1 foot, and average areas were computed from average heights and widths so obtained. Measurement data for the static stations and test sections are given in Table 5.

TABLE 5.—*Average-measurement data for static stations and test sections of entries*

Designation	Width	Height	Area	Length	Perimeter
STATIC STATIONS:	*Feet*	*Feet*	*Square feet*	*Feet*	*Feet*
A	9.9	6.7	65.9		
B	10.1	6.6	65.9		
C	10.1	6.6	66.4		
D	10.0	6.6	65.2		
E	9.9	5.7	56.5		
F	9.8	6.1	60.0		
X	8.9	6.9	61.1		
Y	9.4	6.2	58.3		
Z	9.8	6.2	60.3		
ENTRY SECTIONS:					
A to *B*	9.2	6.2	57.1	335	30.8
B to *X*	9.3	6.5	60.0	50	31.5
X to *C*	9.0	6.6	59.8	110	31.2
C to *D*	9.5	6.2	58.6	250	31.4
A to *Y*	9.5	6.3	59.4	215	31.5
Y to *D*	9.3	6.1	57.2	180	30.9
A to *Z*	9.7	6.5	62.8	115	32.3
Z to *D*	9.7	6.3	61.2	80	32.0
Z to *F*	9.3	6.1	56.6	80	30.7

TEST PROCEDURE

Test series originally included tests at five standard velocities—approximately 150, 300, 500, 700, and 900 feet per minute through test sections having average areas of about 60 square feet—with velocities nearly three times as great at the air-measuring station 20 square feet in area. The pressure losses at 150 feet per minute were so erratic, varying as much as 40 per cent, that tests at this low velocity were abandoned. Pressures obtained in test work, in which the actual velocities varied as much as 2 per cent from the standard velocities and in which the weight of air differed slightly from the selected standard of 0.075 pound per cubic foot, were corrected to standard velocity and weight of air; the pressures are so given in all of the tabular data in this report.

For each test the gauge used in measuring center-velocity pressure was set at the value corresponding to the velocity wanted for the test, and the fan attendant moved an air-control valve until the meniscus of the gauge fluctuated back and forth across the hair line. The gauges reading static pressures were then adjusted, micrometer readings were taken on all gauges, and a set of scale readings at 15-second intervals was started. At first 10 readings and later 20 readings were averaged to obtain the scale deflection for micrometer correction.

Following each test, which required but a few minutes' time, wet and dry bulb temperatures were taken in the airway at 1B–100 and at static station *A*; dry-bulb temperatures were taken at all the gauges; the barometric pressure in the instrument chamber was observed; and the difference in pressure between this station and one of the static stations was noted. From these data the weight of air flowing was calculated for two points, and average weights were estimated closely for the section under test. Temperatures at the instruments were required for the reduction and correction of observed readings to a common base—inches of water at 60° F.

PRESSURE-LOSS CALCULATIONS

Friction factors for the entry sections were computed from the formula:

$$K=\frac{5.2\,HA}{SV^2}\times\frac{0.075}{d}$$

which is derived from the standard air-flow formula:

$$p=\frac{KSV^2}{A}$$

by assigning a standard weight of air of 0.075 pound per cubic foot to *K*. In these formulas,

K=friction factor, or empirical number denoting variables not included in other terms of the equation.

H=loss in pressure in test section in inches of water at test conditions.

$p = 5.2\ H$ = pressure loss in pounds per square foot.
S = rubbing surface in square feet = perimeter (P) times length (L).
V = average mean velocity of air flow in feet per minute.
A = average cross-sectional area in square feet.
d = weight of air in pounds per cubic foot at test conditions.

Pressure losses due to obstructions and bends were determined by subtracting the normal loss for a similar clear straight section from the total loss found. The result obtained was expressed as an equivalent resistance, either in feet of airway or in ratios of velocity pressure; the latter expression is of general application, whereas the former applies directly only to exactly similar airways. Values in feet for dissimilar airways will vary inversely as their $\frac{KP}{A}$ ratios.

DOOR-LEAKAGE TESTS

Four doors were situated in two pairs forming two air locks on the air course as shown in Figure 1; one air lock was located outby the fan drift and the other between No. 1 and No. 2 butt entries. All of the doors were of the single vertical type about 7 feet wide and 5 feet high and were made of two layers of 1 by 12 inch boards set at right angles to each other with heavy building paper between the two layers. All were set in concrete frames and closed fairly flush with the door jambs. The main source of leakage was along the sill, where a narrow clearance opening existed in addition to 4 to 6 inch gaps at the rails. However, this source of leakage was reduced somewhat by 6-inch canvas strips nailed to the bottom of each door on the pressure side. These doors, it is thought, permit minimum leakage under mine conditions—especially the set between the butt entries where the canvas flaps were damp. On the doors near the fan drift the canvas flaps were dry and less efficient. Figure 19 shows one of these doors. The gauge shown mounted on the door frame was used to measure the pressure on the door.

Four groups of tests were made, as follows: (1) Both doors closed at both air locks; (2) one door on each lock open; (3) outer lock sealed, both doors closed at inner lock; (4) outer lock sealed, one door closed at inner lock. Each test consisted of taking 20 readings, at 15 to 30 second intervals, of center-velocity pressures at 1B–100 station and at the fan-drift station. Volumes were computed from calculated average center velocities by means of the center constants and areas previously determined. The differences in pressure on both sides of doors under test were also taken simultaneously with other data. Leakage was calculated by correcting the absolute differences determined from test results for the normal differences in air measurement between the two stations as found in the check air-measurement series of tests. The results of the door-leakage tests are given in Table 6.

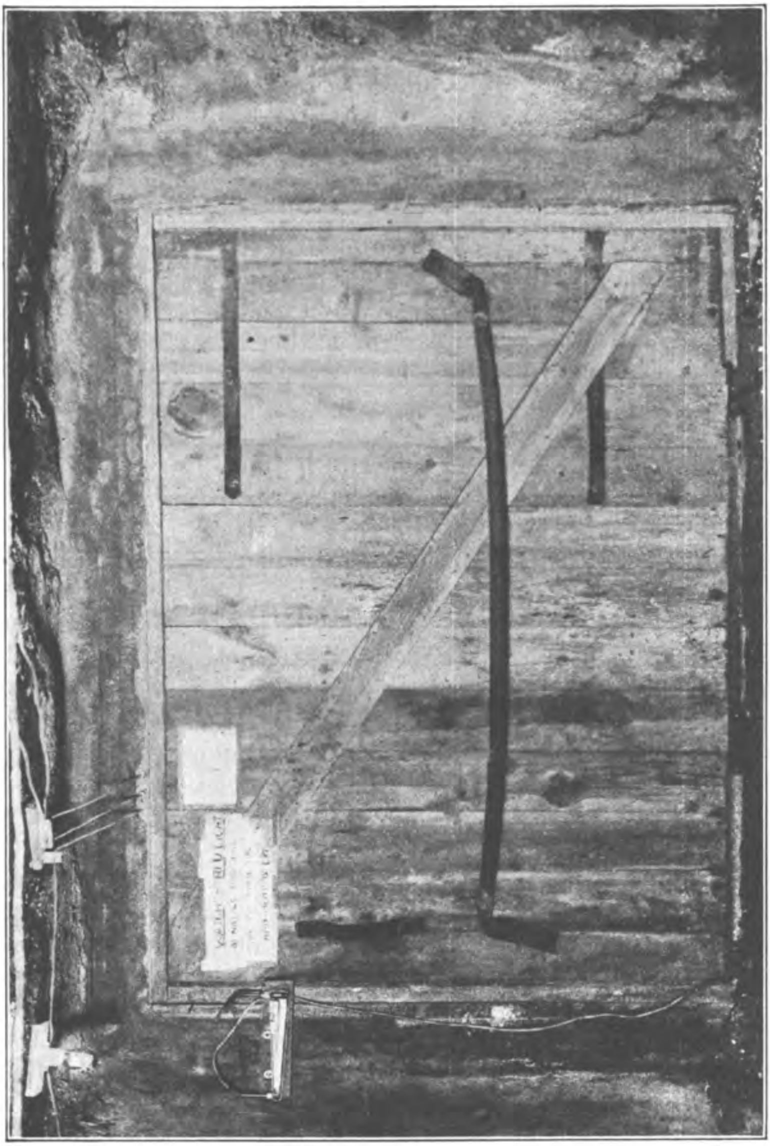


FIGURE 19.—Ventilation door between butt entries

TABLE 6.—*Door-leakage tests, April 25 and 26, 1922*

Test No.	Static pressures, inches of water		Volume, cubic feet per minute			Plus[1] correction	Leakage	
	Outer air lock	Inner air lock	Fan-drift station	1B-100 station	Difference		Cubic feet per minute	Percentage of total[2]
(1) BOTH DOORS CLOSED AT BOTH AIR LOCKS								
133	0.100	0.041	11,850	11,660	190	220	410	3.5
136	.252	.120	20,930	19,650	1,280	320	1,600	8.1
138	.752	.364	37,400	35,250	2,150	350	2,500	7.1
140	1.18	.555	46,400	43,900	2,500	800	3,300	7.5
(2) ONE DOOR CLOSED AT EACH AIR LOCK								
135	0.100	0.041	11,700	11,430	370	220	590	5.2
137	.224	.113	20,400	19,130	1,270	320	1,590	8.3
139	.725	.345	37,700	34,650	3,050	350	3,400	9.8
141	1.11	.525	47,500	42,750	4,750	800	5,550	13.0
(3) SEAL AT OUTER AIR LOCK; BOTH DOORS CLOSED AT INNER AIR LOCK								
149	0.080	0.037	10,820	10,960	−140	220	80	0.7
147	.203	.104	19,120	18,750	370	320	690	3.7
144	.752	.358	36,300	36,000	300	350	650	1.8
142	1.20	.558	45,900	45,600	300	800	1,100	2.4
(4) SEAL AT OUTER AIR LOCK; ONE DOOR CLOSED AT INNER AIR LOCK								
150	0.080	0.036	10,810	10,590	220	220	440	4.2
148	.204	.101	18,850	18,610	240	320	560	3.0
145	.722	.339	35,850	35,450	400	350	750	2.1
143	1.20	.562	46,300	45,800	500	800	1,300	2.8

[1] Correction based on differences in observed air measurements with air-tight airway.
[2] Based on volumes at 1B-100 station.

The results in the foregoing table show very much less leakage at the inner doors than at the outer doors; this difference is attributed to the fact that the canvas flaps at the former were damp to wet, while at the latter they were quite dry and flapped up and down at the higher pressures. The higher percentages of leakage at lower pressures for tests in groups 3 and 4 are attributed to the fact that the pressures were too low to hold the canvas flaps tight against the sill. Groups 3 and 4 seem to indicate an average leakage of 2 to 3 per cent as a minimum for the best mine doors under moderate pressure conditions. Comparison of groups 1 and 2 with 3 and 4 indicates that lack of efficient protection, such as wet canvas flaps along the sill, may easily allow leakages of 5 to 10 per cent, even with doors ordinarily considered satisfactory.

Although the foregoing expressions of results on a percentage basis are helpful in that they bring out the relative significance of door-leakage losses to total circulation, they can apply only under approximately similar conditions, as the leakage depends entirely on the pressure differences and total area of openings. Under constant conditions of opening, the quantity of air passed varies as the square root of the pressure, and an analysis of the test results shows that leakages may be determined more accurately for the two types of doors by assuming the following average leakages at 1-inch pressure:

	Cubic feet per minute
Air lock, wet flaps	1, 400
Single door, wet flaps	1, 700
Air lock, dry flaps	2, 000
Single door, dry flaps	3, 000 to 4, 000

These figures correspond to equivalent orifices of 0.6 to 1.6 square feet and to resistance factors (pressure difference in inches of water required to pass 100,000 cubic feet per minute) of 5,100 to 610.

PRESSURE LOSSES IN STRAIGHT ENTRIES

TEST SECTIONS USED

The test work on the resistance of straight entries was done in section *A–B* of No. 2 butt entry (fig. 1), and a few check results were obtained in section *C–D* of No. 1 butt entry. In the development of the mine these entries had been driven on sights by men working on a tonnage basis, and the irregularities are such as would be encountered in an operating mine. The butt entries are driven at an angle of 10° to the face cleats, giving the rib a kind of saw-toothed appearance on a large scale; this effect is shown at the top of Figure 20, which also shows two typical cross sections.

Figure 21 shows test section *A–B* on a larger scale than does Figure 1. The variation of the entry ribs from a straight line was not enough to be shown in its true proportion at this scale, but the variation in area was considerable, involving changes in both width and height, and is shown on the area graph drawn parallel to the diagram of the entry.

Three cut-throughs on 100-foot centers had been turned off from the entry between *A* and *B*, and each had been closed by an air-tight stopping near the middle; this left three dead ends about 20 feet long opening out of the section. There were two similar cut-through dead ends in section *C–D*, but room openings off the latter were bratticed off flush with the ribs. Section *C–D* differed from section *A–B* mainly in that it had twelve 2 by 12 inch planks on 10-foot centers across the roof and 6 to 10 inches below it. These had been used as shelves for coal dust in coal-dust explosion tests.

SCOPE OF TEST WORK

In determining the resistance of a clear straight entry, tests were made in sections *A–B* and *C–D* with and without deflector brattices placed across the cut-through dead ends. Tests were also made in section *A–B* to determine the effect of shelter holes in the side of the

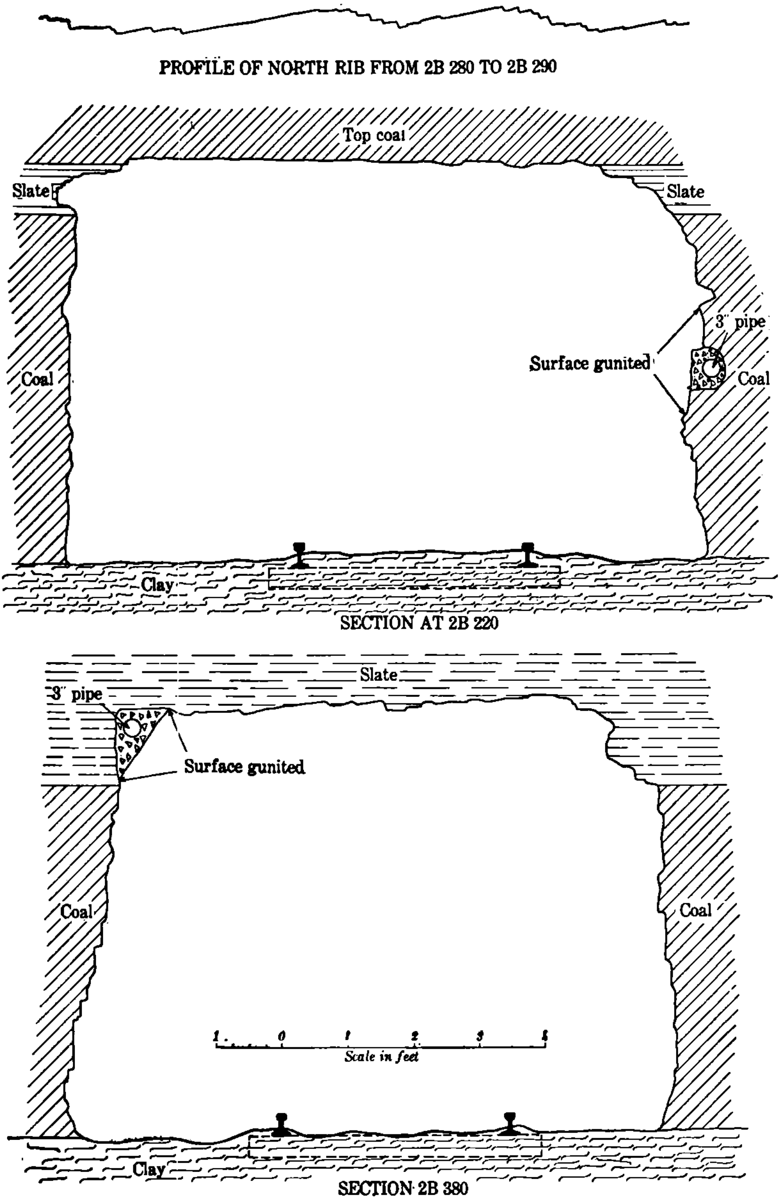


FIGURE 20.—Typical rib profile and cross sections along butt entries

entry midway between the cut-throughs. No timbered entry sections were available at the experimental mine; so four types of timbering were installed and tested in section *A–B*—20 three-piece sets on 5 and 10 foot centers, 20 crossbars on 5-foot centers, and 40 posts on 5-foot centers. During these tests on timbering, deflector brattices were in place in the cut-throughs.

RESISTANCE OF CLEAR STRAIGHT ENTRIES

An unobstructed straight entry with three cut-through dead ends opening out of it on 100-foot centers was the most simple and fundamental condition that could be tested. Tests in section *A–B* were repeated a number of times because of interruptions. The results of these tests are given in Table 7.

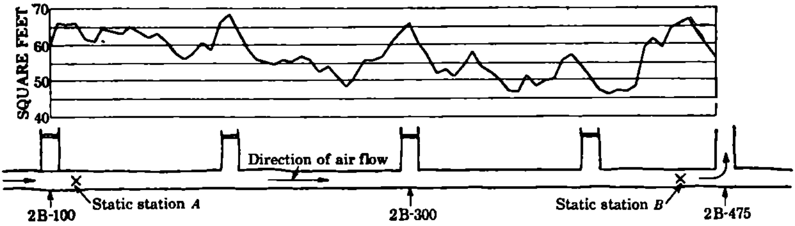


FIGURE 21.—Test section *A–B* with corresponding area graph

TABLE 7.—*Pressure-loss tests in clear straight entry with cut-through dead ends every 100 feet*

A.—PRESSURE LOSS, INCH OF WATER

Velocity, feet per minute	July 27, 1922	May 31, 1923	June 8, 1923	June 19, 1923
300	[1] 0.0115	0.0109	0.0126	
500		.0304	.0318	0.0328
700		.0600	.0615	.0590
900		.0978	.1002	.0986

B.—COMPUTED FRICTION FACTORS, *K*[2]

300	[1] $0.0^{8}368$	$0.0^{8}349$	$0.0^{8}403$	
500		$.0^{8}350$	$.0^{8}366$	$0.0^{8}378$
700		$.0^{8}352$	$.0^{8}361$	$.0^{8}347$
900		$.0^{8}347$	$.0^{8}356$	$.0^{8}350$

---

[1] Average of four tests.

[2] The index number 8 in the values of *K* means that there are eight ciphers between the decimal point and the first significant figure.

The variations shown in Table 7 could not be correlated with any change in test conditions, so that the results for each velocity have been averaged, giving the following values for *K*:

$0.0^{8}371$ at 300 feet per minute.
$.0^{8}365$ at 500 feet per minute.
$.0^{8}353$ at 700 feet per minute.
$.0^{8}351$ at 900 feet per minute.

These figures show a decrease in friction factor with increasing velocity and tend to approach a constant value at higher velocities. This slight variation in the value of *K*, when compared with the large variations in *K* attending slight changes in airway conditions, is of no practical importance at ordinary velocities.

EFFECT OF DEFLECTOR BRATTICES ACROSS CUT-THROUGH DEAD ENDS

Three sets of comparative tests were made with and without closing the dead ends of cut-throughs with deflector brattices. Two sets of the tests were made in section *A–B*, one with canvas and one with wooden deflector brattices placed across the three cut-throughs flush with the ribs. The third set was made in section *C–D*, where the two cut-throughs were closed with wooden brattices. The results of these tests are given in Table 8.

TABLE 8.—*Tests with deflector brattices across cut-through dead ends*

SECTION A-B.—CANVAS BRATTICES, MAY 31, 1923

Velocity, feet per minute	Without brattices		With brattices		Decrease due to brattice, per cent
	Pressure loss, inch of water	Friction factor, *K*	Pressure loss, inch of water	Friction factor, *K*	
300	0.0109	$0.0^{8}349$	0.0109	$0.0^{8}349$	[1] 0.0
500	.0304	$.0^{8}350$	.0291	$.0^{8}335$	4.6
700	.0600	$.0^{8}352$	.0562	$.0^{8}330$	6.8
900	.0978	$.0^{8}347$	.0919	$.0^{8}326$	6.3
SECTION A-B.—WOODEN BRATTICES, JUNE 8, 1923					
300	0.0126	$0.0^{8}403$	0.0116	$0.0^{8}371$	8.6
500	.0318	$.0^{8}366$	.0300	$.0^{8}345$	6.1
700	.0615	$.0^{8}361$	.0541	[2] $.0^{8}318$	[1] 13.5
900	.1002	$.0^{8}356$	.0962	$.0^{8}342$	4.1
SECTION C-D.—WOODEN BRATTICES, SEPT. 29, 1923					
300	0.0098	$0.0^{8}423$	0.0108	$0.0^{8}466$	[1] [2] 10.1
500	.0276	$.0^{8}429$	.0266	$.0^{8}413$	3.8
700	.0542	$.0^{8}429$	.0505	$.0^{8}400$	7.2
900	.0876	$.0^{8}420$	.0850	$.0^{8}407$	3.2

[1] Results apparently seriously in error.

[2] Increase instead of decrease.

An examination of the rather erratic results obtained in the three groups of tests shown in Table 8 indicates that the installation of deflector brattices in this type of entry reduced the friction factor about 6 per cent on the average. However, the corresponding saving in power per day is very small. For example, if the air in No. 2 butt entry traveled at 900 feet per minute for 24 hours a day, the power saving resulting from the use of the brattices would amount to less than 0.2 hp. for each 1,000 feet of entry; with electricity costing 1.25 cents per kilowatt hour, this would mean a saving of less than 5 cents per day.

EFFECT OF ROUGHENING OF FLOOR

In order to determine base values for application to other test results, five sets of tests were made on section *A–B* with wooden deflector brattices in place at the cut-throughs. Two of the test series preceded and three followed moderate roughening of the entry floor consequent to erecting and removing timber sets. A comparison of these two groups of tests, as given in Table 9, shows an average increase of 4.5 per cent in resistance due to the roughening of the floor. It seems safe to assume, then, that a fairly liberal spillage of coal on an entry floor would easily increase the friction factor at least 10 per cent over that for the clean entry with a comparatively smooth floor.

