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“Water-Supply for California Oilfields.”

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(Abstract.)

IN this Paper an account is given of a water-system installed under the Author's supervision to supply the property of the California Oilfields, Limited, in the Coalinga District, California. The demand on the old system had been as high as 340,000 gallons per day, so the new system was installed with a capacity of 420,000 gallons per day, in order to meet future requirements.

The following conditions had to be met in planning the system. The property lies on the extreme eastern edge of the coast range of mountains forming the western boundary of the San Joaquin Valley, the more or less flat bottom of which is over 100 miles broad at this point. The western boundary of the property lies among steep hills intersected by deep cañons. These disappear toward the centre of the property in a shallow valley, which is bounded on the east by low undulating hills. The elevation of the highest ground on which development was likely to proceed is about 1,417 feet above sea-level, and the lowest point about 700 feet. Nowhere in the hills has any considerable amount of water been discovered, but in the lower levels water is found in plenty at depths ranging from 100 feet downward. The only method practicable, therefore, was to obtain the water from wells sunk on the lower ground, thence pumping it up to storage-tanks, from which it could gravitate to the points required.

In November and December, 1910, a 10-inch diameter test well was sunk to a depth of 665 feet through 60 feet of water-bearing sandstone. On being tested for 7 days at full speed with no decrease in its delivery of 126,000 gallons per 24 hours, it was considered satisfactory evidence that the supply of water was sufficient, and the chemical analysis also proved satisfactory.

Distributing System.—The new wells and pumping-station are connected by a 6-inch diameter main to the new 420,000-gallon tank. The distance between the pumping-station and the main

storage-tank is 18,000 feet and the difference of elevation is 810 feet. Connections were inserted in this main for supplying tanks Nos. 1 and 2, and also for feeding any future storage-tanks that may be erected. Further subsidiary tanks were supplied to act as additional storage and also to reduce the pressure on the distributing pipe mains.

AIR-LIFT.

The advantages of the air-lift system are that maintenance costs are less, there is no machinery outside the pumping-station requiring attention, and there is no need to pull the tubing out of the well and so interfere with the supply. Furthermore, the one air-compressor in an engine-room, out of the dust and directly under the supervision of the engineer, is more easily and properly cared for than three separate steam-cylinders at some distance from the rest of the machinery. It was found also that the initial cost of three deep well-pumps, complete with steam-cylinders, would be approximately the same as that of one air-compressor. There is, however, one drawback to the use of the air-lift system, viz., the rapid corrosion of the interior of the steel pipe-lines due to the combination of the excessive percentage of air dissolved in the water together with the salts.

PUMPING-STATION EQUIPMENT.

The air-compressor is of the two-stage direct steam-driven horizontal cross-compound type, the air-cylinders being tandem with the steam-cylinders. The air-inlet valves on the low-pressure cylinder are of the semi-rotary pattern driven by an eccentric and rocker arm from the crank-shaft. All other air-valves are of the automatic spring-loaded and air-cushioned pattern. The air-suction pipe is taken underground in a trench to a point outside the engine-room and ends in a vertical length, the top of which is about 3 feet above ground on the shady side of the building. A combined fore-cooler and filter was erected around this suction-pipe, consisting of a rectangular wooden frame covered with burlap which is kept wet. The compressor at 100 revolutions per minute is capable of delivering 500 cubic feet of free air per minute at a working pressure of 160 lbs. per square inch, with a starting pressure of 217 lbs. per square inch gauge, the stroke of the pistons being 18 inches. The discharge-pipe is taken outside the building to a horizontal receiver 3 feet in diameter and 8 feet long, whence 2-inch diameter mains are laid to the wells. There are no stop-valves between the

compressor and the receiver, and the latter is fitted with a safety-valve. There are three separate systems of supplying the cooling water for the air-cylinders and intercooler, each of which is easily capable of reducing the temperature of the air leaving the intercooler to that of the air entering the low-pressure cylinders.