TABLE 9.—*Base values of friction factor and pressure loss for section A–B with board brattices in the cut-through dead ends*

Velocity, feet per minute	Tests prior to July 1, 1923, Nos. 600 to 700		Tests after July 1, 1923, Nos. 701 to 996		Increase in friction factor, per cent
	Friction factor, *K*	Pressure loss, inch of water	Friction factor, *K*	Pressure loss, inch of water	
300	$0.0^{8}366$	0.0114	$0.0^{8}371$	0.0116	1.3
500	$.0^{8}333$	.0289	$.0^{8}360$	.0313	8.1
700	$.0^{8}331$	.0564	$.0^{8}348$	.0593	5.1
900	$.0^{8}330$	.0929	$.0^{8}342$	.0963	3.6

EFFECT OF SHELTER HOLES

The Pennsylvania bituminous mining law requires shelter holes or other openings where available, at intervals of 15 yards along entries in which mechanical haulage is used. Such a condition could not be duplicated exactly in section *A–B*; however, the 200, 300, and 400 cut-throughs were used, and standard-size shelter holes were cut at 2B–250 and 2B–350, making the distance between openings 16⅔ yards instead of the regulation 15 yards. This condition was used in a group of four tests on September 24, 1923. Comparison of these test results with those obtained in a group of tests made three days earlier with board deflector brattices across the cut-through dead ends shows that the cut-throughs and shelter holes combined to increase the friction factor 5, 1.7, 6, and 7.5 per cent, respectively. Rejecting the low value as obviously in error, the average increase is 6 per cent; as this amount agrees with that determined for the cut-throughs alone, it is apparent that the shelter holes caused no measurable increase in resistance, as might have been predicted from their small size.

CHECK TESTS IN SECTION C–D

The foregoing results appeared to be satisfactory, but they could be roughly checked by tests made in section *C–D* of No. 1 butt; this section, with the room openings bratticed off, had physical characteristics similar to those of section *A–B*, with the exception of the twelve 2-inch cross shelves in place between 1B–187 and 1B–363.

The results of tests made in section *C–D*, both with and without board brattices across the cut-through dead ends, are reported in Table 8, page 41. Friction factors determined in section *C–D* with the board brattices in place compared with base values for similar condition in section *A–B* in tests 701 to 996 (Table 9) show that the results in section *C–D* were 27, 14.7, 14.9, and 19 per cent higher than similar results in section *A–B* at 300, 500, 700, and 900 feet per minute, respectively. The average of results at 500, 700, and 900 feet per minute shows the value of *K* to be 16.5 per cent higher in section *C–D* with cross shelves than in section *A–B* without cross shelves, or an absolute increment to the friction factor of about 0.0^96. This is well within the limits of what might be charged to the cross shelves and indicates that the friction factors determined in the two sections are in close agreement.

RESISTANCE OF TIMBERED STRAIGHT ENTRIES

Timbering exposed to air currents is one of the chief causes of high resistance to air flow in mine entries. Sixty-four tests were made in section *A–B* in order to determine the resistance caused by four different arrangements of timber. The majority of the tests were made with sets consisting of two posts and a crossbar. The timber available for installation of the sets was split, not square-sawed or round, as is more common in mining practice. The split pieces were fairly regular in shape, having a cross section resembling a deformed square, and an average width of about 10 inches faced the air current. Open spaces above crossbars were lagged shut with pieces of 3 by 4 inch or smaller timber. The condition of the sets can best be judged from Figure 22, which shows a number of them erected in section *A–B*. No attempt was made to keep the posts in alignment, consequently the variation in the areas inside of the sets was considerable.

In all tests measurements for areas were made inside of the timbers with no allowance for spaces outside of them. The spaces between posts and ribs varied irregularly from a fraction of an inch up to 9 inches in width, but the flow of air through such spaces was found to be practically nil. Lengths of test sections were determined by multiplying the number of timbers or timber sets by the distance between them. Actual lengths were one timber spacing less than the length determined by this method. In all tests board deflector brattices were in place across the 200, 300, and 400 cut-through dead ends, and the innermost timber or timber set was at 2B–350.

Figure 22.—Split-timber sets used in pressure-loss tests

The tests with timbers can be separated into four groups, as follows: Split-timber sets on 5-foot centers, split-timber sets on 10-foot centers, crossbars only on 5-foot centers, and center posts only on 5-foot centers. Tests were made with the four standard volumes of air used in the clear-entry tests. After the full number of sets available were tried out—20 full sets, 20 crossbars, and 40 posts—they were removed 5 at a time and the tests were repeated.

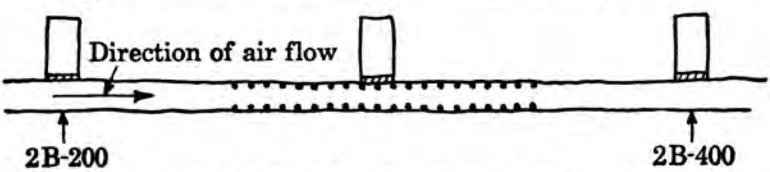


Figure 23.—Area graph of No. 2 butt entry with split-timber sets erected on 5-foot centers

SPLIT-TIMBER SETS ON 5-FOOT CENTERS

In tests using split-timber sets on 5-foot centers the average area with 20 timber sets in place was 41.4 square feet, a reduction of about 27 per cent of the clear area; and with the same air volumes as were used in the clear-entry tests, the average velocities were 38 per cent higher. Figure 23 shows the variation in area in the test section with 20 sets in place.

TABLE 10.—*Tests with split-timber sets on 5-foot centers, August 15, 1923*

FIVE SETS, 2B-350 TO 2B-330

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water			Timber loss in equivalent feet of clear entry	Friction factor based on measurements inside of timbers
		Total loss		Loss due to timbers		
		Section *A-B*	Timbered portion			
773	17,130	0.0165	0.0058	0.0049	141	$0.0^{7}097$
774	28,550	.0459	.0169	.0146	156	$.0^{7}102$
775	39,970	.0877	.0328	.0284	160	$.0^{7}101$
776	51,390	.1436	.0545	.0473	164	$.0^{7}102$
TEN SETS, 2B-350 TO 2B-305						
772	17,130	0.0212	0.0113	0.0096	277	$0.0^{7}099$
771	28,550	.0578	.0312	.0265	284	$.0^{7}098$
770	39,970	.1068	.0564	.0475	268	$.0^{7}091$
769	51,390	.1785	.0966	.0822	286	$.0^{7}094$
FIFTEEN SETS, 2B-350 TO 2B-280						
765	17,130	0.0250	0.0160	0.0134	387	$0.0^{7}103$
766	28,550	.0677	.0434	.0364	390	$.0^{7}101$
767	39,970	.1311	.0851	.0718	406	$.0^{7}101$
768	51,390	.2152	.1405	.1189	414	$.0^{7}101$
TWENTY SETS, 2B-350 TO 2B-255						
764	17,130	0.0310	0.0229	0.0194	560	$0.0^{7}110$
763	28,550	.0796	.0576	.0483	517	$.0^{7}100$
762	39,970	.1551	.1135	.0958	541	$.0^{7}100$
761	51,390	.2521	.1846	.1558	542	$0^{7}099$

The results of four series of tests are given in Table 10. The loss caused by timber sets expressed in equivalent feet of clear entry averages approximately 5.5 times the length of entry that was timbered, or, in other words, the resistance of the timbered entry was 6.5 times that of the untimbered entry. This large increase was due partly to the greater roughness and irregularity of the surfaces and partly to the fact that the same volume of air was passing through smaller areas, hence at higher average velocities.

The computed friction factors show that the pressure losses in these timbered sections varied as the square of the velocity. The values obtained show a satisfactory uniformity. In the 16 tests the friction factor varies from $0.0^{7}091$ to $0.0^{7}110$, with an average value of $0.0^{7}100$. In 13 of the 16 tests the variation is from $0.0^{7}097$

to 0.0^7103, and the average of these 13 is also 0.0^7100. This average figure is therefore fairly well established and can probably be used with assurance provided the measurement of areas is made inside the timbers.

With regard to the possibility of applying results obtained with split timber to airways lined with square or round timber, it appears probable that the width of the surface rather than its shape is the important influence. The greater irregularity of split timbers might be expected to give somewhat higher resistances. Although very consistent results were obtained under the test conditions, it must be remembered that changes in timber alignment, straightness of entry, or roughness of the floor would result in a different value for the friction factor.

It is interesting to compare the factor 0.0^7100 for a timbered entry with 0.0^7035 determined for an unobstructed entry at the higher velocities. With entries of the same size the power required to move a given volume of air is directly proportional to these values. Thus, 10 hp., required to move the air through a certain timbered entry, could be reduced to 3.5 hp. by filling in the spaces between the timber sets so that they presented a surface comparable to that of an ordinary coal rib—a saving in power of 65 per cent. If the same condition was obtained by recessing the posts in the ribs, this saving would be enlarged to approximately 85 per cent because of increase in area. With main air courses continuously carrying large volumes of air at high velocities for years, such savings may well justify special construction.

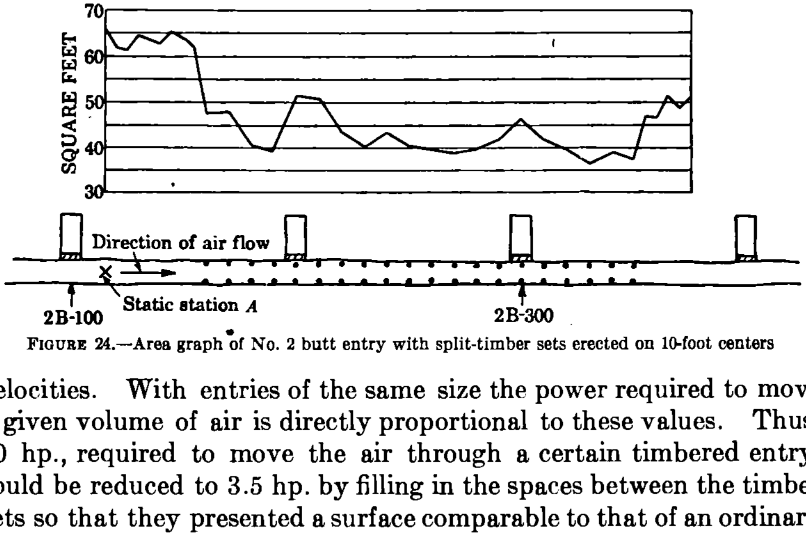


FIGURE 24.—Area graph of No. 2 butt entry with split-timber sets erected on 10-foot centers

SPLIT-TIMBER SETS ON 10-FOOT CENTERS

The tests of sets on 10-foot centers differed only in respect to spacing from the preceding group. Figure 24 is an area graph of the test section with 20 sets in place. For this condition the average area was 42.3 square feet, a reduction of 26 per cent in the area of the clear entry, resulting in velocity increases of 35 per cent. The results of four series of tests are given in Table 11.

TABLE 11.—*Pressure-loss tests with split-timber sets on 10-foot centers, September 14, 1923*

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water			Timber loss in equivalent feet of clear entry	Friction factor based on measurements inside of timbers
		Total loss		Loss due to timbers		
		Section *A–B*	Timbered section			
FIVE SETS, 2B-350 TO 2B-310						
916	17,130	0.0178	0.0079	0.0062	179	$0.0^{8}65$
915	28,550	.0405	.0139	.0092	98	$.0^{8}42$
914	39,970	.0934	.0430	.0341	193	$.0^{8}65$
913	51,390	.1523	.0704	.0560	195	$.0^{8}64$
TEN SETS, 2B-350 TO 2B-260						
909	17,130	0.0251	0.0169	0.0135	390	$0.0^{8}75$
910	28,550	.0696	.0476	.0383	410	$.0^{8}76$
911	39,970	.1325	.0909	.0732	414	$.0^{8}74$
912	51,390	.2191	.1516	.1228	427	$.0^{8}75$
FIFTEEN SETS, 2B-350 TO 2B-210						
908	17,130	0.0308	0.0244	0.0192	554	$0.0^{8}78$
907	28,550	.0931	.0758	.0618	662	$.0^{8}87$
906	39,970	.1678	.1351	.1085	613	$.0^{8}79$
905	51,390	.2753	.2221	.1790	623	$.0^{8}79$
TWENTY SETS, 2B-350 TO 2B-160						
901	17,130	0.0376	0.0329	0.0260	751	$0.0^{8}83$
902	28,550	.1053	.0927	.0740	792	$.0^{8}84$
903	39,970	.2006	.1767	.1413	798	$.0^{8}82$
904	51,390	.3259	.2871	.2296	799	$.0^{8}81$

The loss caused by the timbers expressed in equivalent feet of clear entry averages four times the length of the section timbered; that is, the pressure loss in the timbered entry was five times that in clear entry with the same volume of air moving. When the sets were on 5-foot centers the loss was 6.5 times that in clear entry.

The average friction factors indicated in Table 11 are $0.0^{8}65$, $0.0^{8}75$, $0.0^{8}79$, and $0.0^{8}82$ with 5, 10, 15, and 20 timber sets, respectively. These values are based on a length of entry equal to ten times the number of timber sets present. If they are based on the distance from first to last timber set, the friction factors become $0.0^{8}81$, $0.0^{8}83$, $0.0^{8}85$, and $0.0^{8}86$ for the respective sets. When the distance between timber sets becomes so great that the air reassumes its normal distribution between sets it apparently becomes necessary to regard the timber sets as a series of separate resistances rather than as a single resistance.

EFFECT OF TIMBER SPACING ON RESISTANCE

Expressed in equivalent feet of clear entry, the loss caused by a given number of timber sets on 10-foot centers is greater than that caused by the same number on 5-foot centers. This result is quite analogous to the increase observed, as described in a later section (pp. 57 to 60), when cars were separated from each other. With timber sets on 5-foot centers, the air does not resume its normal distribution between sets as it does when the spacing is increased to 10 feet. This is evidenced by the fact that the equivalent resistance increases at a less rapid rate than the number of timber sets with 5-foot spacing. With a 10-foot spacing, however, the increase in equivalent resistance is proportional to the number of sets, allowance being made for variation in area. A further separation of the timbers would cause no increase in the absolute loss due to them. Friction factors computed from measured losses, however, would steadily decrease in value, because the loss due to a given number of timbers would be distributed over a steadily increasing length of entry. On the other hand, the friction factor should increase as the distance between timber sets is decreased until the minimum separation that will allow full expansion of the air between timber sets is reached. Beyond this point the friction factor should again decrease until it reaches a minimum value with a solidly timbered entry, that is, with the sets placed together without recesses between them. The friction factor obtained with the timber sets on 5-foot centers is probably not very far from the maximum value, and is the factor better adapted to operating mines because of the greater similarity of such test conditions to conditions normally encountered.

CROSSBARS ONLY ON 5-FOOT CENTERS

The crossbars, or collars without posts, were installed in the same locations as the 20 timber sets on 5-foot centers, but they were made of square instead of split timber. This change would make little difference, except as it caused the crossbars to present to the air a surface of more uniform size. Any open spaces over the collars were lagged shut, as with the full timber sets.

The distance from the bottom of the crossbar to the roof varied from 8 to 13.5 inches and averaged 9.5 inches, of which 7.5 inches was timber and the remainder was lagging. The average distance from the bottom of the crossbar to the roof was not greatly different from that found with the split collars used on the full sets. The width of the crossbars in the direction of air flow was 5 to 5.5 inches. With 20 crossbars in place, the average area was 47.6 square feet, a reduction of about 17 per cent of the clear area, and the velocities increased 20 per cent for the same air volumes. Results of the four series of tests are shown in Table 12.

TABLE 12.—*Pressure-loss tests with crossbars only on 5-foot centers, September 20, 1923*

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water			Timber loss in equivalent feet of clear entry	Friction factor based on measurements under the crossbars
		Total loss		Loss due to timbers		
		Section *A–B*	Timbered portion			
FIVE CROSSBARS, 2B-350 TO 2B-330						
953	17, 130	0. 0143	0. 0036	0. 0027	78	$0.0^{8}83$
954	28, 550	. 0368	. 0078	. 0055	59	$.0^{8}64$
955	39, 970	. 0729	. 0180	. 0136	77	$.0^{8}76$
956	51, 390	. 1152	. 0261	. 0189	66	$.0^{8}67$
TEN CROSSBARS, 2B-350 TO 2B-305						
949	17, 130	0. 0159	0. 0060	0. 0043	124	$0.0^{8}74$
950	28, 550	. 0428	. 0162	. 0115	123	$.0^{8}72$
951	39, 970	. 0831	. 0327	. 0238	134	$.0^{8}74$
952	51, 390	. 1377	. 0558	. 0414	144	$.0^{8}77$
FIFTEEN CROSSBARS, 2B-350 TO 2B-280						
945	17, 130	0. 0178	0. 0088	0. 0062	179	$0.0^{8}80$
946	28, 550	. 0466	. 0223	. 0153	164	$.0^{8}59$
947	39, 970	. 0913	. 0453	. 0320	181	$.0^{8}76$
948	51, 390	. 1471	. 0724	. 0508	177	$.0^{8}73$
TWENTY CROSSBARS, 2B-350 TO 2B-255						
944	17, 130	0. 0201	0. 0120	0. 0085	245	$0.0^{8}80$
943	28, 550	. 0541	. 0321	. 0228	244	$.0^{8}77$
942	39, 970	. 1036	. 0620	. 0443	250	$.0^{8}76$
941	51, 390	. 1648	. 0973	. 0685	238	$.0^{8}72$

The resistance of the crossbars expressed in feet of clear entry is equivalent to that of a distance about 2.5 times the length of the timbered section; that is, pressure loss with the crossbars is about 3.5 times that of the clear entry. With full timber sets the pressure loss was 6.5 times that of clear entry.

The loss expressed in equivalent feet of clear entry increases at a slightly slower rate than the number of crossbars, showing that the spacing is a little less than that required for a full expansion of the air between the timbers. Comparison of Tables 10 and 12 shows that the equivalent resistance of the crossbars alone is about 45 per cent of the equivalent resistance of the full timber sets. In the timber set the crossbar was 9 feet long and each post was 5 feet high, giving a total timber length of 19 feet, of which the crossbar was 47 per cent. The closeness of this ratio to the resistance ratio is certainly suggestive and, because of the uniformity of the result with different numbers of timber sets, the agreement appears to be more than coincidence.

The friction factors in Table 12 have average values of $0.0^{8}73$, $0.0^{8}74$, $0.0^{8}77$, and $0.0^{8}76$ with 5, 10, 15, and 20 crossbars, respectively. A general average value for the friction factor would be $0.0^{8}75$. This figure is more than twice the value obtained for clear entry and is three-fourths of that obtained with the full timber sets.

CENTER POSTS ONLY ON 5-FOOT CENTERS

For the group of tests with center posts, 40 split-timber posts were installed on 5-foot centers. The practical effect as regards air flow was to divide the entry into two separate compartments. With 40 posts in place the average total area of the two compartments was 52.6 square feet, a reduction of 8 per cent in clear area, with resulting average velocity increases of 9 per cent. The results of four series of tests are given in Table 13.

TABLE 13.—*Pressure-loss tests with center posts only on 5-foot centers, September 18, 1923*

TEN POSTS, 2B-350 TO 2B-305

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water			Timber loss in equivalent feet of clear entry	Friction factor based on measurements of area on each side of posts
		Total loss		Loss due to posts		
		Section *A–B*	Timbered portion			
940	17,130	0.0157	0.0058	0.0041	118	$0.0^{8}61$
939	28,550	.0421	.0155	.0108	116	$.0^{8}59$
938	39,970	.0812	.0308	.0219	124	$.0^{8}59$
937	51,390	.1325	.0506	.0362	126	$.0^{8}59$
TWENTY POSTS, 2B-350 TO 2B-255						
933	17,130	0.0183	0.0101	0.0067	194	$0.0^{8}56$
934	28,550	.0521	.0301	.0208	223	$.0^{8}60$
935	39,970	.0993	.0577	.0400	226	$.0^{8}58$
936	51,390	.1640	.0965	.0677	235	$.0^{8}59$
THIRTY POSTS, 2B-350 TO 2B-205						
929	17,130	0.0227	0.0163	0.0111	321	$0.0^{8}61$
930	28,550	.0533	.0360	.0220	236	$.0^{8}49$
931	39,970	.1205	.0878	.0612	346	$.0^{8}60$
932	51,390	.1966	.1434	.1003	349	$.0^{8}60$
FORTY POSTS, 2B-350 TO 2B-155						
928	17,130	0.0251	0.0204	0.0135	390	$0.0^{8}61$
927	28,550	.0700	.0574	.0387	414	$.0^{8}62$
926	39,970	.1353	.1114	.0760	429	$.0^{8}61$
925	51,390	.2230	.1842	.1267	441	$.0^{8}61$

These tests show that with the maximum quantity of air moving the equivalent resistance of the posts is 2.3 times the length of entry timbered, so that an entry with center posts on 5-foot centers has about 3.3 times the resistance that it would have if untimbered. This relation holds for an entry 6 feet high and 9 feet wide with posts 8 or 9 inches wide, measured at right angles to the direction of air flow. If the entry is wider, the resistance will be less; if narrower, it will be more; but the rate of change can not be predicted. If the width remained the same and the height were changed, the equivalent resistance would probably remain the same, since the area of the entry and the length of the post would change in proportion. Smaller posts would have less resistance, but within the limits of commercial practice the difference would probably have no great significance.

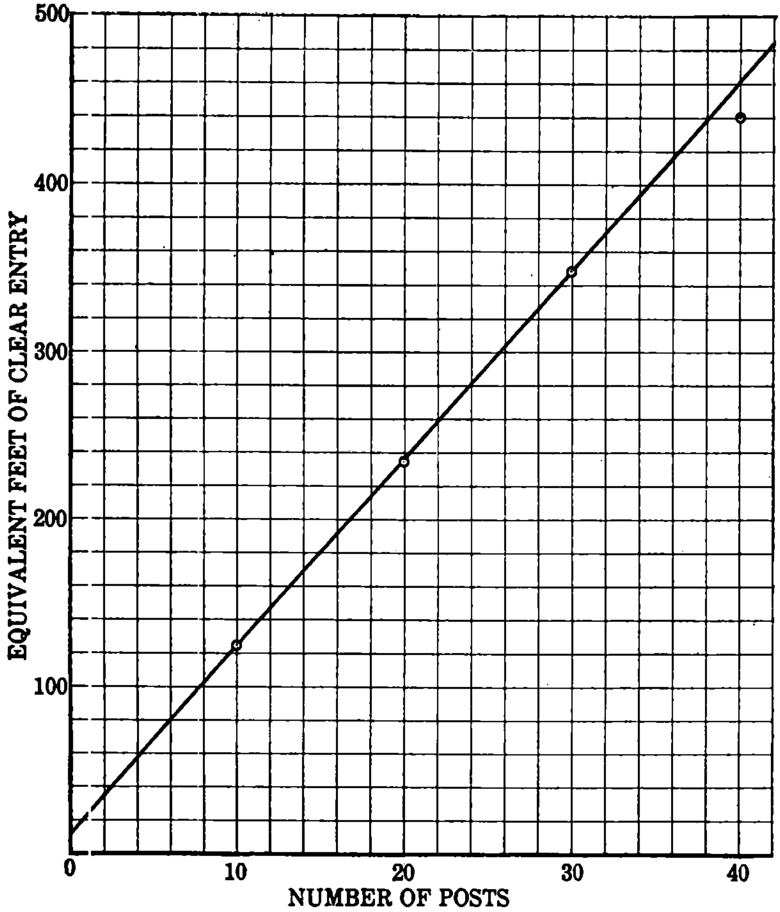


FIGURE 25.—Variation of resistance with number of center posts

The friction factors derived from these tests are quite uniform. The average friction factors in the four groups of tests, rejecting tests 930 and 933 as obviously out of line and erroneous, are $0.0^{8}60$, $0.0^{8}59$, $0.0^{8}60$. and $0.0^{8}61$, or an average value of $0.0^{8}60$. The friction factor $0.0^{8}60$ for the posted entry may be compared with $0.0^{8}35$ for unobstructed entry. Substituting a 9-inch solid wall for the posts would reduce the factor to the latter value and result in a 40 per cent saving in power in such an entry for the same volume of flow.

Some interesting relations are revealed by the resistances expressed as equivalent feet of clear entry in Table 13. In Figure 25 the equivalent resistance is plotted against the number of posts for the four tests in which the maximum volume of air was moving. A straight line has been drawn which resembles one (fig. 28) obtained in the following section for the variation in resistance with a varying number of cars. This line indicates that the row of posts had an end resistance equivalent to 10 feet of clear entry and that each post added an average of slightly more than 11 feet to this resistance.

PRESSURE LOSSES CAUSED BY MINE CARS

The resistance caused by cars is an important part of the total resistance which the air must encounter in haulage entries. More than 100 tests were made in section *A–B* with mine cars in different combinations. Figure 26 shows the main dimensions of the car used. These cars have a capacity of about 1 ton of coal when not topped above the side. The end area exposed to the air current is about 10 square feet, including the obstruction caused by the wheels and axle, or about 17.5 per cent of the average area of the clear section *A–B*. Figure 27 shows this car with two smaller cars used for a special series of tests.

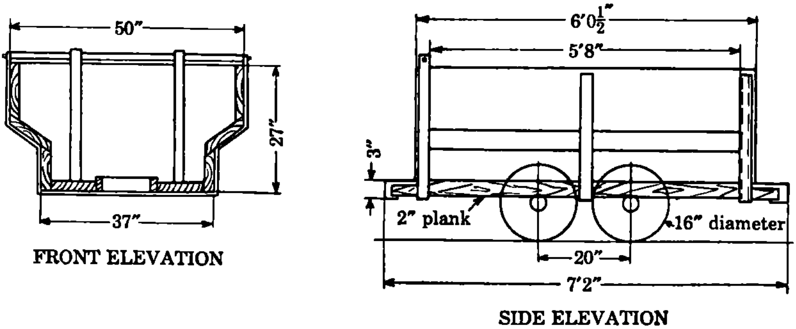


FIGURE 26.—Mine car used in pressure-loss tests

Most of the tests of cars were made in clear untimbered entry, but a few of these were duplicated in sections of the entry timbered with sets on 5 and 10 foot centers. The 200, 300, and 400 cut-throughs had board deflector brattices in them during the car tests, which made No. 2 butt in effect a long unbroken entry. This was done because it was originally thought that the resistance caused by a car might differ when the car was opposite a cut-through dead end.

Tests were made at four standard volumes of air flow of 17,130, 28,550, 39,970, and 51,390 cubic feet per minute corresponding to average velocities of 300, 500, 700, and 900 feet per minute in the clear entry. Variations in area, and consequently in velocities, in the short sections actually occupied by the cars during tests caused large variations in results, as computed on the basis of average areas and velocities for the total test section, and required a more detailed analysis of test conditions and results than was originally contemplated.

The pressure loss caused by the cars is expressed by the ratio of the pressure loss to the velocity pressure of the air in, and the equivalent feet of, an unobstructed entry.

FIGURE 27.—Mine cars used in pressure-loss tests

TESTS IN UNTIMBERED ENTRY

The tests with cars in an untimbered entry can be separated into six groups as follows: (1) Variation in the number of cars coupled together; (2) variation in location of five cars in test section; (3) variation in space between cars; (4) variation in size of car; (5) comparison of empty and loaded cars; (6) comparison of car resistance when in normal entry and when opposite a cut-through dead end.

EFFECT OF NUMBER OF CARS IN TRIP

A single empty car was placed with its inner end at 2B–200, and the pressure loss was determined. Two more empty cars were then run in from the air course and coupled to the first car, and the pressure loss was redetermined. This procedure was repeated until tests had been made with 1, 3, 5, and 7 cars. A seven-car trip occupied about 50 feet of entry when the cars were pushed bumper to bumper.

The results of four series of tests are given in Table 14. Expressed in equivalent feet of clear entry, the pressure loss is practically independent of the velocity (or volume) of air moving. Rejecting the results of tests 706, 712, and 716 as obviously in error, the averaged results of the remainder for each number of cars are as follows:

Number of cars	Average equivalent feet of clear entry
1	54
3	125
5	156
7	208

TABLE 14.—*Pressure-loss tests to determine the effect of varying the number of cars in a trip, August 3 and 6, 1923*

ONE CAR, 2B-200

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss	
		Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry
705	17,130	0.0136	0.0020	0.36	58
706	28,550	.0347	.0034	.22	36
707	39,970	.0685	.0092	.30	52
708	51,390	.1110	.0147	.29	51
THREE CARS, 2B-200 TO 2B-179					
712	17,130	0.0175	0.0059	1.05	170
711	28,550	.0435	.0122	.78	131
710	39,970	.0806	.0213	.70	120
709	51,390	.1306	.0343	.68	119
FIVE CARS, 2B-200 TO 2B-165					
716	17,130	0.0179	0.0063	1.12	182
715	28,550	.0458	.0145	.93	155
714	39,970	.0867	.0274	.90	155
713	51,390	.1418	.0455	.90	158
SEVEN CARS, 2B-200 TO 2B-151					
717	17,130	0.0193	0.0077	1.37	223
718	28,550	.0492	.0179	1.15	192
719	39,970	.0957	.0364	1.19	206
720	51,390	.1565	.0602	1.19	209

These average values are plotted in Figure 28. A straight line, drawn through the values for 3, 5, and 7 cars, intersects the zero vertical coordinate at a point indicating an original equivalent resistance of 60 feet of entry. This may be explained by the following reasoning:

A flat surface at right angles to an air current will offer resistance thereto which is measurably independent of the thickness of the body when its thickness is small in comparison with the exposed area. The end of the car facing the air current represents such a condition; if the remainder of the car could be considered removed, there would be a base pressure loss caused by the end and the eddy currents around it. This loss will be a function of the ratio of the end area of the car to the cross-sectional area of the entry at the point where the end is located. As the length of the car or trip of cars increases, a second loss arises from the friction of the air on the side surface of the car and roadway. This loss will vary with the length of the trip, the amount and character of the rubbing surface exposed, and inversely with the cube of the area through which the air has to pass, supposing that a constant volume of air is being passed per unit of time. Additional losses due to eddy currents between or in the empty cars will be included in this second loss. The measured loss due to the cars in trips is then the sum of the two losses, which may be designated as end resistance and side resistance, respectively. For constant conditions end resistance is independent of the number of cars in the trip, whereas the side resistance varies directly with the number of cars.

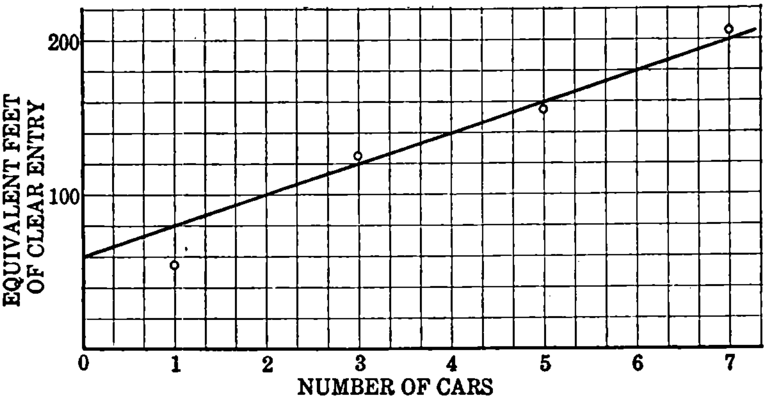


FIGURE 28.—Variation of pressure loss with number of cars

It is to be remembered, however, that both losses involve the size and shape of the cars and the size and shape of the entry where they are placed, as well as the roughness of the surfaces on which the air rubs. The present series of tests illustrates this fact by the divergence of the value for one car from the line drawn. The area of the entry was fairly uniform over the section occupied by 3, 5, and 7 cars, but at the one-car position the net area available for flow was increased about 11 per cent above the average of the other three positions. The larger area might decrease the pressure loss as much as 30 per cent, and if the determined equivalent resistance for one car is increased in this proportion, it becomes 77 feet as compared with 80 feet indicated by the line of Figure 28. Values taken from such a computation, however, are open to some question, as is also the absolute location of the line of Figure 28. Nevertheless, the theory is in large measure substantiated.

EFFECT OF DIFFERENT LOCATIONS IN TEST SECTION

The results of four series of tests with the inner end of a trip of five empty cars at 2B–200, 2B–250, 2B–300, and 2B–350, respectively, are given in Table 15. Expressed as equivalent feet of clear entry the pressure loss is practically independent of the velocity (or volume) of air moving. Rejecting the results of tests 716 and 724 as probably erroneous, the average of the remainder for each location is as follows:

Location of trip	Resistance in equivalent feet of clear entry
2B–200	156
2B–250	220
2B–300	246
2B–350	281

These tests show a steady increase in resistance as the cars are moved along the entry in the direction of air travel.

TABLE 15.—*Pressure-loss tests to determine the effect of varying the position of a five-car trip in the test section, August 6, 1923*

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss	
		Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry
2B-200 TO 2B-165					
716	17,130	0.0179	0.0063	1.12	182
715	28,550	.0458	.0145	.93	155
714	39,970	.0867	.0274	.90	155
713	51,390	.1418	.0455	.90	158
2B-250 TO 2B-215					
724	17,130	0.0203	0.0087	1.55	251
723	28,550	.0522	.0209	1.34	224
722	39,970	.0982	.0389	1.28	220
721	51,390	.1587	.0624	1.24	217
2B-300 TO 2B-265					
725	17,130	0.0198	0.0082	1.46	237
726	28,550	.0540	.0227	1.46	243
727	39,970	.1038	.0445	1.46	251
728	51,390	.1691	.0728	1.44	253
2B-350 TO 2B-315					
732	17,130	0.0215	0.0099	1.77	286
731	28,550	.0565	.0252	1.62	270
730	39,970	.1103	.0510	1.67	288
729	51,390	.1772	.0809	1.60	281

In seeking an explanation of the results shown in Table 15, the measurements of the entry at the various short sections involved were examined to see if the variations were of the proper magnitude and sequence to cause the changes observed. The entry constants are given in Table 16.

TABLE 16.—*Entry constants for different locations of a trip of cars*

Location of trip	Average area of entry, square feet	Estimated average area for passage of air, square feet	Average perimeter, feet	Area of entry at end of car facing the air, square feet
2B-200	60.9	50.9	32.0	61.5
2B-250	55.8	45.8	30.5	56.1
2B-300	57.3	47.3	31.2	48.4
2B-350	53.2	43.2	29.3	52.2

Leaving the 2B–300 location out of consideration for the moment, it will be observed that the average area of the entry decreased as the trip was moved inward from the first to the last point. There was also a similar decrease in area at the point where the air was forced to divide around the cars. These changes are more than 10 per cent of the total area and would cause an increase in resistance that might be even greater than that observed. At location 2B–300 there was a 3 per cent increase in average area over 2B–250, but the area at the end of the trip was the smallest of any location and was 14 per cent less than that at 2B–250. Apparently the decrease overbalanced the slight increase in average area, and the net result was an increase in resistance over 2B–250.

No quantitative conclusions can be safely drawn from these data, except that the resistance of cars and trips may vary considerably according to their exact location in what may appear to be an entry of fairly regular area.

EFFECT OF DIFFERENT SPACINGS BETWEEN CARS

The results of four series of tests of five cars spaced on 7, 15, 25, 35, 40, and 45 foot centers are given in Table 17.

TABLE 17.—*Pressure-loss tests to determine the effect of varying the space between the cars*

FIVE CARS ON 7-FOOT CENTERS (COUPLED), 2B-350 TO 2B-315

Test sheet No.	Date, 1923	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss	
			Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry
732	Aug. 7	17, 130	0. 0215	0. 0099	1. 77	286
731	do	28, 550	. 0565	. 0252	1. 62	270
730	do	39, 970	. 1103	. 0510	1. 67	288
729	do	51, 390	. 1772	. 0809	1. 60	281
FIVE CARS ON 15-FOOT CENTERS, 2B-350 TO 2B-283						
736	Aug. 8	17, 130	0. 0244	0. 0128	2. 29	370
735	do	28, 550	. 0654	. 0341	2. 19	365
734	do	39, 970	. 1271	. 0678	2. 22	383
733	do	51, 390	. 2059	. 1096	2. 17	381
FIVE CARS ON 25-FOOT CENTERS, 2B-350 TO 2B-243						
737	Aug. 8	17, 130	0. 0296	0. 0180	3. 21	520
738	do	28, 550	. 0690	. 0377	2. 42	404
739	do	39, 970	. 1353	. 0760	2. 49	429
740	do	51, 390	. 2240	. 1277	2. 53	444
FIVE CARS ON 35-FOOT CENTERS, 2B-350 TO 2B-203						
744	Aug. 8	17, 130	0. 0254	0. 0138	2. 47	399
743	do	28, 550	. 0681	. 0368	2. 36	394
742	do	39, 970	. 1355	. 0762	2. 50	431
741	do	51, 390	. 2152	. 1189	2. 36	414
FIVE CARS ON 40-FOOT CENTERS, 2B-360 TO 2B-193						
659	June 1	17, 130	0. 0265	0. 0151	2. 70	436
658	do	28, 550	. 0683	. 0394	2. 53	422
657	do	39, 970	. 1290	. 0726	2. 38	410
656	do	51, 390	. 2168	. 1239	2. 45	431
664	June 8	17, 130	. 0261	. 0147	2. 62	425
663	do	28, 550	. 0699	. 0410	2. 63	439
662	do	39, 970	. 1334	. 0770	2. 52	435
661	do	51, 390	. 2220	. 1291	2. 56	449
FIVE CARS ON 45-FOOT CENTERS, 2B-350 TO 2B-163						
745	Aug. 8	17, 130	0. 0244	0. 0128	2. 29	370
746	do	28, 550	. 0648	. 0335	2. 15	359
747	do	39, 970	. 1296	. 0703	2. 30	397
748	do	51, 390	. 2129	. 1166	2. 31	406

The results given in Table 17 are not as consistent in each group of tests as those considered in preceding tables. Test 737 is the only one to be definitely discarded, however, as considerably out of line with the rest. Considered on the basis of equivalent feet of clear entry, there appears to be a tendency for the pressure loss to increase with increasing velocity. This tendency is not definite and uniform enough to be taken into account, however, and the results of each group are averaged.

The average results should agree substantially with the theory developed in the last two sections, if the theory is to be held at all. As the cars are separated the air after passing the first will tend to resume the distribution it would have had if the car had not been present. How closely the air will approach this distribution will depend on the distance between the cars, because as the air approaches the second car it will be forced again into the clear area around the car; this cycle of events will be repeated for each car.

As the cars are separated the pressure loss should gradually increase until the distance between the cars becomes so great that the air has time to resume its normal distribution before each successive car is reached. The total pressure loss of the cars should then remain constant for a further increase in spacing and should be equal to the pressure loss of one car times the number of cars present. This theory, of course, assumes an entry of uniform cross section; but it is also to be remembered that when a single car is considered, the end resistance is 75 per cent of the total resistance; consequently, the cross-sectional area at the end of the car, rather than the average area along it, is the factor of primary importance. The average resistances determined in the tests of Table 17 and the average cross-sectional area of the entry at the approach end of the cars for each group of the table are given in Table 18.

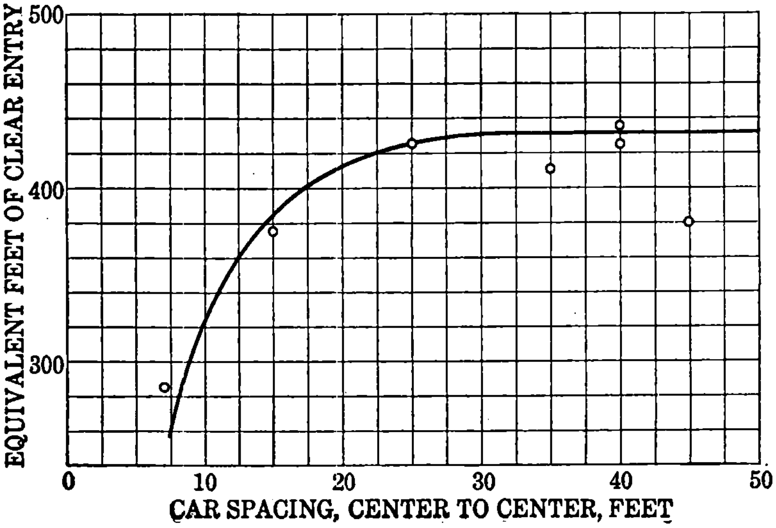


FIGURE 29.—Variation of resistance of five cars with spacing of cars

TABLE 18.—*Entry constants for different car spacings*

Group	Center to center distance between cars, feet	Average equivalent feet of clear entry	Average area of entry at end of cars, square feet	Group	Center to center distance between cars, feet	Average equivalent feet of clear entry	Average area of entry at end of cars, square feet
1	7	285	52.2	5	40	425	55.2
2	15	375	56.3	6	40	437	55.2
3	25	426	55.1	7	45	383	58.9
4	35	410	57.7				

In group 1, Table 18, the cars are coupled together; as the cars are separated the resistance increases rapidly to group 3 and is then variable. The points have been plotted in Figure 29, and a curve has been drawn which agrees with the theory. The variation of the size of the entry explains the deviation of the points from the curve qualitatively; the data do not permit exact quantitative deductions. The average areas in groups 3 and 5 are the same, and group 6 is a duplicate of group 5. The differences between groups 5 and 6 show the errors of duplicate experiments. Group 3 and the average of groups 5 and 6 are then the main determining points of the curve. The area of group 1 is 5.3 per cent small, and the areas of groups 2, 4, and 7 are 2.2, 4.7, and 6.9 per cent large, respectively. The resistance of group 1 will then be too high, and that of the others will be too low. Also, the resistance will vary with some power of the area greater than the first; therefore the deviation of the points of groups 4 and 7 should be considerable, as the curve shows. The shape of the curve is then fairly well established, but its location and the point at which it becomes horizontal may be slightly different from those of Figure 29.

The maximum resistance with five cars, however, is approximately equivalent to 430 feet of clear entry under the conditions obtained; this is 86 feet per car, as compared with 80 feet for a single car deduced from the tests with a varying number of cars. (See fig. 28.) The tests for a single car were based on a section of the entry having a larger area, which gave a lower resistance per car.

EFFECT OF SIZE OF CAR

The preceding tests have shown that a variation in the size of the entry will produce a marked difference in the pressure loss caused by a car, and it follows that a variation in the size of the car will produce a similar result.

The three cars shown in Figure 27 were located at 2B–200 during tests to determine their resistance. The medium-size car had an end-resistance area of about 7 square feet, and the top of the sides was 27 inches above the rail. These measurements were taken to represent the size of cars used in low beds of coal. The lowest car was nothing more than a truck with a single board on each side and no end boards. The end-resistance area was between 2 and 3 square feet, but an accurate estimate was difficult to make. The purpose of using these different-size cars was to determine, if possible, the effect of varying the ratio of end area of the car to total area of the entry. Results of three series of tests are shown in Table 19.

TABLE 19.—*Tests to determine the pressure loss caused by different-size cars, September 21, 1923*

CAR TRUCK ONLY

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss	
		Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry
961	17,130	0.0120	0.0004	0.07	12
962	28,550	.0327	.0014	.09	15
963	39,970	.0598	.0005	.02	3
964	51,390	.0988	.0025	.05	9
CAR WITH LOW SIDES					
965	17,130	0.0129	0.0013	0.23	38
966	28,550	.0330	.0017	.11	18
967	39,970	.0631	.0038	.12	21
968	51,390	.1058	.0095	.19	33
FULL-SIZE CAR					
969	17,130	0.0137	0.0021	0.38	61
970	28,550	.0361	.0048	.31	51
971	39,970	.0688	.0095	.31	54
972	51,390	.1140	.0177	.35	62

The test results are unsatisfactory. The absolute value of the resistance caused by the car is small in all of the tests, and experimental error will play a larger proportionate part in them. Tests 969 to 972 with the full-size car are duplicates of tests 705 to 708 made seven weeks before and given in Table 14. In the earlier tests the average equivalent length of entry was 53 feet and in the later tests was 57 feet. This is as close as duplicate tests of this kind will agree.

The average equivalent length of clear entry was 10, 28, and 57 feet under the three conditions in Table 18, and the corresponding ratios of car to entry area were 0.37, 0.104, and 0.148. These values are plotted in Figure 30. From the curve obtained it would appear that the resistance increased approximately as the square of the ratio of car area to entry area. The curve represents the combined effect of the end and side resistance of the car, and as these tests were made with single cars the end resistance is the dominant factor. This conclusion is confirmed by other series of tests on the standard-size car in timbered and untimbered entry.

LOADED AND EMPTY CARS

Table 20 gives the results of two series of tests in which the resistance of three empty cars located at 2B–200 was compared with that of three loaded cars at the same location. Test 712 is discarded as evidently in error. The average equivalent resistance of the empty cars was 123 feet and of the loaded cars was 127 feet. This difference is not much greater than that which would be found with duplicate experiments. The loaded cars might be expected to give a somewhat higher pressure loss because they were loaded with slate and dirt so that the center was 6 to 9 inches above the sides and the clear area for passage of the air was somewhat reduced. It is apparent that the difference between loaded and empty cars will have no practical significance when the cars occupy not more than 15 or 20 per cent of the entry area.

TABLE 20.—*Tests to compare the pressure loss caused by loaded and empty cars, August 3 and 9, 1923*

THREE EMPTY CARS, 2B-200 TO 2B-179

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss	
		Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry
712	17,130	0.0175	0.0059	1.05	170
711	28,550	.0435	.0122	.78	131
710	39,970	.0806	.0213	.70	120
709	51,390	.1306	.0343	.68	119

THREE LOADED CARS, 2B-200 TO 2B-179

Test sheet No.	Air volume, cubic feet per minute	Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry
752	17,130	0.0159	0.0043	0.77	124
751	28,550	.0424	.0111	.71	119
750	39,970	.0825	.0232	.76	131
749	51,390	.1352	.0389	.77	135

CARS OPPOSITE CUT-THROUGH DEAD ENDS

Single empty cars were placed opposite the openings into the 200, 300, and 400 cut-through dead ends. Pressure-loss measurements were then made with the board brattices in place and again after they had been removed. The cars were in exactly the same place in both tests. As the cars were 2 to 3 feet shorter than the width of the openings, it would be expected that air flowing to the side of the car would be deflected into the cut-through dead end when the brattices were not present.