The main-line pump is a horizontal cross-compound of the crank and fly-wheel pattern with double plungers and external glands, the diameter and stroke of the plungers being $5\frac{1}{2}$ inches and 18 inches respectively. The water passes through a Venturi meter having a 2-inch throat, the recording gear for which is arranged in one corner of the engine-room.

The oil-fuel pumps are of the Worthington duplex pattern, with $2\frac{3}{4}$ -inch diameter and 4-inch stroke oil-pistons, and are mounted side by side on top of the oil-heater. The oil on leaving the pump passes through this cast-iron base on its way to the burner, and the exhaust steam passes through a copper coil inside this base. The oil-pressure regulator consists of a copper diaphragm, one side of which is exposed to the pressure in the oil-delivery pipe, and the other, spring-loaded, is connected to a steam throttle-valve. A spring-loaded safety-valve is also fitted to the oil-delivery pipe. The oil-suction pipes are fitted with large strainers to catch any suspended matter in the oil.

The boilers, two in number, are of the Parker downward-flow water-tube pattern, 137 HP. each, according to the American Society of Mechanical Engineers' rating, and are set in battery at one end of the engine-room, there being no reason for a separate boiler-room, as with oil fuel there is no dirt or grit as with coal firing.

AIR-LIFT EQUIPMENT AND TESTS.

In July, 1911, tests were made of wells Nos. 1 and 2, the results being shown in columns 1 and 2 of the Table in the Appendix. During these tests the compressor was run at such a speed that the discharge from the well was continuous, changing in form, however, periodically from a spray of high velocity to a solid stream of water at a lower velocity, as it was believed from the results of the experiments described by Mr. Kelly,¹ that the highest efficiency would be obtained under such conditions. The revolutions were counted every $7\frac{1}{2}$ minutes for a period of 2 minutes, and care taken to keep the compressor running as steadily as possible during the tests. The temperature of the air was noted, and the pressure at the air-

¹ Minutes of Proceedings Inst. C.E., vol. clxiii, p. 353.

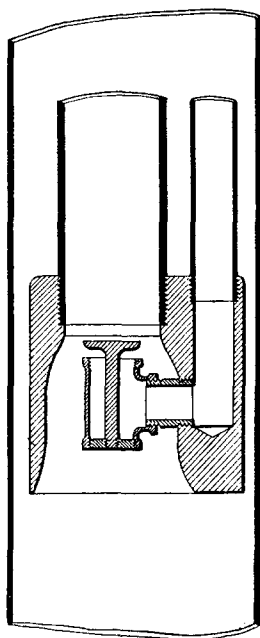
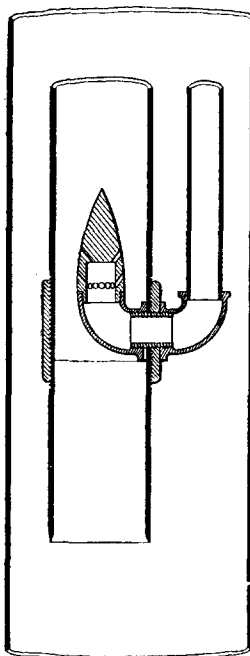
AIR-LIFT EQUIPMENT AND TESTS.

Two wells 10 inches in diameter.