The results of the two series of tests are given in Table 21. There was no difference between the average results obtained with the cars opposite the open cut-throughs and opposite the cut-throughs closed with brattices, in spite of the fact that conditions of air flow were certainly different for the two conditions. This may be explained by supposing that, although the air had a chance to expand into a larger area with the open cut-through, the increased eddy current in the cut-through consumed more power; hence the total loss remained the same as when a solid wall was present.

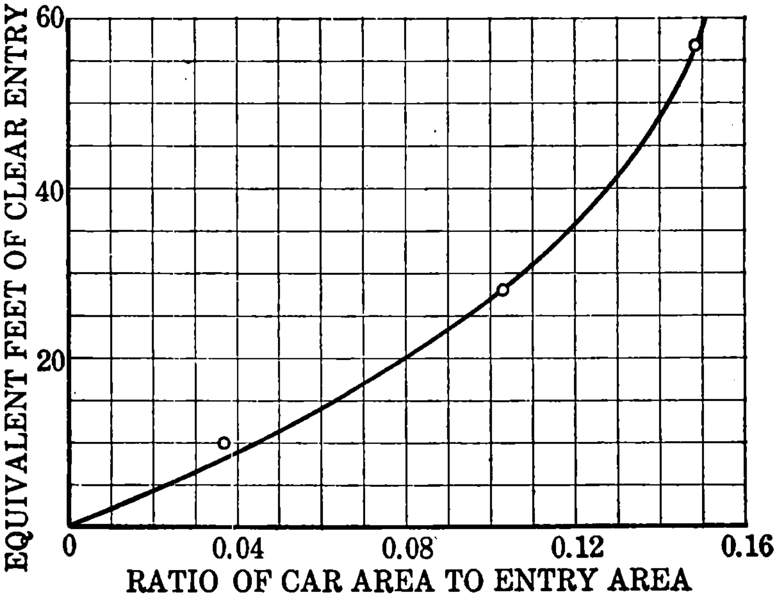


FIGURE 30.—Relation of single-car resistance and ratio of car area to entry area

TABLE 21.—*Tests to compare the resistance caused by cars in unbroken entry and opposite cut-through dead ends*

UNBROKEN ENTRY

Test sheet No.	Date, 1923	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss	
			Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry
653	June 1	17, 130	0. 0163	0. 0049	0. 88	144
654	do	28, 550	. 0452	. 0163	1. 04	189
655	do	39, 970	. 0902	. 0338	1. 11	201
OPPOSITE CUT-THROUGH DEAD ENDS						
638	May 31	17, 130	0. 0171	0. 0050	0. 89	147
639	do	28, 550	. 0477	. 0169	1. 08	196
640	do	39, 970	. 0920	. 0320	1. 05	190

TESTS IN TIMBERED ENTRY

Four series of tests were made with cars in a timbered entry, using a trip of five empty cars at two different locations in a section containing 20 split-timber sets on 5-foot and 10-foot centers. Figure 31 shows the trip of cars in the timbered portion of No. 2 butt entry.

FIVE-CAR TRIP WITH TIMBERS ON 5-FOOT CENTERS

In the tests with timbers on 5-foot centers the timbers extended from 2B–350 to 2B–255. The inner end of the trip of five empty cars was located first at 2B–350 and then at 2B–300. In these positions the cars occupied approximately 24 per cent of the area inside of the timbers, and the timbers reduced the clear area for passage of air around the cars about 30 per cent. The results of these two series of tests are given in Table 22.

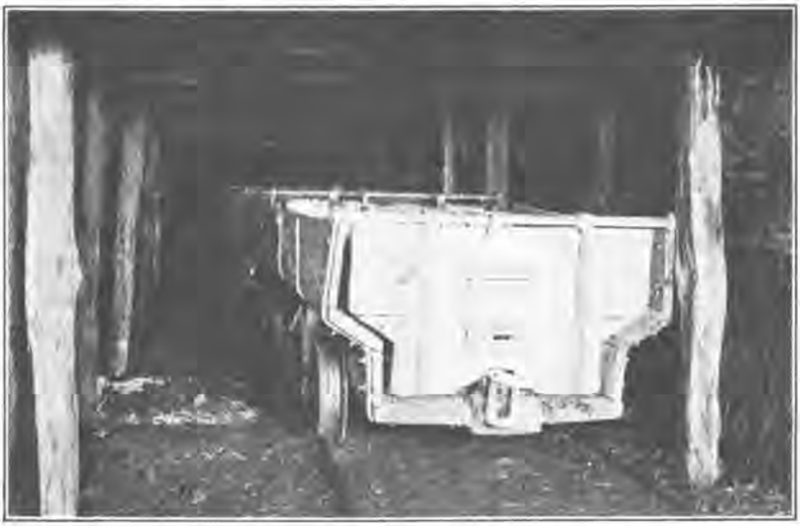


FIGURE 31.—Trip of cars used in timbered section in pressure-loss tests

The car-loss results in Table 22 expressed in equivalent feet of clear entry compared with the two similar series of results for cars in untimbered entry given in Table 15 show that the equivalent resistance of the cars was multiplied by 3.5. The equivalent resistance of the trip was less at 2B–300 than at 2B–350 because of slight differences in average areas. The car loss expressed as equivalent feet of timbered entry is much smaller than that for clear entry because the normal loss for the timbered entry is higher.

Comparison of the velocity-pressure ratios of Tables 15 and 22 gives average values of 1.56 and 2.84, or an increase of 82 per cent. The respective ratios of car area to entry area are 17.5 and 24, and, with resistance increasing inversely as the square of the ratios, an increase of 88 per cent would be indicated. It therefore appears that car losses expressed in velocity-pressure ratios are independent of the particular characteristics of the airway and that the square of the ratio of car area to entry area is a good criterion for comparative purposes.

TABLE 22.—*Pressure-loss tests with a trip of five empty cars in an entry having timber sets at 5-foot intervals, August 14, 1923*

FIVE CARS, 2B-350 TO 2B-315

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss		
		Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry	Equivalent feet of timbered entry
756	17,130	0.0602	0.0292	2.75	843	142
755	28,550	.1680	.0884	2.98	946	155
754	39,970	.3241	.1690	2.91	954	151
753	51,390	.5484	.2963	3.09	1,031	160
FIVE CARS, 2B-300 TO 2B-265						
757	17,130	0.0594	0.0284	2.67	820	138
758	28,550	.1633	.0837	2.82	896	147
759	39,970	.3163	.1612	2.78	910	144
760	51,390	.5120	.2599	2.71	904	105

FIVE-CAR TRIP WITH TIMBERS ON 10-FOOT CENTERS

In the tests with timbers on 10-foot centers the timbers extended from 2B–350 to 2B–160, and the inner end of the trip of five empty cars was located first at 2B–350 and then at 2B–250. In these positions the cars occupied approximately 22 per cent of the area inside of timbers, and the timbers reduced the clear area for passage of air around the cars about 13 per cent. The results of these two series of tests are given in Table 23.

The results of the tests given in Table 23 are analogous to those in Table 22 discussed in the preceding paragraphs, but no comparative data for tests in untimbered entry are available. The absolute values of car resistance with timber sets on 10-foot centers are somewhat less than those for 5-foot timber spacing; this difference was due to slightly larger areas within the timber sets and to wider spacing of the sets, which allowed complete expansion of the air in the space between sets. There is also a larger difference in results at the two locations. These tests present no new points and are not as representative of ordinary mine conditions as were those with timber sets on 5-foot centers.

TABLE 23.—*Pressure-loss tests with a trip of five empty cars in an entry having timber sets at 10-foot intervals, September 14, 1923*

FIVE CARS, 2B-300 TO 2B-265

Test sheet No.	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of car loss		
		Observed loss	Loss due to cars	Ratio to velocity pressure	Equivalent feet of clear entry	Equivalent feet of timbered entry
897	17, 130	0. 0605	0. 0229	2. 25	661	144
898	28, 550	. 1697	. 0644	2. 27	689	145
899	39, 970	. 3163	. 1157	2. 08	654	133
900	51, 390	. 5332	. 2073	2. 25	721	144
FIVE CARS, 2B-200 TO 2B-165						
896	17, 130	0. 0553	0. 0177	1. 74	511	111
895	28, 550	. 1552	. 0499	1. 76	534	113
894	39, 970	. 2929	. 0923	1. 66	521	106
893	51, 390	. 4888	. 1629	1. 77	567	113

PRESSURE LOSSES CAUSED BY RIGHT-ANGLE BENDS

TEST SECTION USED

All tests on the pressure losses caused by bends were confined to tests of right-angle bends and with the exception of a few special tests were made in the test section *B–C*. (See fig. 1.) The air passing up No. 2 butt crossed the 475 cut-through and returned down No. 1 butt, thus making two right-angle bends in the same direction but 50 feet apart, a condition quite common in American coal mines. Static stations *B* and *C* were two of the original four that had been carefully trimmed to equal areas. A few preliminary tests showed the necessity for a static tube in the 475 cut-through, and a static station was located at *X*. Because of the proximity of *X* to the bend differential static-pressure measurements were made in the plane of the *X* station itself in order to determine the reliability of the results obtained at that point. These tests have been described under "Static differentials at static stations" (p. 30). The dimensions of sections *B–X* and *X–C* are given in Table 5 (p. 33). Figure 32 is a plan of section *B–C* with corresponding area graph.

SCOPE OF TEST WORK

In the primary or base condition of the entry there were square corners at the junctions of the 475 cut-through with the two butt entries, and the entry dead ends beyond the cut-through were open. In subsequent tests these conditions were modified in a number of ways to determine:

A.—The effect on the resistance of a single right-angle bend—
1. Of a dead end opening off of it.
2. Of modifying the inner corner only with a bevel and with curved surfaces.
3. Of modifying the outer corner only with curved surfaces.
4. Of modifying both corners in various combinations.
5. Of radial vanes in combination with curved surfaces.
6. Of Venturi bends.

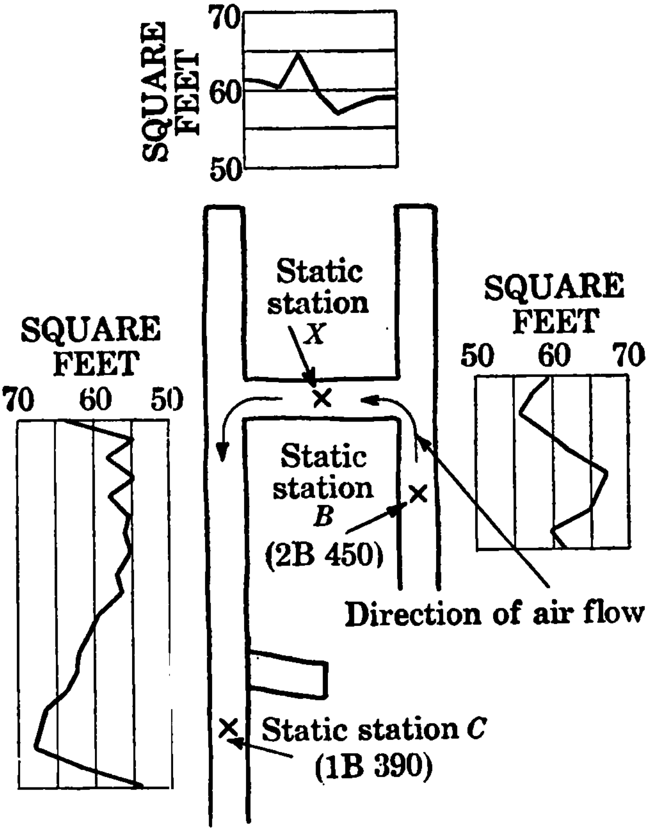


FIGURE 32.—Test section *B–C* with corresponding area graph

B.—The effect on the resistance of two closely spaced right-angle bends—
1. With the flow deflected in the same direction at each—
   (*a*) Of modifications of the first bend only.
   (*b*) Of similar modifications of both bends—
      (1) With open dead ends.
      (2) With curves and radial vanes.
      (3) With Venturi bends.
2. Of deflecting the flow in opposite directions.

RESISTANCE OF A SINGLE RIGHT-ANGLE BEND

In determining the resistance of each of the two right-angle bends that occur in the test section *B–C* it was found that, with the bends 50 feet apart, the presence of the first bend materially affected the resistance of the second; results of tests on the first bend are therefore presented as the normal condition that would obtain at a single bend. Discussion of this effect of one bend on a following bend is reserved for a later section. The following determinations on the resistance of a single bend were obtained in test section *B–X*.

EFFECT OF OPEN DEAD END

The bend had the short dead end of No. 2 butt entry opening off of it in the direction of the air flow, and it was noted that an eddy current rotated slowly in this opening. The dead end was closed with a board brattice, and duplicate series of tests were made with and without the brattice in place. The results are shown in Table 24.

Table 24.—*Pressure-loss tests on a single right-angle bend with and without a dead-end extension, August 20, 1923*

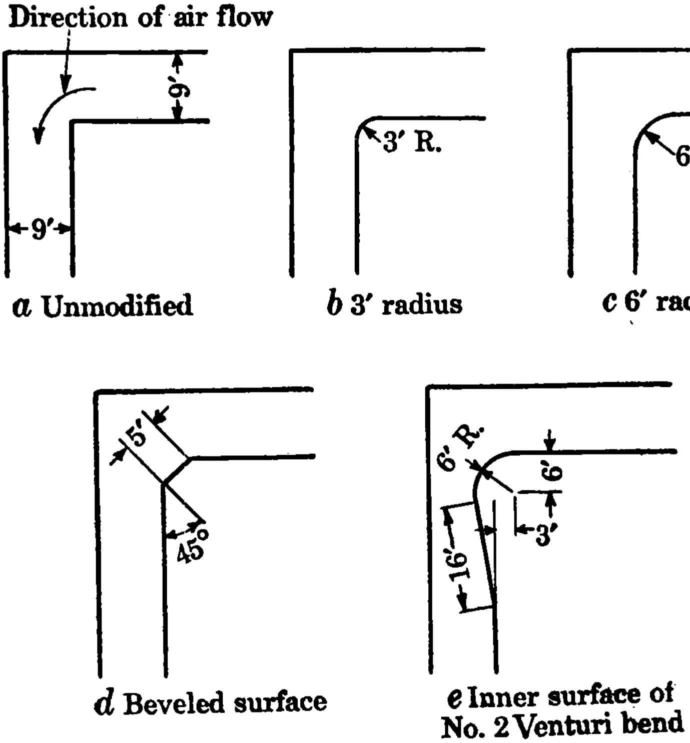
WITH DEAD-END EXTENSION

Test No.	Air velocity, feet per minute	Pressure loss, inch of water		Ratio of bend loss to velocity pressure	Equivalent feet of clear entry
		Mean total loss	Loss due to bend		
781	300	0.0100	0.0083	1.48	246
782	500	.0258	.0213	1.37	237
783	700	.0508	.0422	1.38	247
784	900	.0834	.0694	1.37	250
785	300	.0099	.0082	1.46	243
786	500	.0249	.0204	1.31	227
787	700	.0503	.0417	1.37	244
788	900	.0837	.0697	1.38	251
WITHOUT DEAD-END EXTENSION					
780	300	0.0095	0.0078	1.39	232
779	500	.0262	.0217	1.39	241
778	700	.0522	.0436	1.43	255
777	900	.0830	.0690	1.37	248
792	300	.0096	.0079	1.41	235
791	500	.0290	.0245	1.57	272
790	700	.0514	.0428	1.40	251
789	900	.0863	.0723	1.43	260

The pressure loss expressed as a ratio to velocity pressure was independent of the velocity, showing that the pressure loss varied directly as the square of the velocity. When expressed as equivalent feet of clear entry, the loss was greater at the higher velocities because the pressure loss in clear entry increased at a rate somewhat less than the square of the velocity, as was shown in the preceding chapter. Consequently, comparisons should be made on the basis of velocity-pressure ratios. The average values of these ratios in the two groups, rejecting those of the two most erratic tests, 781 and 791, were then 1.38 with dead-end extension and 1.40 without dead-end extension.

Closing off the dead-end extension of No. 2 butt entry apparently resulted in an increased pressure loss, but the difference is within the limit of error of duplicate experiments. The bend caused a pressure loss approximately equal to that of 250 feet of clear entry—a striking example of the power required to change the course of an air current. Similar losses of greater or less degree occur wherever roof falls, overcasts, irregularities in the line of the entry, or other obstructions cause a change in direction of air flow.

For determining the relative value of modifications of the bend, which were made with the board brattice in place, a base figure of



a Unmodified *b* 3' radius *c* 6' radius

d Beveled surface *e* Inner surface of No. 2 Venturi bend

FIGURE 33.—Modifications of inner corner of single right-angle bend

1.40 times the velocity pressure was taken as the pressure loss caused by the bend with full square corner.

EFFECT OF CURVES AND BEVEL ON INNER CORNER

The base condition of the square-corner bend was modified by changing the inner and outer corners both separately and in combination. The inner square corner was replaced successively by a curve of 3-foot radius, a curve of 6-foot radius, a 45° beveled flat surface 5 feet long, and the inner surface of a Venturi bend. These conditions are illustrated in plan in Figure 33. The results of these four series of tests, preceded by the series of basic test results for the square-corner bend, are given in Table 25.

TABLE 25.—*Pressure-loss tests with modification of inner corner only of right-angle bend*

Test No.	Date, 1923	Air velocity, feet per minute	Pressure loss, inch of water		Ratio of bend loss to velocity pressure	Equivalent feet of clear entry
			Mean total loss	Loss due to bend		
AVERAGE BASE CONDITION, WITH INNER AND OUTER SQUARE CORNERS						
		300	0.0095	0.0078	1.40	233
		500	.0264	.0218	1.40	243
		700	.0513	.0427	1.40	250
		900	.0848	.0707	1.40	257
THREE-FOOT-RADIUS CURVE ON INNER CORNER						
840	Aug. 29	300	0.0074	0.0057	1.02	170
839	do	500	.0177	.0132	.85	147
838	do	700	.0344	.0258	.85	151
837	do	900	.0520	.0380	.75	137
SIX-FOOT-RADIUS CURVE ON INNER CORNER						
884	Sept. 10	300	0.0054	0.0037	0.66	110
883	do	500	.0134	.0089	.57	99
882	do	700	.0261	.0175	.57	103
881	do	900	.0404	.0264	.52	95
FIVE-FOOT, 45° BEVELED FLAT SURFACE ON INNER CORNER						
888	Sept. 12	300	0.0067	0.0050	0.89	149
887	do	500	.0161	.0116	.74	129
886	do	700	.0290	.0204	.67	120
885	do	900	.0474	.0334	.66	120
INNER SURFACE ONLY OF NO. 2 VENTURI BEND						
836	Aug. 28	300	0.0104	0.0087	1.55	258
835	do	500	.0250	.0205	1.31	228
834	do	700	.0444	.0358	1.17	210
833	do	900	.0729	.0589	1.17	212

The results given in Table 25 show that beveling the inner corner of the bend or replacing it with curved surfaces reduced the pressure loss caused by the bend. When expressed as a ratio of the velocity pressure, the pressure loss decreased as the air velocity increased. The loss expressed on this basis was independent of velocity before the modifications were made, so that the curves became more effective in reducing pressure loss as the velocity increased. This result may be taken to indicate that the turbulence caused by the inner corner was reduced and the condition of air flow was approaching that in straight entry—a theory that is supported by the fact that when expressed as equivalent feet of clear entry the pressure loss either decreased or was constant with increasing velocity.

The 6-foot-radius curve was most effective in reducing pressure loss. The ratio at the highest velocity for this condition was 0.52, as compared with 1.40 for the base condition.

Taking the pressure loss of the base condition as 100 per cent, the pressure losses of the modifications at 900 feet per minute velocity were:

	Per cent
Inner surface only of No. 2 Venturi bend	84
Three-foot-radius curve	54
Five-foot 45° beveled flat surface	47
Six-foot-radius curve	37

The pressure loss at a right-angle bend is shown to be halved simply by cutting off the inner square corner on an angle of 45° with the two passageways. The new surface should have a length not less than two-thirds the diameter of the entry, such diameter being defined as one-half the sum of width and height. If the beveled surface is longer, a greater reduction may be anticipated. Cutting the inner corner as a curved surface whose radius is 80 per cent of the diameter is more difficult in practice but will reduce the pressure loss still further. The inner surface of the Venturi bend had little value alone.

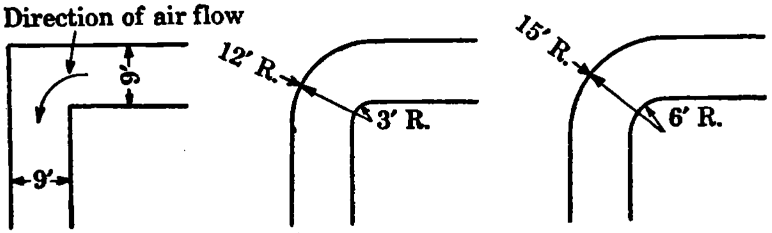
EFFECT OF CURVE ON OUTER CORNER

Table 26 gives the results of duplicate tests with the outer corner changed to a 12-foot-radius curve by means of zinc-coated iron plates nailed to 2 by 4 inch posts. The results of the tests do not agree. In the first test the pressure loss was greater with the curve present, and in the second it was unchanged by the curve. The difference may be due to errors of measurement, or it may be due to unnoticed differences of construction in the second test. This condition gave the poorest air distribution at static station *X*, and the probable error of the results is consequently greater. The results of Tables 25 and 26, however, show that if reduction of pressure loss is to be accomplished by modifying one corner only the inner corner should be the one modified. The air on the outer side of the bend then automatically adjusts itself to the path of least resistance. For these reasons it was considered unnecessary to test other modifications of the outer corner.

Table 26.—*Pressure-loss tests with modification of outer corner only of right-angle bend*

AVERAGE BASE CONDITION, WITH INNER AND OUTER SQUARE CORNERS

Test No.	Date, 1923	Air velocity, feet per minute	Pressure loss, inch of water		Ratio of bend loss to velocity pressure	Equivalent feet of clear entry
			Mean total loss	Loss due to bend		
		300	0.0095	0.0078	1.40	233
		500	.0264	.0218	1.40	243
		700	.0513	.0427	1.40	250
		900	.0848	.0707	1.40	257
TWELVE-FOOT-RADIUS CURVE ON OUTER CORNER						
796	Aug. 21	300	0.0109	0.0092	1.64	274
795	do	500	.0330	.0285	1.83	317
794	do	700	.0636	.0550	1.80	322
793	do	900	.1040	.0899	1.78	324
856	Sept. 4	300	.0090	.0073	1.30	217
855	do	500	.0266	.0221	1.42	246
854	do	700	.0512	.0426	1.40	250
853	do	900	.0849	.0709	1.40	255



a Unmodified

b Short radius modification

c Long radius modification

Figure 34.—Modifications of both inner and outer corners of right-angle bend

EFFECT OF CURVES ON BOTH CORNERS

Two modifications of both corners in combination were tested. The first series of tests was made with the inner corner rounded to a curve of 3-foot radius and the outer corner curved on a 12-foot radius. For the second test series the inner corner was changed to a curve of 6-foot radius, and the outer corner was on a 15-foot radius. These arrangements are illustrated in Figure 34. The results of these two series of tests are given in Table 27.

Although an outer curve did not give any advantage by itself it caused a further reduction in pressure when used with an inner curve, as the tests of Table 27 show. This effect may be due to the fact that the outer curve eliminated the eddy current which rotated in the outer square corner. With 3-foot and 12-foot radius curves the ratio of bend loss to velocity pressure at the highest velocity was 0.60, as compared with 0.75 when the 3-foot inner curve was used alone. With 6-foot and 15-foot radius curves the ratio was 0.29, as compared with 0.52 when the 6-foot inner curve was used alone. The outer curve was more effective with the longer radius, a fact which may be ascribed to the increase in size of the eddy current in the outer corner as the inner corner was cut back. With 6-foot and 15-foot radius curves (center-line radius equal to 1.4 entry diameter) the resistance of the bend was only 21 per cent of that of a square-corner bend and was then approximately equivalent to that of 50 feet of clear entry. It is certain that the use of curves of longer radii would give further reductions in pressure loss, but laboratory tests of ventilating equipment indicate that there is little advantage in increasing the center line radius beyond 1.5 diameters.

TABLE 27.—*Pressure-loss tests with modification of both inner and outer corners of right-angle bend*

Test No	Date, 1923	Air velocity, feet per minute	Pressure loss, inch of water		Ratio of bend loss to velocity pressure	Equivalent feet of clear entry
			Mean total loss	Loss due to bend		
AVERAGE BASE CONDITION, WITH INNER AND OUTER SQUARE CORNERS						
		300	0.0095	0.0078	1.40	233
		500	.0264	.0218	1.40	243
		700	.0513	.0427	1.40	250
		900	.0848	.0707	1.40	257
INNER AND OUTER CORNERS MODIFIED WITH 3-FOOT AND 12-FOOT RADIUS CURVES						
804	Aug. 22	300	0.0059	0.0042	0.75	119
803	do	500	.0150	.0105	.67	117
802	do	700	.0281	.0195	.64	114
801	do	900	.0443	.0303	.60	109
INNER AND OUTER CORNERS MODIFIED WITH 6-FOOT AND 15-FOOT RADIUS CURVE						
872	Sept. 7	300	0.0035	0.0018	0.32	54
871	do	500	.0091	.0046	.30	51
870	do	700	.0177	.0091	.30	53
869	do	900	.0284	.0144	.29	52

EFFECT OF RADIAL VANES

The effect of radial vanes extending through a quadrant or quarter circle and concentric with inner and outer curved surfaces was the subject of a number of tests. The vanes were constructed of 2 by 4 inch studding and zinc-coated iron sheets in the same manner as the outer curve of the bend. The 2 by 4 inch pieces were placed with a 2-inch surface facing the air. As shown in Figure 35, the vanes extended from the floor to the roof and presented a curved surface of known radius which forced the air around the turn. This arrangement prevented crowding of the air on the outer side of the turn, a condition that normally occurs because of the tendency of the air column to continue moving in a straight line. It was possible,

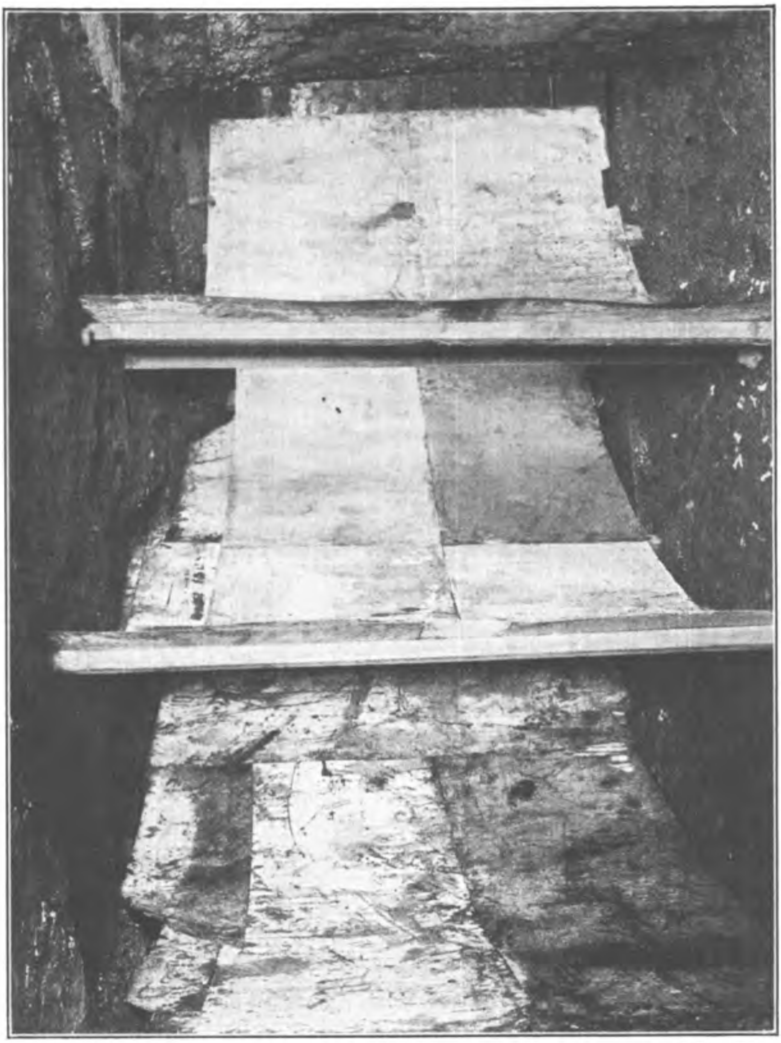
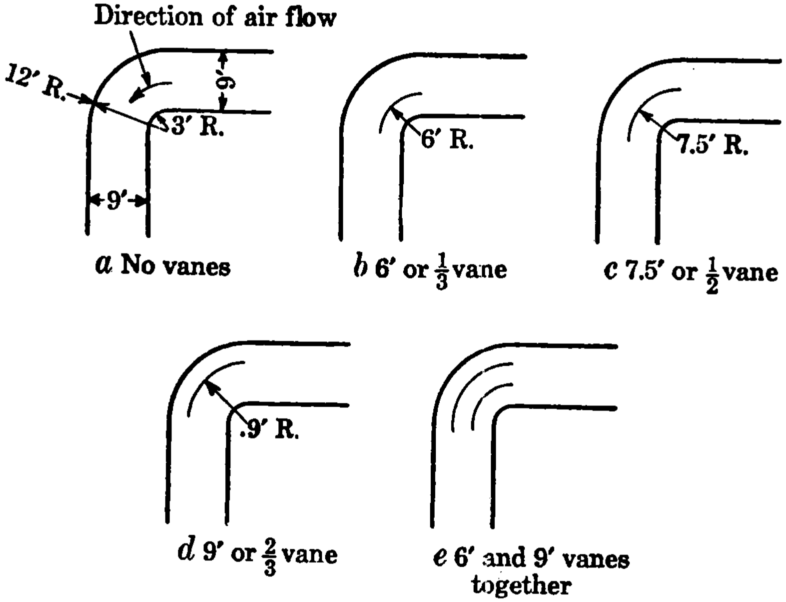


FIGURE 35.—Curves and radial vanes on the corner of No. 2 butt and the 475 cut-through

of course, to locate a vane at any point between the two ribs, and a number of different locations were tried both singly and in combination.

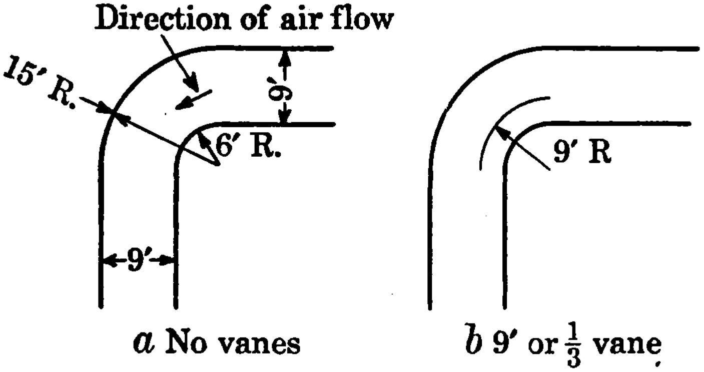


a No vanes *b* 6' or $\frac{1}{3}$ vane *c* 7.5' or $\frac{1}{2}$ vane

d 9' or $\frac{2}{3}$ vane *e* 6' and 9' vanes together

FIGURE 36.—Radial vanes used in addition to curved surfaces of 3 and 12 foot radii

With the inner and outer corners modified by 3-foot and 12-foot radius curves, separate series of tests were made with a 6-foot radius or one-third vane, a 7.5-foot radius or one-half vane, a 9-foot radius or two-thirds vane, and 6-foot and 9-foot radius vanes together—all of which are illustrated in plan in Figure 36. The tests with the 6-foot-radius vane were made in duplicate. A 9-foot-radius vane, a one-third vane under these conditions, was also used in one series of tests in conjunction with inner and outer curves of 6 and 15 foot radii, as shown in Figure 37.



a No vanes *b* 9' or $\frac{1}{3}$ vane.

FIGURE 37.—Radial vane used in addition to curved surfaces of 6 and 15 foot radii

The results of these six series of tests and of the comparable series without vanes are given in Table 28.

TABLE 28.—*Pressure-loss tests with radial vanes in addition to curved surfaces*

PART I.—WITH 3-FOOT-RADIUS INNER AND 6-FOOT-RADIUS OUTER CURVED SURFACES

Test No.	Date, 1923	Air velocity, feet per minute	Pressure loss, inch of water		Ratio of bend loss to velocity pressure	Equivalent feet of clear entry
			Mean total loss	Loss due to bend		
BASE CONDITION, WITHOUT VANES						
804	Aug. 22	300	0.0059	0.0042	0.75	119
803	do	500	.0150	.0105	.67	117
802	do	700	.0281	.0195	.64	114
801	do	900	.0443	.0303	.60	109
WITH 6-FOOT RADIUS OR ONE-THIRD VANE						
816	Aug. 24	300	0.0042	0.0025	0.45	74
815	do	500	.0106	.0061	.39	68
814	do	700	.0197	.0111	.36	65
813	do	900	.0312	.0172	.34	62
844	Aug. 31	300	0.0039	0.0022	0.39	65
843	do	500	.0106	.0061	.39	68
842	do	700	.0200	.0114	.37	67
841	do	900	.0312	.0172	.34	62
WITH 7.5-FOOT RADIUS OR ONE-HALF VANE						
820	Aug. 24	300	0.0043	0.0026	0.46	77
819	do	500	.0109	.0064	.41	71
818	do	700	.0198	.0112	.37	66
817	do	900	.0314	.0174	.34	63
WITH 9-FOOT RADIUS OR TWO-THIRDS VANE						
812	Aug. 23	300	0.0050	0.0033	0.59	98
811	do	500	.0129	.0084	.54	94
810	do	700	.0249	.0163	.53	96
809	do	900	.0382	.0242	.48	87
WITH 6-FOOT AND 9-FOOT RADIUS VANES						
808	Aug. 23	300	0.0042	0.0025	0.45	74
807	do	500	.0108	.0063	.40	70
806	do	700	.0196	.0110	.36	65
805	do	900	.0309	.0169	.33	61

PART II.—WITH 6-FOOT-RADIUS INNER AND 15-FOOT-RADIUS OUTER CURVED SURFACES

BASE CONDITION, WITHOUT VANES						
872	Sept. 7	300	0.0035	0.0018	0.32	54
871	do	500	.0091	.0046	.30	51
870	do	700	.0177	.0091	.30	53
869	do	900	.0284	.0144	.29	52
WITH 9-FOOT RADIUS OR ONE-THIRD VANE						
876	Sept. 10	300	0.0031	0.0014	0.25	42
875	do	500	.0087	.0042	.27	47
874	do	700	.0176	.0090	.30	53
873	do	900	.0271	.0137	.27	49

The results of the various groups of tests in Table 28 agree within themselves in a satisfactory manner. The duplicate tests with the 6-foot-radius vane in Part I check very closely; the agreement is the more significant as the vane was taken down and reerected between the two groups of tests. At the highest velocity the 6-foot-radius vane reduced the bend-loss ratio from 0.60 to 0.34, but it was still slightly higher than that obtained with 6-foot and 15-foot radius curves without vanes, as shown in the first group of Part II of the table. When the vane was midway between the two ribs it had the same effect as when in the one-third position; but when in the two-thirds position it was less effective than in the first two places. The use of a 9-foot radius or two-thirds vane in addition to the 6-foot radius or one-third vane gave no additional saving. The 6-foot radius or one-third vane used alone was more efficient in decreasing pressure loss, for though the 7.5-foot radius or one-half vane gave an equal reduction more material was required for its construction.

When the surfaces of the bend were curves of 6-foot and 15-foot radii the pressure loss without vanes was less than in any of the tests given in Part I of Table 28. The addition of a 9-foot radius or one-third vane to the long-radius curved surfaces gave no material advantage, and the matter was not investigated further.

The results may be summarized by saying that with the ribs curved on 3-foot and 12-foot radii (center-line radius equal to 1 entry diameter) a 6-foot radius or one-third vane caused an appreciable reduction in pressure loss, but a greater reduction was obtained by omitting the vane and increasing the radii of the rib surfaces to 6 and 15 feet (center-line radius equal to 1.4 entry diameter). No other combinations tried were of any great value.

EFFECT OF STRAIGHT EXTENSIONS TO RADIAL VANES

While the tests on radial vanes were being made, the effects of straight extensions both on the approach and departure ends were investigated. The extensions were 8 feet long and paralleled the ribs of No. 2 butt on the approach end and the ribs of the cut-through on the departure end of the vane. It was found that these extensions caused a slight increase in the pressure loss at the bend and were consequently of no value. The detailed results are omitted because of this fact.

EFFECT OF VENTURI BENDS

The Venturi bend is a special construction in a square corner that reduces the amount of power required to move the air around the bend; it is of use where the inner corner can not be cut back to a long radius. The bend consists of an outer radial curve which joins the ribs on the outside of the turn and an inner curve which starts from the rib on the approach side and swings out, narrowing the departure side of the bend to two-thirds of its normal width. A straight deflector brattice then expands the entry to its normal width on a long slope. The space left for passage of the air with this bend is practically that which the air takes at a square corner. The air normally crowds to the outer side of the bend, and there is a strong eddy current at the inner corner. The Venturi bend prevents the eddy current and so reduces the turbulence of the air and the power required to move it around the corner.

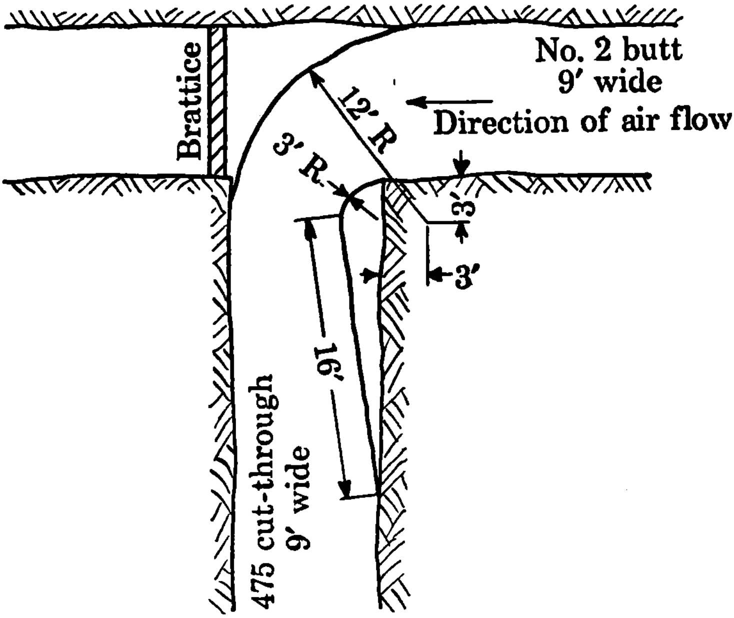


FIGURE 38.—First type of Venturi used on right-angle bends in pressure-loss tests

In this work two types of Venturi bends were used. These types are shown in Figures 38 and 39 and were designated No. 1 and No. 2 Venturi. They differed only in the radius of the inner curve, which was 3 feet for No. 1 and 6 feet for No. 2. The departure side of the corner was narrowed to a width of 6 feet in both types. With No. 1 Venturi the 3-foot-radius curve was placed directly on the square inner corner, whereas the 6-foot-radius curve of No. 2 Venturi extended 3 feet down No. 2 butt and necessitated a small amount of trimming on the rib to make it a true curve of 6-foot radius.

The results obtained in three series of tests are given in Table 29. The duplicate tests with No. 2 Venturi bend do not agree at the higher velocities as closely as they should. The results of the first group are somewhat higher than would be expected, whereas those of the second group give decreasing ratios with increasing velocity, as did the tests with curves and vanes. The No. 2 Venturi bend was taken down and reerected between the two groups of tests.

TABLE 29.—*Pressure-loss tests with Venturi bends*

AVERAGE BASE CONDITION, WITH SQUARE CORNERS

Test No.	Date, 1923	Air velocity, feet per minute	Pressure loss, inch of water		Ratio of bend loss to velocity pressure	Equivalent feet of clear entry
			Mean total loss	Loss due to bend		
		300	0.0095	0.0078	1.40	233
		500	.0264	.0218	1.40	243
		700	.0513	.0427	1.40	250
		900	.0848	.0707	1.40	257
No. 1 VENTURI BEND						
800	Aug. 22	300	0.0078	0.0061	1.09	182
799	do	500	.0202	.0157	1.01	175
798	do	700	.0390	.0304	1.00	178
797	do	900	.0616	.0476	.94	171
No. 2 VENTURI BEND						
832	Aug. 26	300	0.0056	0.0039	0.70	116
831	do	500	.0157	.0112	.72	125
830	do	700	.0302	.0216	.71	127
829	do	900	.0504	.0364	.72	131
860	Sept. 5	300	.0059	.0042	.75	125
859	do	500	.0149	.0104	.67	116
858	do	700	.0279	.0193	.63	113
857	do	900	.0457	.0317	.63	114

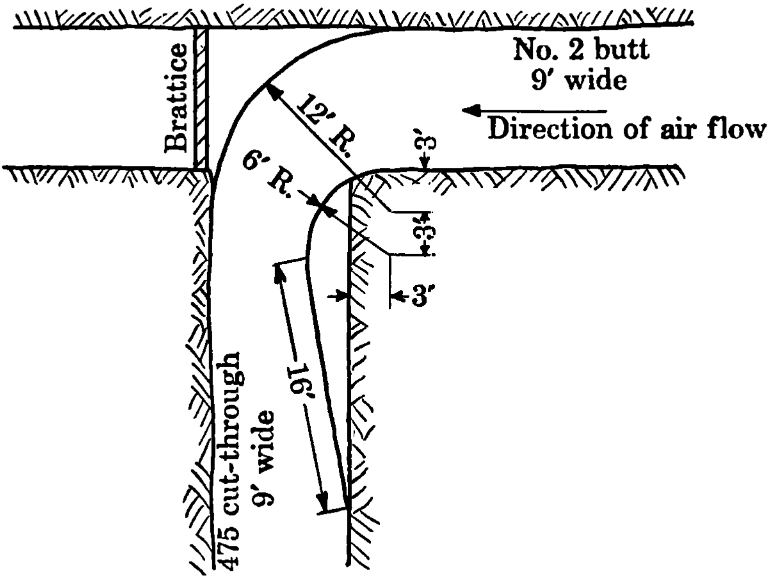


FIGURE 39.—Second type of Venturi used on right-angle bends in pressure-loss tests

The ratio of bend loss to velocity pressure with No. 1 Venturi was 0.94 at the highest velocity, a decrease of 33 per cent from base conditions. With No. 2 Venturi the similar ratio was 0.63 in the second group of tests, a decrease of 55 per cent. This, however, was no better than inner and outer curves of 3-foot and 12-foot radius, as shown in Table 27. The Venturi bend can consequently be of value only where space limitations would otherwise prevent a sufficient curvature of the inner corner, a condition rarely met in coal mines.

RESISTANCE OF TWO CLOSELY SPACED RIGHT-ANGLE BENDS

In the work on the primary test section *B–C* great differences in pressure losses, as between subsections *B–X* and *X–C*, were noted, and two groups of tests were carried out. One group was made to determine the relative effect of modifications of the first bend on the second, and the other to determine the relative reduction of the normal loss at each bend for similar modifications of each.

At both of the bends the air flow was deflected in the same direction. The theory developed to explain the actual results indicated that entirely different results would be obtained if the air flow was deflected in opposite directions at the two bends. A separate group of tests was therefore made in a test section that included the 200 cut-through where the air flow at the second bend could be deflected in either direction. These tests thoroughly substantiated the theory developed from the preceding groups. Two bends in series will be referred to as a double bend where the air flow is deflected in the same direction at each and as a reverse bend where the flow is deflected in opposite directions.

RESISTANCE OF A DOUBLE RIGHT-ANGLE BEND

EFFECT OF MODIFICATIONS OF FIRST BEND ON PRESSURE LOSSES AT SECOND BEND

Conditions in *X–C*, which included the second bend, were held constant in two groups of tests, and the conditions at the first bend in section *B–X* were changed. In one group the second bend was unmodified—inner corner square and dead end open—while 11 different conditions were tried at the first bend. In the other group the second bend was modified by 3-foot and 12-foot curves on the inner and outer corners and by a 6-foot or one-third vane, while five combinations were tried at the first bend.

High resistance at second bend.—Results of the first group of 11 series of tests with high resistance at the second bend are given in Table 30.

TABLE 30.—*Pressure loss at a second right-angle bend having high resistance when conditions at the first bend are varied*

Date, 1923	Conditions at corner of No. 2 butt and 475 cut-through (first bend)	Test No.	Air velocity, feet per minute	Ratio of first bend loss to velocity pressure	Test data for loss in section X-C				Ratio of total loss of both bends to velocity pressure
					Pressure loss, inch of water		Ratio of second bend loss to velocity pressure	Equivalent feet of clear entry	
					Mean total loss	Loss due to bend			
Aug. 21	Inner and outer corners square.	792	300	1.41	0.0076	0.0039	0.70	117	2.11
		791	500	1.57	.0213	.0114	.73	126	2.30
		790	700	1.40	.0390	.0202	.66	119	2.06
		789	900	1.43	.0622	.0316	.63	115	2.06
30	Inner corner square. Dead end of No. 2 butt open.	785	300	1.46	.0063	.0026	.46	78	1.92
		786	500	1.31	.0186	.0087	.56	96	1.87
		787	700	1.37	.0368	.0180	.59	106	1.96
		788	900	1.38	.0565	.0259	.51	93	1.89
28	Outer corner square; inner corner modified by surface of No. 2 Venturi bend.	836	300	1.55	.0064	.0027	.48	81	2.03
		835	500	1.31	.0199	.0100	.64	112	1.95
		834	700	1.17	.0357	.0169	.55	98	1.72
		833	900	1.17	.0602	.0296	.59	106	1.76
22	No. 1 Venturi bend	800	300	1.09	.0082	.0045	.80	133	1.89
		799	500	1.01	.0202	.0103	.66	114	1.67
		798	700	1.00	.0397	.0209	.69	123	1.69
		797	900	.94	.0646	.0340	.67	122	1.61
29	Outer corner square; inner corner cut to 3-foot radius.	840	300	1.02	.0076	.0039	.70	117	1.72
		839	500	.85	.0215	.0116	.74	130	1.59
		838	700	.85	.0426	.0228	.75	134	1.60
		837	900	.75	.0666	.0360	.71	129	1.46
28	No. 2 Venturi bend	832	300	.70	.0098	.0061	1.09	182	1.79
		831	500	.72	.0232	.0133	.85	149	1.57
		830	700	.71	.0373	.0185	.61	109	1.32
		829	900	.72	.0701	.0395	.78	142	1.50
22	Inner and outer surfaces of 3-foot and 12-foot radius curves.	804	300	.75	.0095	.0058	1.04	173	1.79
		803	500	.67	.0225	.0126	.81	141	1.48
		802	700	.64	.0426	.0238	.78	140	1.42
		801	900	.60	.0686	.0380	.75	137	1.35
23	Surfaces of 3-foot and 12-foot radii, plus a 9-foot-radius vane.	812	300	.59	.0083	.0046	.82	136	1.41
		811	500	.54	.0244	.0145	.93	161	1.47
		810	700	.53	.0470	.0282	.92	164	1.45
		809	900	.48	.0758	.0452	.90	162	1.38
24	Surfaces of 3-foot and 12-foot radii, plus a 6-foot-radius vane.	816	300	.45	.0111	.0074	1.32	221	1.77
		815	500	.39	.0242	.0143	.92	160	1.31
		814	700	.36	.0482	.0294	.96	171	1.32
		813	900	.34	.0793	.0487	.96	175	1.30
24	Surfaces of 3-foot and 12-foot radii, plus a 7.5-foot-radius vane.	820	300	.46	.0096	.0059	1.05	176	1.51
		819	500	.41	.0265	.0166	1.06	184	1.47
		818	700	.37	.0491	.0303	.99	178	1.36
		817	900	.34	.0871	.0565	1.12	203	1.46
23	Surfaces of 3-foot and 12-foot radii, plus 6-foot and 9-foot radius vanes.	808	300	.45	.0050	.0013	.23	39	.68
		807	500	.40	.0277	.0178	1.14	199	1.54
		806	700	.36	.0509	.0321	1.05	188	1.41
		805	900	.33	.0790	.0484	.96	174	1.29

Examination of the results in Table 30 reveals a number of important features:

1. When the corners at both bends were square the loss at the second bend was less than one-half of the loss at the first bend.

2. When the loss at the first bend was decreased by the use of modifications the loss at the second bend increased, but at its maximum this loss was only two-thirds that found at the first bend when unmodified.

3. The actual pressure loss at the second bend was so small that errors of measurement formed a large share of the total at the lower velocities. Results at the two higher velocities are fairly consistent, however, and appear to be reliable, with one or two exceptions.

4. The resistance at the second bend appeared to decrease with increasing air velocity, but the decrease was not as regular as was observed in the tests on the first bend.

5. When both bends were unmodified their combined resistance was only 1.5 times the resistance of the first bend alone. A decrease of 76 per cent in resistance at the first bend caused a decrease of only 37 per cent in the total resistance of the two bends.

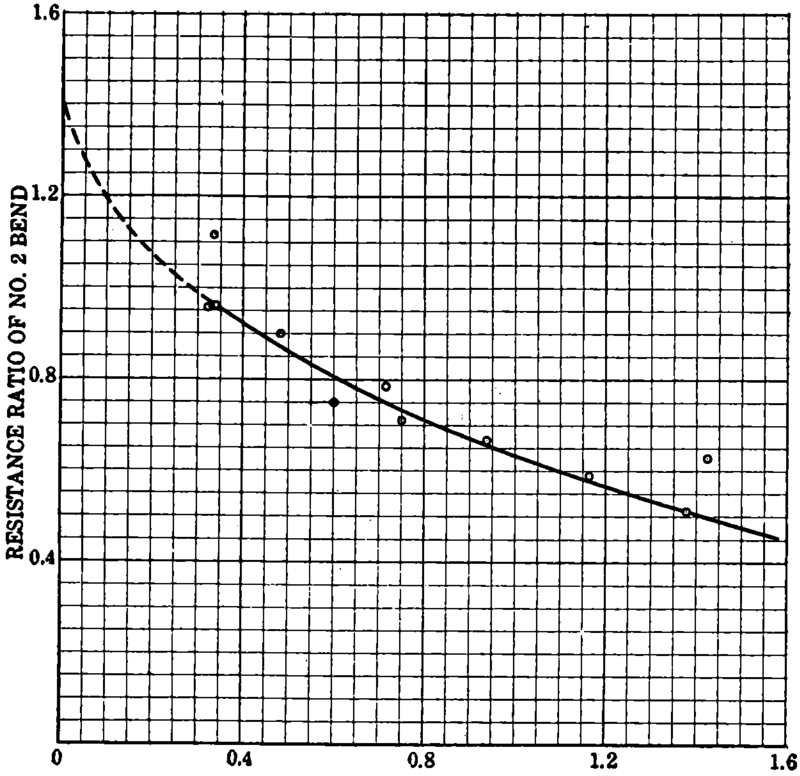


FIGURE 40.—Relation of resistance of the two bends in test section *B-C*

The relation of the decrease in resistance at the second bend to the increase at the first is well illustrated in Figure 40. The values used in this figure are those obtained at a velocity of 900 feet per minute and were taken as having the least experimental error. Nine of the 11 points fall on or close to a curve which has been extended dotted to the left. The second bend did not differ essentially in form from the first, and it may be assumed that under normal conditions the resistance ratio would have been approximately the same as that of the first bend. In other words, if the resistance ratio of the first bend was reduced to zero, that of the second bend would be approximately 1.4, so the curve was extrapolated to this value.

It has been found that the presence or absence of a dead-end extension at the first bend affected the pressure loss of that bend only slightly, but comparison of the results of the first two series of this group shows a material difference induced at the second bend by these conditions. With the dead end at the first bend closed, the velocity-pressure ratio for the second bend was 0.63 at 900 feet per minute and with the dead end open the ratio was but 0.51. Results of a similar series made with the dead end open at the second bend gave very similar results—0.71 and 0.59 velocity-pressure ratios, respectively. The outstanding point in these averages is that the presence of the dead end at the first bend caused a very decided reduction in pressure loss at the second bend, whereas the presence of a dead end at either the first or second bend caused little or no change at its location. This result, while interesting and of value theoretically, can be of no great importance under actual mining conditions.

TABLE 31.—*Pressure loss at a second right-angle bend having low resistance when conditions at first bend are varied*

Date, 1923	Condition at corner of No. 2 butt and 475 cut-through (first bend)	Test No.	Air velocity, feet per minute	Ratio of first bend loss to velocity pressure	Test data for loss in section X-C				Ratio of total loss of both bends to velocity pressure
					Pressure loss, inch of water		Ratio of second bend loss to velocity pressure	Equivalent feet of clear entry	
					Mean total loss	Loss due to bend			
Sept. 12	Outer corner square; inner corner beveled, 5 feet long.	888	300	0.89	0.0036	0.0000	0.00	0	0.89
		887	500	.74	.0107	.0008	.05	9	.79
		886	700	.67	.0200	.0012	.04	7	.71
		885	900	.66	.0325	.0019	.04	7	.70
10	Outer corner square; inner surface of 6-foot radius.	884	300	.66	.0043	.0006	.12	18	.78
		883	500	.57	.0109	.0010	.06	11	.63
		882	700	.57	.0201	.0013	.04	8	.61
		881	900	.52	.0336	.0030	.06	11	.58
Aug. 31	Surfaces of 3 and 12 foot radii plus a 6-foot-radius vane.	844	300	.39	.0052	.0015	.27	45	.66
		843	500	.39	.0133	.0034	.22	39	.61
		842	700	.37	.0254	.0066	.22	39	.59
		841	900	.34	.0409	.0103	.20	37	.54
Sept. 7	Surfaces of 6 and 15 foot radii	872	300	.32	.0050	.0013	.23	39	.55
		871	500	.30	.0129	.0030	.19	33	.49
		870	700	.30	.0246	.0058	.19	34	.49
		869	900	.29	.0399	.0090	.18	33	.47
10	Surfaces of 6 and 15 foot radii plus a 9-foot-radius vane.	876	300	.25	.0053	.0016	.29	48	.54
		875	500	.27	.0134	.0035	.22	38	.49
		874	700	.30	.0260	.0072	.24	41	.54
		873	900	.27	.0399	.0093	.18	35	.45

Low resistance at second bend.—For the group of tests of low resistance the inner corner of the second bend was trimmed to a 3-foot-radius curve, and the outer corner was changed to a curve of 12-foot radius. A vane of 6-foot radius was added. This arrangement was tested with five different conditions at the first bend to find the effect of change of air conditions. The results are given in Table 31. For direct comparison the pressure losses with high resistance at the second bend for the above five conditions at the first bend should be available, but such tests were made for only one of the conditions.

The outstanding feature in Table 31 is that the measured pressure loss of section *X-C* is shown to be reduced almost to that of a perfectly straight section. This effect may mean that some of the rotational kinetic energy of the air was recovered as pressure, but it was probably also caused by the substitution of smooth surfaces for coal surfaces.

The pressure loss at the second bend increased slowly as that at the first bend decreased. Thus while the ratio at the first bend decreased from 0.66 to 0.52, 0.34, 0.29, and 0.27, that of the second bend rose from 0.04 to 0.06, 0.20, 0.18, and 0.18. The figures for the second bend may be divided into two parts, the low values (0.04 and 0.06) and the high values (0.20, 0.18, and 0.18). The low values were obtained when the outer corner of the first bend was square, and the high values were obtained when this corner was modified by curves of 12-foot and 15-foot radii. The change at the first bend from a square outer corner to a curved surface was apparently more important in its effect on the pressure loss at the second bend than were the changes at the inner corner or the change from 12-foot to 15-foot radii on the outer corner of the first bend.

RELATIVE EFFECT OF SIMILAR MODIFICATIONS OF BOTH BENDS

The effect of using the same form of modification first on one and then on both bends is best illustrated by collecting data that has been given in previous tables. Both bends had square corners originally. The first bend was then modified by the use of curved surfaces of 3-foot and 12-foot radii, to which was added a 6-foot-radius vane. Similar modifications were then placed on the second bend. The results of these changes at the highest velocity are traced in Table 32.

TABLE 32.—*Change in pressure loss at a double right-angle bend when modified by curved surfaces of 3 and 12 foot radii and a 6-foot-radius vane*

Condition of bends	Average ratio of pressure loss to velocity pressure		
	First bend	Second bend	Both bends
Square corners on both bends	1.40	0.63	2.03
First bend only modified	.34	.96	1.30
Both bends modified	.34	.20	.54

The figures in Table 32 show clearly the shifting of pressure loss from the first to the second bend when the first bend only is modified. When the second bend is modified in addition the pressure loss at the first bend remains constant and that at the second bend falls. When the two bends are considered together each modification has the same absolute effect. When the first bend was modified the pressure-loss ratio for the two bends fell from 2.03 to 1.30, a decrease of 0.73. When the second bend was modified in addition the pressure-loss ratio fell from 1.30 to 0.54, a decrease of 0.76. When the first bend was modified the pressure loss of the two bends was 64 per cent of the pressure loss found with no modification. When both bends were modified their combined pressure loss was but 27 per cent of the normal for the unmodified bends.

Similar tests were made with the No. 2 Venturi at the first bend only and at both bends, and similar relative results were obtained as shown in Table 33.

TABLE 33.—*Change in pressure loss at a double right-angle bend when modified by No. 2 Venturi*

Condition of bends	Average ratio of pressure loss to velocity pressure		
	First bend	Second bend	Both bends
Square corners on both bends	1. 40	0. 63	2. 03
First bend only modified	. 72	. 78	1. 50
Both bends modified	. 67	. 31	. 98

The Venturi at the first bend was taken down after it was used alone and was reerected when both bends were modified simultaneously. The slightly lower pressure-loss ratio obtained in the latter test is thought to be due to construction differences. The values show the same character of change as did those for the curved surfaces and vanes given in Table 32. The absolute values, of course, are different. Thus with a Venturi curve on each bend the pressure-loss ratio was 48 per cent of the unmodified value, showing that this Venturi was about half as efficient as the curved surfaces of Table 32. When the two bends are taken together each Venturi caused approximately the same reduction in pressure loss—a result similar to that pointed out in the discussion of Table 32. For one Venturi bend the reduction in ratio is 0.53, and for the second Venturi it is 0.52.

The absolute value of the modification of a right-angle bend appears therefore to be constant and independent of the condition of air flow approaching it.

THEORY OF AIR FLOW AT A DOUBLE RIGHT-ANGLE BEND

The pressure loss caused by bends is a measure of the power consumed in forcing the air to change its direction of motion. As the air passes around the first bend, the air at the outer corner must travel much faster than that at the inner corner. Also, because of its inertia, the air crowds to the outside of the bend and is compressed. A rotary as well as a translatory motion is thus imparted to the air while turning the corner. After the bend is passed the expansion of the compressed air gives a component of motion across the duct until all the energy stored in the rotating air is either converted to useful pressure or destroyed by friction. How far the rotating or eddying of the air would continue if the air met no additional bends can not be said. The distance would depend in part on the configuration of the entry in which the air is traveling. It follows that a true determination of the loss due to a single bend would require measurement over a section long enough to allow the conversion or destruction of all rotational energy. The results of tests so far given are then relative instead of absolute. The absolute loss due to a single bend would be higher, but it is thought that the unmeasured portion bears only a small ratio to the total loss.

If the air at the second bend is deflected in the same direction as at the first bend, a set of operations similar to those at the first bend must ensue; but the action is modified by the fact that the air has cross components of motion due to expansion that will help it around the second bend, so that only a small amount of additional power is required. In other words, kinetic energy stored in the air at the first bend is used to pass the air around the second bend, and measurements taken on the second bend show that only a small amount of additional energy is introduced.

If the first bend is modified by curves or vanes to pass the air around it more easily, less energy is required to deflect it at the first bend; therefore greater amounts of energy must be supplied at the second bend, the relative effect depending on the distance between the bends.

RESISTANCE OF A REVERSE RIGHT-ANGLE BEND

The foregoing theory of air flow at a double right-angle bend will apply in full only when the air makes two successive bends in the same direction. When the second bend reverses the direction of flow the expansion of the slightly compressed air produces a cross current which will oppose the movement of the air around the reverse bend, and the pressure loss will be greater than for the second of two bends in the same direction, the relative effect depending upon the distance between the bends. It is improbable that the process is as simple as this, however, but the following qualitative facts should be found: When a double right-angle bend is changed to a reverse right-angle bend—

(1) The pressure loss at the first bend should remain the same.

(2) The pressure loss at the second bend should be greatly increased and might be as large as the loss at the first bend.

A group of experiments was made to test these conclusions. In the experiments the 475 cut-through was closed and the 200 cut-through was opened. Static station *Z* was placed in the middle of the 200 cut-through. The air then traveled from static station *A* past stations *Z* and *D* to the 1B–100 air-measuring station. After pressure-loss measurements had been made with this arrangement an air-tight stopping was erected across the No. 1 butt at the outby edge of the 200 cut-through. Tight stoppings were also placed in

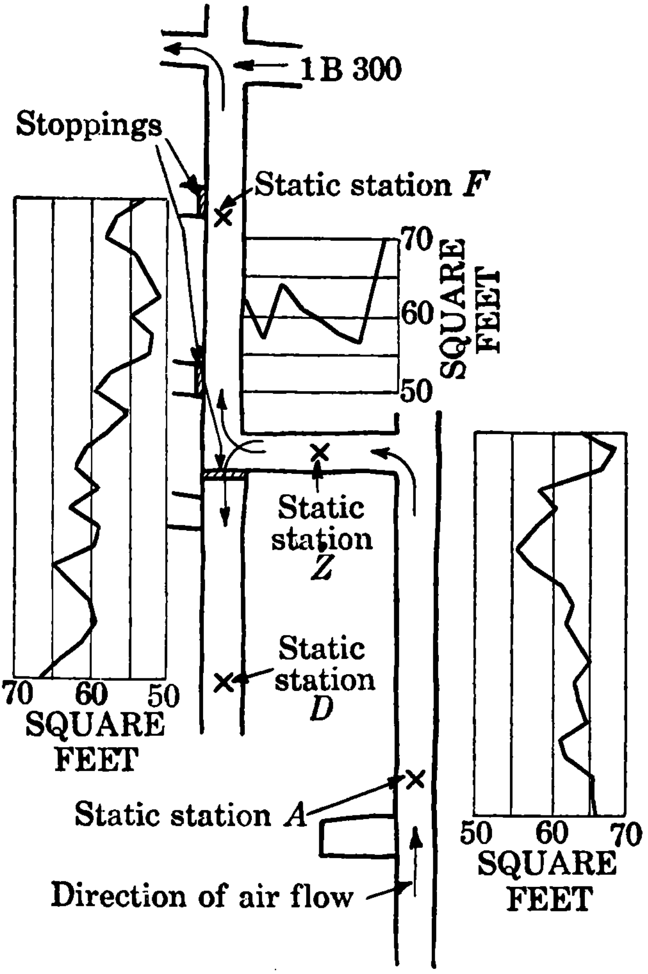


FIGURE 41.—Test sections *A–Z*, *Z–D*, and *Z–F* with corresponding area graphs

the necks of Nos. 4 and 5 rooms. The air was then forced to pass from static station *A* to stations *Z* and *F*. The bend at the corner of No. 1 butt was thus reversed from the direction it had when the air passed directly from *Z* to *D*. After passing station *F* the air passed into No. 6 room, returned through the rooms and out No. 3 room neck to No. 1 butt, and from there resumed its original course. This path may be traced on Figure 1. Figure 41 shows sections *A–Z*, *Z–D*, and *Z–F* on a large scale with their area graphs. The location of the stoppings is also shown. The results of the tests are given in Table 34.

TABLE 34.—*Comparison of pressure loss at a double right-angle and a reverse right-angle bend November 15, 1923*

A.—DOUBLE RIGHT-ANGLE BEND, SECTIONS *A-Z* AND *Z-D*

Test No.	Air velocity, feet per minute	Test data for first section			Test data for second section			Ratio of total loss of both bends to velocity pressure
		Pressure loss, inch of water		Ratio of bend loss to velocity pressure	Pressure loss, inch of water		Ratio of bend loss to velocity pressure	
		Mean total loss	Loss due to bend		Mean total loss	Loss due to bend		
1241	300	0.0103	0.0065	1.16	0.0067	0.0040	0.71	1.87
1240	500	.0297	.0193	1.24	.0176	.0102	.65	1.89
1239	700	.0599	.0402	1.32	.0337	.0198	.65	1.97
1238	900	.1005	.0682	1.35	.0564	.0336	.67	2.02
B.—REVERSE RIGHT-ANGLE BEND, SECTIONS *A-Z* AND *Z-F*								
1245	300	0.0110	0.0072	1.29	0.0089	0.0061	1.09	2.38
1244	500	.0301	.0197	1.26	.0255	.0179	1.15	2.41
1243	700	.0584	.0387	1.27	.0497	.0352	1.15	2.42
1242	900	.0985	.0662	1.31	.0800	.0563	1.12	2.43

The results at the highest velocity may be summarized as follows:

1. The first bend had a ratio of loss to velocity pressure of 1.35 for the double right-angle bend and of 1.31 for the reverse right-angle bend, a difference within the error of duplicate experiments. Compared with the similar value in section *B–X* (corner of No. 2 butt and 475 cut-through) of 1.40, a slight decrease is noted for section *A–Z*, attributable to the fact that the corners of the 200 cut-through were somewhat beveled because of falls of coal and slate induced by weathering and roof pressure.

2. The second bend had a ratio of loss to velocity pressure of 0.67 for the double right-angle bend and of 1.12 for the reverse right-angle bend. Changing the conditions almost doubled the pressure loss. The second bend of section *X–C* had a loss ratio of 0.63, which is in substantial agreement with the value 0.67 determined in section *Z–D*.

3. The total loss ratio of the double right-angle bend was 2.02, and that of the reverse right-angle bend was 2.43. an increase of 20 per

cent. The double right-angle bend in section *B–C* gave a total loss ratio of 2.06, which is quite close to that obtained for section *A–Z–D.*

It will be seen from the foregoing statements that the double right-angle bend *B–X–C* gave a pressure-loss ratio nearly equal both in part and whole to that found in section *A–Z–D.* The differences are ascribable to small variations in the conditions of the two test sections. Furthermore, the change from a double right-angle to a reverse right-angle bend produced changes in pressure loss of the nature predicted, although the magnitude could not be foretold. It is obvious that a quantitative study should proceed on a smaller scale.

PRESSURE LOSSES AND LEAKAGE OF CANVAS BRATTICES

Two groups of tests were made to determine the pressure losses caused by canvas brattices and to establish their effectiveness as used to deflect air flow to room and entry faces. One group of tests was made with various combinations of check and line brattices in a short room section, and the other group dealt with line brattices of varying lengths in an entry dead end. The brattice cloth used in these tests was of closely woven jute weighing 14 ounces per square yard.

Measurement of the pressure losses involved no extension of the test methods used in previous tests. Measurements to determine leakage, however, required the use of anemometers, which were calibrated for this work at the 1B–100 air-measuring station. The anemometer to be calibrated was fastened to the end of a light steel rod held rigid at a point of the air-measuring plane for which a "position factor" had previously been determined. Calibration factors for a number of velocities were obtained by computation from simultaneous readings of the anemometer and center Pitot-tube pressures.

Although it was found that calibrations might change a few per cent with use, such changes were of little moment under the conditions in which the anemometers were used. The planes of measurement were very irregular in areas, and traverses were not only difficult to make but often involved such low velocities that no great degree of accuracy could be obtained. Hence, the figures given for leakage of the brattices tested must be taken as approximations only; however, considering the multitudinous variations that might obtain in test conditions and their extremely approximate correlation to average mine conditions, great accuracy was not essential.

CHECK AND LINE BRATTICES IN ROOMS

TEST SECTION USED

Rooms Nos. 4, 5, and 6 off No. 1 butt entry were used in the tests of brattices for room ventilation. Pressure losses were determined in test section *C–D,* the normal loss for which was available from previous determinations. The direction of air flow was as shown in

Figure 1; that is, the air reached No. 6 room first. These rooms, nominally 20 feet wide, were connected by three cut-throughs 30, 135, and 205 feet, respectively, from the center line of No. 1 butt entry. The rooms were standing practically as mining had left them. Entering the room, the track was on the right side with a clear space 6 to 7 feet wide. In the remainder of the room which had been more or less filled with slate and refuse there were three rows of posts on 4-foot centers. The rooms had been open several years, and air slacking had reduced most of the exposed slate to fine material except near the faces where the slate was more angular. The quantity of refuse was also greater near the face of the rooms, but there was space enough to permit crawling over the gob at nearly any point.

FIGURE 42.—View of No. 6 room from the room neck

Figures 42 and 43 show in a general way the condition of the rooms. The vertical strings in the foreground in these photographs were used to facilitate the determination with anemometers of the average air velocity.

SCOPE OF TEST WORK

In order to simulate operating conditions, average velocities of 200, 300, and 400 feet per minute in section *C–D* were selected for the test work; these correspond in round numbers to 12,000, 18,000, and 24,000 cubic feet of air per minute. A single-thickness check brattice was first placed in No. 1 butt just outby No. 6 room in order to deflect a portion of the air into No. 6 room. This brattice was the type commonly used in the Pittsburgh district, though not necessarily the standard type for coal mines in general. The brattice consisted of a piece of canvas nailed to a crossbar at the roof and extending to within 18 inches of the floor. The common practice of cutting vertical slits in the canvas to facilitate passage of cars was followed. Figure 44 shows this brattice.

In the first tests there were no brattices in the cut-throughs between the rooms, and the air entering No. 6 room was allowed to take whatever path it would to regain the butt entry. Canvas brattices were then successively placed in the first and second cut-throughs to force the air to the face. With these brattices in place the next step was to replace the single-thickness check brattice on No. 1 butt with a double-thickness check brattice. This type of brattice differed from the single check in that a double thickness of canvas extending to the floor was used. This arrangement is shown in Figure 45. Tests were next made of a canvas door used as a check brattice. The door was constructed by stretching canvas tightly over a light wooden frame. (See fig. 46.)

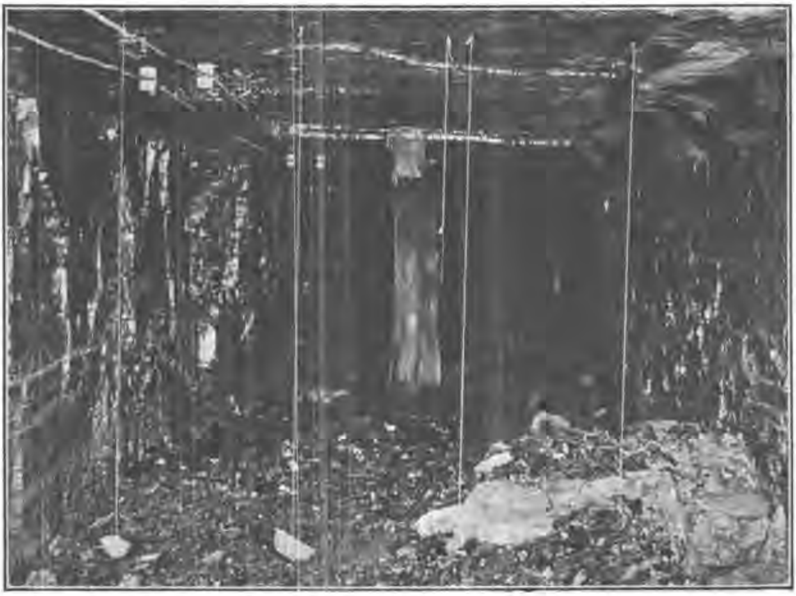


FIGURE 43.—Last cut-through from No. 4 to No. 5 room

After these tests were completed, the next step was to close the last cut-through between the rooms with tight board stoppings. The second cut-through was then the open one, and the rooms had dead ends about 70 feet long. The canvas door was left in place on No. 1 butt, and a line brattice was placed in No. 6 room to conduct the air to the face. Similar brattices were then added in No. 5 and No. 4 rooms. These latter brattices had loose checks across the track such as would be required in an operating mine to permit moving the cars in and out.

RESULTS OF PRESSURE-LOSS TESTS

The pressure-loss measurements are best considered before, and independent of, the leakage. Pressure losses were small in a majority of the tests because of the low velocities. The velocity pressures were also low. Thus, the velocity pressure at 200 feet per minute for air weighing 0.075 pound per cubic foot is 0.0025 inch of water; at 300 feet per minute it is 0.0056 inch, and at 400 feet per minute it is

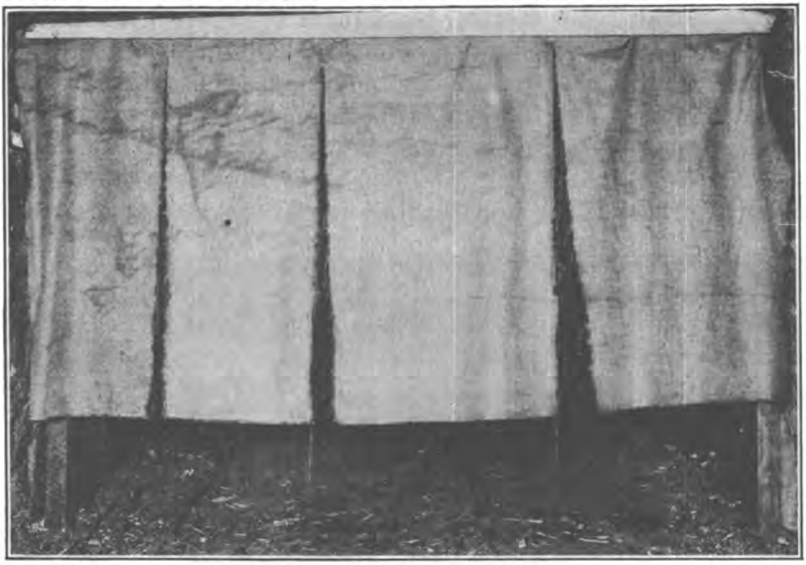


FIGURE 44.—Single-thickness check brattice in place on No. 1 butt entry immediately outby No. 6 room

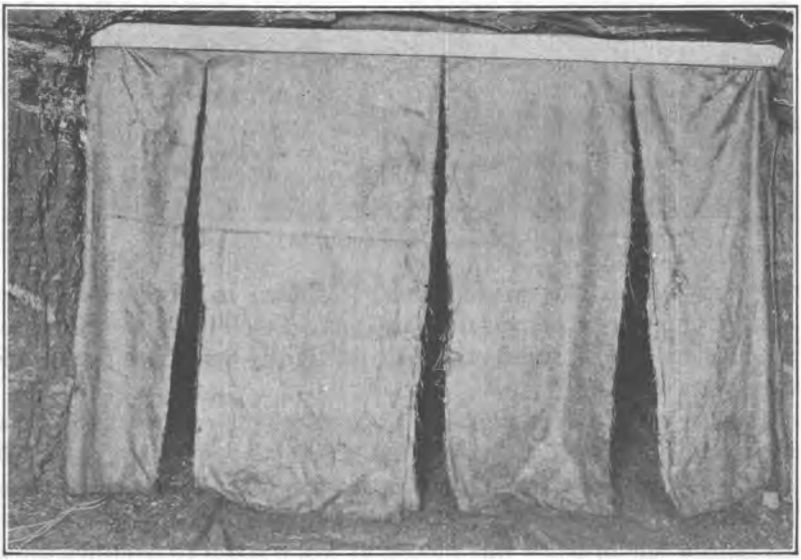


FIGURE 45.—Double-thickness check brattice on No. 1 butt entry

0.0100 inch of water. The results of the tests are given in Table 35, which is similar in arrangement to preceding pressure-loss tables.

The results given in Table 35 show that brattices of the type used cause a very high pressure loss when the loss is expressed as a ratio to other losses at the same velocity. Placing the single check brattice on No. 1 butt was equivalent to adding 200 feet to the length of the entry. Bratticing the first and second room cut-throughs added resistance equivalent to another 150 feet of entry at the lowest velocity, but it made practically no change at the highest velocity. The reason for this is that at the highest velocity there was very little more air entering the rooms than at the lowest; the balance was leaking past the check brattice.

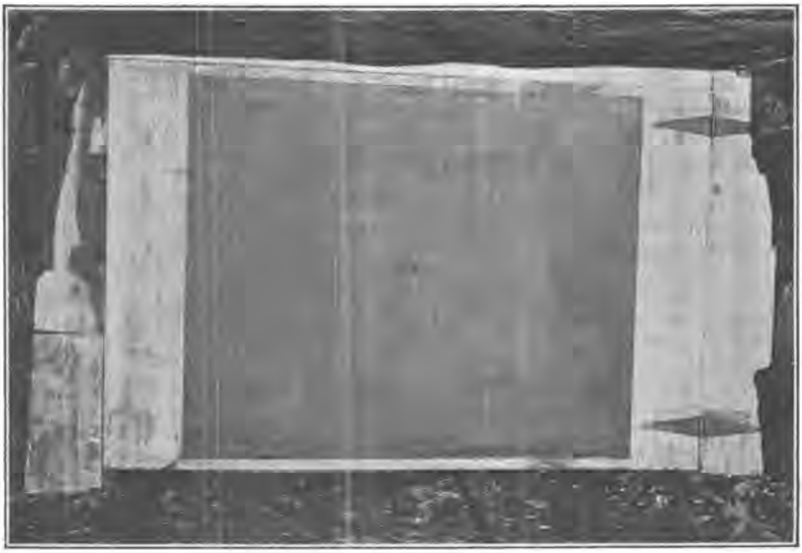


FIGURE 46.—Canvas door in place on No. 1 butt entry

Replacing the single check brattice on No. 1 butt with a double check brattice caused another sharp rise in pressure loss. There was still a much greater leakage at the higher velocities, and the equivalent loss was consequently less at the higher velocity. When the canvas door was used the pressure loss rose again. The equivalent resistance was then the same at all velocities, showing that leakage on No. 1 butt had been virtually eliminated. This arrangement of brattices was causing as much pressure loss as 740 feet of unobstructed entry.

Large as the losses just discussed appear, they were moderate when compared with the losses caused by line brattices in the rooms. When the cut-throughs at the face were closed and a line brattice was placed in No. 6 room the pressure loss from the brattices was more than doubled. The greater leakage at the higher velocities reappeared, because of the much higher pressure drops across the various brattices. Adding the line brattices in No. 5 and No. 4 rooms caused additional losses. These were not as large as the first, however, as there was heavy leakage past the loose checks at the points where the line brattices crossed the tracks in the rooms. The final arrangement of brattices—canvas door on entry and line brattices in the rooms—caused as much loss as 3,000 feet of unobstructed entry. The magnitude of pressure losses due to brattices is startling, but their true value can be judged only when the amount of air delivered to the face is known.

TABLE 35.—*Pressure-loss tests with check and line brattices in rooms, October, 1923*

Test conditions			Test No.	Air velocity, feet per minute	Air volume, cubic feet per minute	Pressure loss, inch of water		Comparison of brattice loss	
No. 1 butt	Room cut-through	Line brattices				Observed loss	Loss due to brattices	Ratio to velocity pressure	Equivalent feet of clear entry
Single brattice.	Open	None	1068	200	11,720	0.0079	0.0036	1.44	209
			1067	300	17,580	.0187	.0090	1.61	232
			1066	400	23,440	.0313	.0139	1.39	200
Do	First bratticed, others open.	do	1071	200	11,720	.0097	.0054	2.16	314
			1070	300	17,580	.0205	.0108	1.93	278
			1069	400	23,440	.0314	.0140	1.40	201
Do	First and second bratticed, third open.	do	1074	200	11,720	.0103	.0060	2.40	349
			1073	300	17,580	.0216	.0119	2.16	307
			1072	400	23,440	.0324	.0150	1.50	216
Double brattice.	do	do	1088	200	11,720	.0145	.0102	4.08	594
			1087	300	17,580	.0287	.0190	3.40	490
			1086	400	23,440	.0439	.0265	2.65	381
Canvas door	do	do	1094	200	11,720	.0170	.0127	5.08	739
			1093	300	17,580	.0388	.0291	5.20	750
			1092	400	23,440	.0683	.0509	5.09	732
Do	First bratticed, second open, third closed.	No. 6 room only.	1097	200	11,720	.0371	.0334	13.37	1,943
			1096	300	17,580	.0776	.0679	12.13	1,751
			1095	400	23,440	.1371	.1197	11.97	1,720
Do	do	Nos. 6 and 5 rooms.	1100	200	11,720	.0463	.0420	16.80	2,443
			1099	300	17,580	.1021	.0924	16.50	2,382
			1098	400	23,440	.1793	.1619	16.19	2,327
Do	do	Nos. 6, 5, and 4 rooms.	1103	200	11,720	.0579	.0536	21.44	3,117
			1102	300	17,580	.1233	.1136	20.30	2,930
			1101	400	23,440	.2056	.1882	18.52	2,703

RESULTS OF LEAKAGE TESTS

The volume of air approaching No. 6 room was known from the measurements made at the air-measuring station. Measurements were also taken at different points in the rooms in all tests, but because of the large probable error in some of the measurements it is advisable to consider only a limited number of selected results that give a general idea of the leakage. These results have been grouped in Table 36, which shows the actual volume of air at the face of No. 6 and No. 4 rooms and the percentage ratio which this volume bore to the total volume of flow on No. 1 butt.

Table 36.—*Selected results showing leakage of check and line brattices in rooms*

Conditions of test	Volume of air on No. 1 butt, cubic feet per minute	Volume of air at face of—		Percentage of air at face of—	
		No. 6 room, cubic feet per minute	No. 4 room, cubic feet per minute	No. 6 room	No. 4 room
Single-canvas check on No. 1 butt; no brattices in first and second room cut-throughs	11,700	1,500	800	13	7
Single-canvas check on No. 1 butt; brattices in first and second room cut-throughs	11,700	5,000	3,000	43	26
	17,500	6,500	4,000	37	23
	23,400	6,500	4,000	28	17
Double-canvas check on No. 1 butt; brattices in first and second room cut-throughs	11,700	10,700		90	
	23,400	12,400		53	
Canvas door on No. 1 butt; brattices in first and second room cut-throughs	11,700	10,000	6,000	85	51
	23,400	20,000	11,500	85	50
Canvas door on No. 1 butt; line brattice in No. 6 room only	11,700	8,000		68	
	23,400	15,500		66	
Canvas door on No. 1 butt; line brattice in Nos. 6, 5, and 4 rooms	11,700	7,500	6,000	64	51
	23,400	14,000	12,000	60	51

Table 36 shows that when a check brattice was placed on the entry and there were no brattices in the room cut-throughs not more than 15 per cent of the total air flow reached the face of No. 6 room and only half that amount reached the face of No. 4 room.

In the second group of tests, given in Table 36, the most common form of bratticing was used—a single-thickness check brattice on the entry and tight brattices in the room cut-throughs. When there was 11,700 cubic feet of air per minute moving on the entry about 5,000 and 3,000 cubic feet reached the faces of No. 6 and No. 4 rooms, respectively; these figures represent 43 and 26 per cent of the main ventilating current. When the air volume on No. 1 butt was increased to 17,500 cubic feet per minute (an increase of 50 per cent) the volume of air entering No. 6 room increased only 33 per cent; and when the main current was increased to 23,400 cubic feet per minute there was no further increase in the amount of air entering No. 6 room. The additional air forced its way past the check brattice and so was of no use as far as ventilation of the room faces was concerned.

When the double-canvas brattice was used on No. 1 butt with 11,700 cubic feet of air per minute, 90 per cent of the total air flow reached the face of No. 6 room, as compared with 43 per cent sent to the face by the single-canvas brattice. Increasing the volume of air on the butt entry did not greatly increase the volume entering No. 6 room; the extra amount simply leaked past the check brattice. Thus whereas 90 per cent of the air reached the face at the lowest velocity, only 53 per cent reached it when the velocity was doubled.

Virtually all the air was forced into No. 6 room at all velocities when the canvas door was used. The leakage past the door could not be measured but was not more than 5 per cent. About 85 per cent of the air reached the face of No. 6 room, and 50 per cent reached the face of No. 4 room. There was nothing to prevent the air from traveling out No. 5 room, and some did take this course; but most of the air coming across the last cut-through from No. 6 room continued straight on into No. 4 room before turning back toward the butt entry.

When a line brattice was put in No. 6 room, with the canvas door across No. 1 butt, about 68 per cent of the air reached the face. There was of course no direct air current at the faces of No. 5 and No. 4 rooms, although there were pronounced eddies in each in the space between the second cut-through and the face. When a line brattice was placed in No. 5 room also, a portion of the air received from No. 6 room was lost at the loose check across the track; a similar loss was found in No. 4 room when a brattice was installed there, so that the volume of air reaching the face of No. 4 room was about 50 per cent of the amount entering No. 6 room.

These tests show that the ordinary form of check brattice used to turn air into rooms can not be expected to deliver more than half the total volume of air on the room entry to the first room face and that each succeeding face will receive less until a second check is reached. The last room face may be getting 20 per cent or less of the air passing on the entry from which the rooms are turned. Additional air can not be forced into the rooms merely by increasing the total quantity in the split, for most of the increase will leak past the check brattices. What appears to be the maximum effectiveness is obtained with an air velocity between 200 and 300 feet per minute measured on the entry from which the rooms are turned.

If there is not enough ventilation at the face of the rooms with ordinary check brattices, a canvas door will force virtually all of the air from the entry into the rooms, but this can be done only with a considerable increase in pressure loss. If line brattices must then be used, further increases in pressure loss may be expected. It is assumed, of course, that the pressure across the split rises as may be required to keep the same volume of air flowing in it. If the pressure across the split is constant, the volume will fall as the brattices are added, and the point may be reached where adding brattices actually reduces the volume of air reaching the face.

LINE BRATTICES IN ENTRY DEAD END

TEST SECTION USED

The butt entries extended only 50 feet beyond the last (475) cut-through (see fig. 1), which was not far enough for tests of line brattices. To secure a longer section the 475 cut-through was closed and the 300 cut-through opened, which made the dead ends of the entries

225 feet long. With line brattices erected in No. 2 butt entry, differential static-pressure measurements were made between static tube *A* and a tube in the middle of the 300 cut-through, designated *Y*. In all tests the entry was closed off 12 feet from the end of the brattice with boards and canvas.

SCOPE OF TEST WORK

The line brattices used for test were constructed by erecting a line of posts on 8-foot centers, 3 feet from the right rib of No. 2 butt entry. A line of brattice boards was nailed to these posts at the floor, and a second line of boards was fastened to them at the roof. Brattice cloth was nailed to the boards and was fastened as close to the roof and floor as was possible. With this arrangement the posts were on the high-velocity side of the canvas and so caused the highest possible pressure loss. This arrangement is that most commonly found in mines, as it is easier to construct a brattice from the wide or track side. The line-brattice tests were made at a time when other work was pressing, and the effects of having the posts on the wide or low velocity side of the brattice were not investigated.

Four groups of tests of line brattices were made. In the first, brattices 25, 50, 100, 150, and 200 feet long were tested with the cut-through end closed by a single thickness of brattice cloth reaching to the floor and left loose in the manner usual where cars must pass through. In the second group of tests, 100 and 200 foot brattices were used with double-thickness loose canvas at the cut-through end. In the third group, tests were made of a 200-foot line brattice having a triple-thickness loose check; in the fourth group, 100 and 200 foot brattices had tight cut-through ends with no provision for haulage through them.

RESULTS OF PRESSURE-LOSS TESTS

Pressure-loss results are best considered independent of the leakage data and are given in Table 37. A number of interesting relations appear when a study of this table is made. Consider first the tests of part A. When the air velocity in the clear entry was 200 feet per minute, the pressure loss caused by a 25-foot brattice was 7.92 times the velocity pressure. As the length of the brattice was increased to 200 feet, the pressure loss caused by it fell to 6.20 times the velocity pressure. This surprising result was due to the fact that as the length of the brattice increased more and more of the air leaked past the loose check at the cut-through; the pressure loss was really that required to force the air past this check, as leakage through the check might be considered as a path parallel to that around the end of the line brattice. As the length of the brattice increased, the pressure on the check increased, forcing it out and opening a larger space through which the air could pass. As a general statement, it may be said that the pressure loss caused by the brattice under these conditions was roughly the same, whatever the length of the brattice, but that the amount of air delivered to the face dropped off rapidly as the length was increased.

TABLE 37.—*Pressure-loss tests of line brattices in dead end of No. 2 butt entry, November, 1923*

Length of brattice, feet	Test No.	Air velocity, feet per minute	Volume of air, cubic feet per minute	Pressure loss, inch of water		Comparison of brattice loss	
				Mean total loss	Loss due to brattice	Ratio to velocity pressure	Equivalent feet of clear entry
A.—BRATTICES WITH SINGLE LOOSE CHECK AT CUT-THROUGH END							
25	1202	200	11, 660	0. 0275	0. 0198	7. 92	1, 215
	1201	300	17, 490	. 0459	. 0279	4. 98	821
	1200	400	23, 320	. 0514	. 0182	1. 82	309
50	1205	200	11, 660	. 0279	. 0202	8. 08	1, 239
	1204	300	17, 490	. 0466	. 0286	5. 11	933
	1203	400	23, 320	. 0500	. 0168	1. 68	285
100	1208	200	11, 660	. 0255	. 0178	7. 12	1, 092
	1207	300	17, 490	. 0430	. 0250	4. 46	735
	1206	400	23, 320	. 0458	. 0126	1. 26	214
150	1211	200	11, 660	. 0247	. 0170	6. 80	1, 042
	1210	300	17, 490	. 0434	. 0254	4. 54	747
	1209	400	23, 320	. 0458	. 0126	1. 26	214
200	1214	200	11, 660	. 0232	. 0155	6. 20	960
	1213	300	17, 490	. 0418	. 0238	4. 25	700
	1212	400	23, 320	. 0454	. 0122	1. 22	207
B.—BRATTICES WITH DOUBLE LOOSE CHECK AT CUT-THROUGH END							
100	1234	200	11, 660	0. 0347	0. 0270	10. 80	1, 656
	1233	300	17, 490	. 0481	. 0301	5. 37	886
	1232	400	23, 320	. 0654	. 0322	3. 22	546
200	1218	200	11, 660	. 0401	. 0324	12. 96	1, 988
	1217	300	17, 490	. 0557	. 0377	6. 73	1, 108
	1216	400	23, 320	. 0759	. 0427	4. 27	734
200	1221	200	11, 660	. 0409	. 0332	13. 28	2, 036
	1220	300	17, 490	. 0553	. 0373	6. 66	1, 097
	1219	400	23, 320	. 0857	. 0525	5. 25	890
C.—BRATTICE WITH TRIPLE LOOSE CHECK AT CUT-THROUGH END							
200	1225	200	11, 660	0. 0259	0. 0182	7. 28	1, 117
	1224	300	17, 490	. 0700	. 0520	9. 28	1, 528
	1223	400	23, 320	. 0936	. 0604	6. 04	1, 023
D.—BRATTICES WITH TIGHT END AT CUT-THROUGH							
100	1231	200	11, 660	0. 0631	0. 0554	22. 16	3, 397
	1230	300	17, 490	. 1353	. 1173	20. 93	3, 450
	1229	400	23, 320	. 2349	. 0604	20. 17	3, 418
200	1228	200	11, 660	. 0624	. 0547	21. 87	3, 355
	1227	300	17, 490	. 1239	. 1059	18. 91	3, 117
	1226	400	23, 320	. 2346	. 2014	20. 14	3, 413

The foregoing statement applies to the results obtained with an air velocity of 200 feet per minute in the clear entry, which was equivalent to an air volume of 11,660 cubic feet per minute. When the velocity of the air approaching the brattice was increased to 300 feet per minute the absolute pressure loss caused by the brattice increased about 50 per cent, but the ratio of pressure loss to velocity pressure decreased. When the air velocity was further increased to 400 feet per minute the absolute pressure loss caused by the brattice decreased and was approximately the same as when the velocity was 200 feet per minute. This effect, of course, resulted in a very large decrease in the ratio of pressure loss to velocity pressure. These changes were directly connected with the quantity of air leaking past the brattice, of which a large share occurred at the loose check at the cut-through; this will be discussed further when the figures for leakage are given. It is evident from the foregoing results that the single-thickness check at the cut-through did not have enough weight to stand the pressure which the long brattice forced on it.

The tests of part B of Table 37 show what improvement could be expected by using a double thickness of brattice cloth in the check. The brattices caused a larger pressure loss than they did with a single check, as more air was being forced to the face. Also, the 200-foot brattice had a larger pressure loss than the 100-foot brattice, the reverse of which was true when the single-thickness check was used. When the air velocity was increased to 300 and 400 feet per minute, the absolute pressure loss increased, although the ratio to velocity pressure decreased. This result indicates that there was a larger proportional leakage at the higher velocities, a theory which the leakage measurements confirm.

Part B of Table 37 also presents the only duplicate tests of the series. Tests 1221, 1220, and 1219 are duplicates of tests 1218, 1217, and 1216. It will be noted that the agreement is satisfactory, although it is not as good as that obtained in other pressure-loss tests where conditions were more rigidly fixed.

The results of a single set of tests of a 200-foot line brattice with a triple-thickness check at the cut-through, in effect an extension of the results of part B, are given in part C of Table 37. The measurements at the lowest velocity are probably in error.

The final tests (part D) show that when the cut-through end of the line brattice was tightly fastened a very large increase in pressure loss was observed. The decrease in ratio of pressure loss to velocity pressure with increasing air velocity became subordinate, which means that leakage was rendered nearly proportional to velocity. As a matter of fact, the leakage was merely transferred from the loose check and distributed all along the brattice, so that the increase in air volume reaching the face was not nearly as great as the increase in pressure loss. Under these test conditions the line brattice was causing as much pressure loss as 3,500 feet of clear entry, and this loss remained practically constant when the length of the brattice was increased from 100 to 200 feet. However, the air distribution was much altered by this change, as will be shown.

RESULTS OF LEAKAGE TESTS

The volume of air passing behind the various brattices was determined at a number of points. With a 200-foot brattice, measurements were made at points 25, 50, 100, 150, and 200 feet from the last cut-through. When shorter brattices were used, measurements were made at such of these points as were available. A very complete chart of the air distribution behind the brattices was thus obtained. The results are given in Table 38.

TABLE 38.—*Leakage tests of line brattices in No. 2 butt entry, November, 1923*

A.—BRATTICES WITH SINGLE LOOSE CHECK AT CUT-THROUGH END

Length of brattice, feet	Test No.	Air velocity, feet per minute	Volume of air outby last cut-through, cubic feet per minute	Volume of air behind brattice at various distances from cut-through, cubic feet per minute					Percentage of air reaching face
				25 feet	50 feet	100 feet	150 feet	200 feet	
25	1202	200	11,660	6,080	----------	----------	----------	----------	52
	1201	300	17,490	6,510	----------	----------	----------	----------	37
	1200	400	23,320	3,600	----------	----------	----------	----------	14
50	1205	200	11,660	4,960	4,650	----------	----------	----------	40
	1204	300	17,490	5,080	4,620	----------	----------	----------	26
	1203	400	23,320	2,720	2,590	----------	----------	----------	11
100	1208	200	11,660	4,820	4,140	3,550	----------	----------	30
	1207	300	17,490	4,590	3,950	3,110	----------	----------	18
	1206	400	23,320	2,360	2,030	1,740	----------	----------	7
150	1211	200	11,660	4,450	4,110	3,000	2,800	----------	24
	1210	300	17,490	4,200	3,800	2,890	2,860	----------	16
	1209	400	23,320	2,420	2,180	1,470	1,500	----------	6
200	1214	200	11,660	4,220	3,830	2,600	2,040	1,760	15
	1213	300	17,490	3,930	3,400	2,300	1,690	1,580	9
	1212	400	23,320	1,670	1,810	1,260	690	500	2

B.—BRATTICES WITH DOUBLE LOOSE CHECK AT CUT-THROUGH END

100	1234	200	11,660	7,660	5,700	4,010	----------	----------	34
	1233	300	17,490	8,400	6,720	4,550	----------	----------	26
	1232	400	23,320	9,350	7,550	5,500	----------	----------	24
200	1218	200	11,660	7,900	6,380	4,190	3,440	2,790	24
	1217	300	17,490	8,590	6,960	4,820	3,780	3,270	19
	1216	400	23,320	8,980	7,420	4,980	4,060	3,480	15
200	1221	200	11,660	7,440	6,020	4,010	3,150	2,670	23
	1220	300	17,490	7,990	6,380	4,250	3,220	2,640	15
	1219	400	23,320	7,760	6,620	4,390	3,430	2,930	13

C.—BRATTICE WITH TRIPLE LOOSE CHECK AT CUT-THROUGH END

200	1225	200	11,660	8,980	6,760	4,350	3,470	2,670	31
	1224	300	17,490	10,040	7,800	5,180	4,180	3,430	20
	1223	400	23,320	11,300	8,850	5,600	4,590	3,880	17

TABLE 38.—*Leakage tests of line brattices in No. 2 butt entry, November, 1923*—Continued

D.—BRATTICE WITH TIGHT END AT CUT-THROUGH

Length of brattice, feet	Test No.	Air velocity, feet per minute	Volume of air outby last cut-through, cubic feet per minute	Volume of air behind brattice at various distances from cut-through, cubic feet per minute					Percentage of air reaching face
				25 feet	50 feet	100 feet	150 feet	200 feet	
100	1231	200	11,660	11,330	9,190	6,320			54
	1230	300	17,490	17,000	13,380	8,960			51
	1229	400	23,320	23,250	18,500	11,400			49
200	1228	200	11,660	11,500	8,700	4,950	4,020	3,290	28
	1227	300	17,490	17,450	13,370	7,490	6,060	5,220	30
	1226	400	23,320	23,300	18,050	10,000	8,180	7,100	30

The figures of part A of Table 38 show quite clearly the decrease in volume of air delivered by a brattice as the length of the brattice increases. With a velocity back of the last cut-through of 200 feet per minute (11,660 cubic feet per minute), a 25-foot line brattice with single-thickness loose check delivered 50 per cent of the air to the face, whereas a 100-foot brattice delivered only 30 per cent, and a 200-foot brattice delivered only 15 per cent of the air that reached its cut-through end. Increasing the velocity of the air approaching the brattice to 300 feet per minute was a disadvantage, as the actual volume of air reaching the face was decreased in all tests except those with the shortest (25-foot) brattice. A further increase in velocity to 400 feet per minute caused still greater losses under all conditions. At the higher velocities the loose check was pushed out at an angle by the air pressure, and the air leaked under and around it.

When the single-thickness check was replaced by a double-thickness check (part B), the added weight more nearly balanced the air pressure; also, an increase in velocity of air approaching the brattice was accompanied by an increase in the volume reaching the face, although this was not large. Thus with a 100-foot brattice the air volumes at the face were 4,010, 4,550, and 5,500 cubic feet per minute when the velocities in the main air current were 200, 300, and 400 feet per minute, corresponding to volumes of 11,660, 17,490, and 23,320 cubic feet per minute. Doubling the thickness of the check did not greatly increase the percentage of air reaching the face at any one velocity. Thus with a 100-foot brattice and a velocity of 200 feet per minute, a single check delivered 30 per cent of the air to the face, whereas a double check delivered 34 per cent. When the velocity was 400 feet per minute the single check delivered 6 per cent and the double check delivered 24 per cent of the air to the face. The use of double canvas on the check is much more efficient at the higher velocities. A triple-thickness check on a 200-foot line brattice (part C) was somewhat more efficient than a double check.

When the cut-through end of the brattice was tightly closed (part D of Table 38) the volume of air delivered to the face was almost directly proportional to the volume approaching the brattice. With a 100-foot brattice, 50 per cent of the air reached the face; and with a 200-foot brattice, 30 per cent of the air reached the face. The leakage was highest near the cut-through, of course, but larger volumes of air reached all points along the brattice.

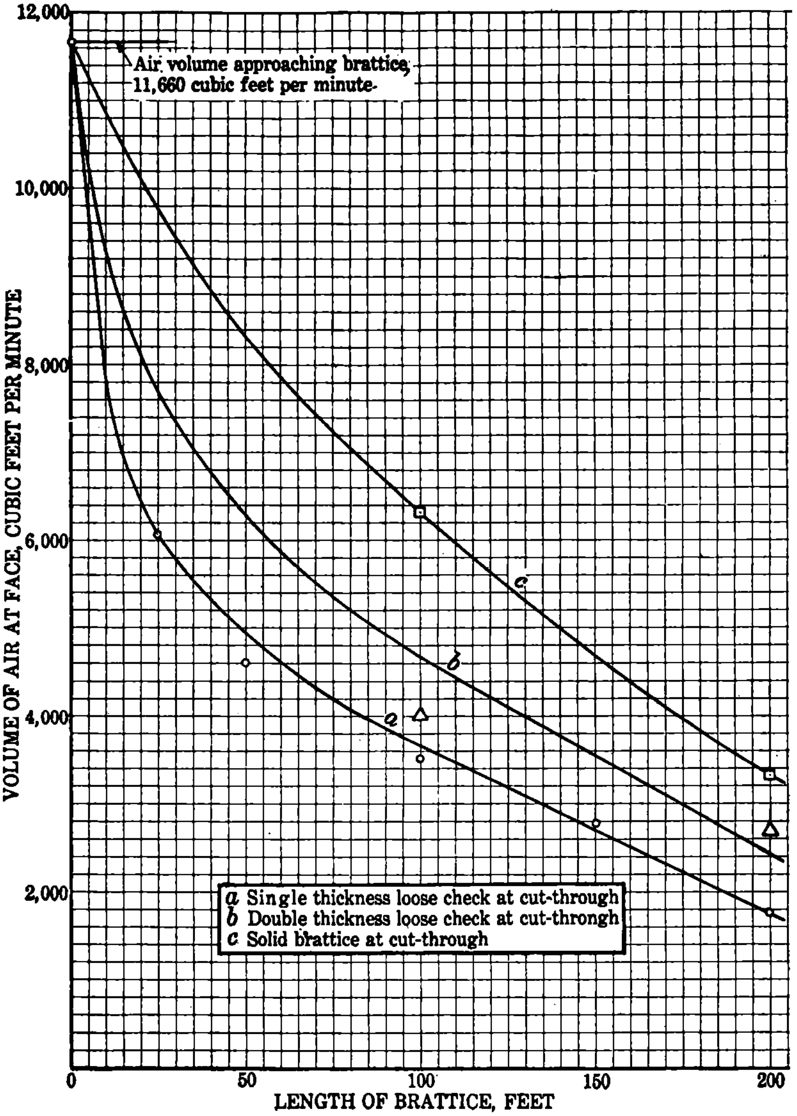


FIGURE 47.—Volume of air delivered to the face of an entry by line brattices

The volume of air delivered by certain of the brattices is shown graphically in Figure 47. The results shown are those obtained at the lowest velocity (200 feet per minute = 11,660 cubic feet per minute), which was selected as representative of the velocity found in the last cut-through connecting room entries in some operating mines.

The curve marked *a* gives the results obtained with the brattices having a single-thickness check at the cut-through end. The circled points give the volumes of air reaching the face when the brattice had various lengths from 25 to 200 feet. Curve *b* is for brattices having a double-thickness check, and curve *c* is for brattices solidly built at the cut-through end. Tests were made with only two lengths of brattice, so that there are only two points each for curves *b* and *c*. All the curves have been carried up to a volume of 11,660 cubic feet with zero length brattice, as this was the volume passing through the last cut-through and would be the volume reaching the face before the entry was advanced beyond the cut-through. The curves show that over half the loss occurs in the first 25 feet of the brattice when a single-thickness check is used and that changing to a tight brattice adds 75 to 80 per cent to the volume of air delivered to the face.

EFFICIENCY OF LINE BRATTICES

The figures given in Tables 37 and 38 are complete enough to warrant computing the relative efficiencies of the brattices. Efficiency may be variously stated according to the viewpoint from which the brattice is regarded. The most efficient brattice may be defined as:

1. The brattice delivering the largest volume of air to the face.
2. The brattice delivering to the face the largest percentage of the air it receives.
3. The brattice delivering to the face the largest volume of air per unit pressure loss.

In order to arrive at a proper comparison a definite length of brattice must be considered, and this length is taken as 100 feet for the present discussion. On the first basis it is then found that the brattice with a tight cut-through end is the most efficient, as it delivered a larger volume of air to the face at all velocities than any other arrangement.

The brattice with a tight cut-through end is also most efficient on the second basis, as it delivered to the face 50 per cent of the air it received, irrespective of the velocity of the air approaching it. This is to be compared with 24 to 34 per cent delivered when there was a double-thickness check, and 7 to 30 per cent delivered when there was a single-thickness check.

The final method of stating the efficiency of the brattices involves the results of both Tables 37 and 38. A convenient way to express the efficiency is to state the number of cubic feet of air delivered to the face for each 0.01 inch of water pressure loss caused by the brattice. These values have been computed for the 100-foot and 200-foot brattices and are given in Table 39.

TABLE 39.—*Volume of air delivered to the face by line brattices for each 0.01 inch of pressure loss caused by them*

A.—SINGLE-THICKNESS CHECK AT CUT-THROUGH

Air approaching brattice		Cubic feet of air delivered per 0.01 inch pressure loss	
Velocity, feet per minute	Volume, cubic feet per minute	100-foot brattice	200-foot brattice
200	11,660	2,000	1,140
300	17,490	1,240	660
400	23,320	1,380	410

B.—DOUBLE-THICKNESS CHECK AT CUT-THROUGH

200	11,660	1,490	860
300	17,490	1,510	870
400	23,320	1,710	820

C.—SOLID BRATTICE AT CUT-THROUGH

200	11,660	1,140	600
300	17,490	760	490
400	23,320	570	350

The values of Table 39 show that when pressure loss is considered the brattice with single-thickness check was the most efficient at the lowest velocity, and the brattice with double-thickness check was the most efficient at the two higher velocities. The solid brattice was least efficient at all velocities, as it delivered the least air per unit of power expended. The same relations existed for both 100-foot and 200-foot brattices, although, as would be expected, there was less air at the end of a 200-foot brattice. The most efficient brattice can not be specified unless the basis of rating is also specified. For most mine work there must be a certain minimum amount of air delivered to the face, and if the brattices with loose checks will deliver this amount, they are the most economical; if they will not deliver the amount desired, the solid brattice must be used.

The brattices as erected in the experimental mine represent better practice and construction than will ordinarily be found in operating mines; the efficiency figures are consequently higher than the average. The deliveries of air will be much lower if the canvas becomes torn or pulled out of place, as it frequently does when cars are hauled through it, and failure properly to fasten line brattices close to the roof will also be a source of much leakage. In the application of the foregoing data on brattices, therefore, it will be necessary to make such allowances for local conditions as good judgment may dictate.

INDEX

Page

- Air, moist, weight of, computation of 11
  - velocity of, determination of 6
- Air flow, basic formula for 11
- Air-measurement tests, check, description of 25
    - results of 25
  - work on 3
- Air-measuring stations, diagrams of 12, 13
  - equipment of 12, 22
    - diagrams of 17, 18, 19, 23
    - views of 20, 21, 24, 26
  - instrument chamber of, views of 20, 21
  - pressure loss due to 19
  - views of 14, 15, 16
- Airways, straight, friction factors for, study of 4
- Allison, V. C., acknowledgment to 3
- Atkinson, J. J., work cited 1
- American Society of Heating and Ventilating Engineers, acknowledgment to 3

- Bends, double right angle, air flow at, theory of 86
    - resistance of, tests of 80
      - diagram illustrating 82
      - results of 81, 83, 84, 85
  - resistance due to, study of 5
  - reverse right angle, resistance of, tests of 86
      - diagrams illustrating 87
      - results of 88
  - right angle, closely spaced, resistance of 80
    - diagrams illustrating 67, 69, 72, 75, 78, 79, 87
    - pressure losses caused by 66
      - tests of, results of 68, 70, 72, 73, 76, 79, 81, 83, 84, 85, 88
- Bevel, on inner corner, diagram of 69
  - effect of, tests of 69
    - results of 70
- Brattices, canvas, pressure losses of, tests of 89
  - deflector, across cut-through dead ends, effect of 41
  - resistance due to, study of 5

- Callen, A. C., work cited 2
- Center constants, computation of 11
  - tests to determine 17, 24
    - results of 19, 25
- Center posts, effect of, tests of 50
    - diagram illustrating 51
    - results of 49
- Check brattices, in rooms, effect of, tests of 89
    - results of 94, 95
  - views of 92
- Crossbars, effect of, tests of 48
    - results of 49
- Curves, diagrams of 69, 72
  - effects of, tests of 69, 71, 72
    - results of 70, 72, 73
  - views of 74

Page

- Day, V. S., work cited 9
- Dead end, open, effect of, tests of 68
    - results of 68
- Doors, leakage around, tests of 35
    - results of 37
- Duct, at fan-drift air-measuring station, view of 24

- Ellison gauge, description of 10
  - view of 10
- Entries, straight, clear, resistance of 40
      - tests of 40
    - pressure losses in 38
    - profile of, diagram of 38
    - section of, diagrams of 38, 40
    - timbered, diagrams of 44, 46
      - resistance of 43
        - effect of spacing on 48
        - tests of 45, 47
      - view of 44
    - untimbered, tests with mine cars in 53
- Experimental mine, Bureau of Mines, description of 6
  - diagram of 7

- Fan drift, air-measuring station at, tests at 22
- Fene, W. J., acknowledgment to 3
- Fitch, T. W., jr., work cited 1
- Floor, roughening of, effect of 42

- Gauges, inclined, in instrument chamber of air-measuring station, view of 20
  - *See also* Ellison gauge; Wahlen gauge.
- Golden, P. L., acknowledgment to 3

- Hertzog, E. S., acknowledgment to 3
- Howarth, H. C., acknowledgment to 2

- Kratz, A. F., work cited 9

- Line brattices, air delivered by, data on 104
  - diagram illustrating 102
  - efficiency of 103
  - in entry dead end, effect of, tests of 96
    - results of 97, 98, 100
  - in rooms, effect of, tests of 89
    - results of 90, 91

- McElroy, G. E., work cited 2
- Mine cars, diagram of 52
  - empty, effect of, tests of 62
    - results of 62
  - in timbered entry, effect of, tests of 64
    - results of 65, 66
    - view of 64
  - leaded, effect of, tests of 62
    - results of 62

Page

Mine cars, location of, effect of, tests of ... 56
  entry constants for ... 57
  results of ... 56
 number of, effect of, tests of ... 53
  diagram illustrating ... 55
  results of ... 54
 opposite cut-through dead ends, effect of, tests of ... 62
  diagram illustrating ... 63
  results of ... 63
 pressure losses caused by, tests of ... 52
 resistance due to, study of ... 4
 size of, effect of, tests of ... 60
  results of ... 61
 spacing of, effect of, tests of ... 57
  diagram illustrating ... 59
  entry constants for ... 60
  results of ... 58
 view of ... 531
Mine doors, leakage at, test work on ... 3
Murgue, D., work cited ... 1

Owings, C. W., acknowledgment to ... 3

Paul, J. W., acknowledgment to ... 2
Peele, Robert, work cited ... 11
Piezometer plates, details of ... 19
Pitot tubes, determination of static pressure by ... 13
 diagrams of ... 17, 23
 guide apparatus for, diagram of ... 18
 use of ... 8
 view of ... 14
 Pressures, barometric, measurement of ... 10
Pressure losses, measurement of ... 27, 34

Rice, G. S., acknowledgment to ... 2
  work cited ... 2
Richardson, A. S., work cited ... 2
Rooms, in experimental mine, views of ... 90, 91
Rowse, W. C., work cited ... 8

Shelter holes, effect of ... 42
Smith, C. M., work cited ... 2

Page

Static pressure, differences in, tests to determine ... 30
Statis pressure stations, description of ... 27
 diagram showing location of ... 7
 equipment for ... 28, 30
  diagram of ... 28
  view of ... 29
Static-pressure tubes, connections for ... 30
 description of ... 28
 diagram of ... 28
 tests of ... 30
 view of ... 29
Static pressures, differential, tests to determine ... 13
Static traverses, differential, results of ... 22

Temperatures, measurement of ... 10
Test sections, measurement of ... 33
 data on ... 33
Test work, duration of ... 2
Timber, in entries, effect of ... 43
Turbulence, extended, effect on pressure-loss measurements ... 32

Vanes, radial, diagrams of ... 75
 effect of, tests of ... 73, 76
  results of ... 76
 view of ... 74
Velocity, determination of, formula for ... 11
Velocity pressures, measurement of ... 8
 procedure for ... 34
 traverse point, tests to determine ... 16
  results of ... 16
Ventilation door, view of ... 36
Venturi bends, diagrams of ... 69, 78, 79
 effect of, tests of ... 69, 77
  results of ... 70, 79

Wahlen gauge, description of ... 8
 views of ... 9, 20
Willard, A. C., acknowledgment to ... 3
 work cited ... 9
Wilson, C. R., acknowledgment to ... 3