| | Sizes of Tubing in Wells (with Taper Pieces 12 Inches long at each Change of Diameter). | Area. |
|---|--|---|
| Well No. 2 with tubing for 126,000 gallons per 24 hours. Test No. 1 | 293 feet of 3-inch . . . 101½ " " 3½-inch . . . 55 " " 4-inch . . . Air pipe 1½-inch nominal . . . | 7.07 square inches. 9.62 " " 12.57 " " 1.49 " " |
| Well No. 1 with tubing for 126,000 gallons per 24 hours. Test No. 2 | 382 feet of 3-inch . . . 158 " " 3½-inch . . . 64 " " 4-inch . . . Air pipe 1½-inch nominal . . . | 7.07 " " 9.62 " " 12.57 " " 1.49 " " |
| Well No. 1 with tubing for 315,000 gallons per 24 hours. Tests Nos. 3, 4, 5 and 6. | 323 feet of 4-inch . . . 81 " " 4½-inch . . . 50 " " 5½-inch . . . 24 " " 5¾-inch . . . Air pipe 1½-inch nominal . . . | 12.57 " " 15.90 " " 21.135 " " 24.85 " " 2.03 " " |
| Well No. 2 with tubing for 275,000 gallons per 24 hours. Tests Nos. 7, 8, 9, 10, 11 and 12 . . . | 356 feet of 4-inch . . . 109 " " 4½-inch . . . 82 " " 5½-inch . . . Air pipe 1½-inch nominal . . . | 12.57 " " 15.90 " " 21.135 " " 1.49 " " |

reservoir and at the well-head, and the amount of air delivered calculated from these figures. The volume of water discharged was measured by taking the depth of water in one of the 84,000-gallon tanks every 30 minutes. The depth of the water-level in the well both when pumping and when not pumping was measured by means of a float on the end of a steel tape line, 3000 feet long, wound on a drum. The float is a piece of wood $\frac{1}{4}$ inch by 1 inch in section and 6 feet long, weighted to float upright. These measurements were taken every $\frac{1}{4}$ hour at first, but were found so regular that they were only taken every $\frac{1}{2}$ hour towards the end of the tests. The results of these two tests were considered very encouraging, first, as the quantity of water obtained exceeded the original estimate, and secondly, as the efficiency was moderate considering that from 50 per cent. to 90 per cent. more water was being raised than the tubing had been designed for, rendering the velocity of the rising column and the friction unduly high. It was decided, therefore, to re-tube well No. 1 on the basis of a probable production of 315,000 gallons per day, with a fall in water-level of 20 feet, and well No. 2 on the basis of a probable production of 275,000 gallons per day. Well No. 2, when first the tubing was inserted in it, some little time after drilling was completed, was found to have filled up with sand to a depth of 470 feet; and it was decided, therefore, to clean it out, and also to deepen it in order to allow greater submergence for the tubing. Meanwhile, well No. 1 was re-tubed.

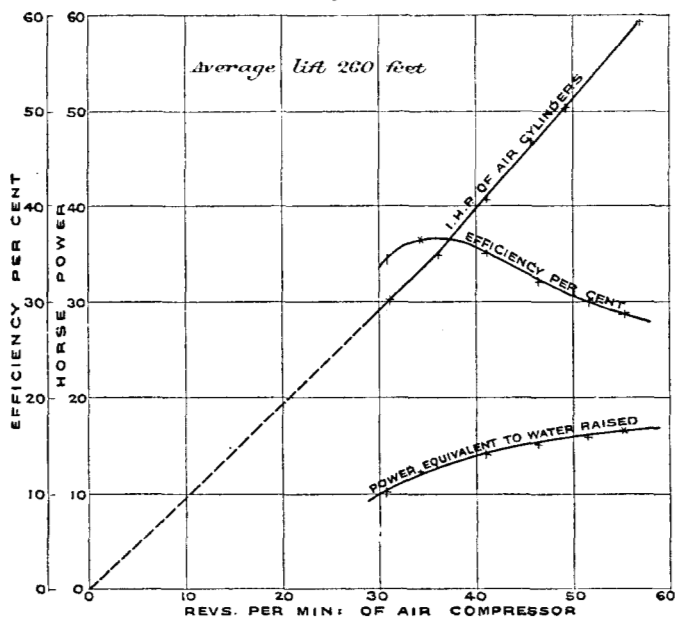
The form of air-injection nozzle shown in *Fig. 1* was used in well No. 1 after equipping it with the larger tubing. On the 4th November and following days, tests Nos. 3, 4, 5 and 6 were made on well No. 1. During these tests the revolutions of the compressor were taken by means of a counter. The discharge from the well was calculated from the Venturi meter readings, the depths in the 84,000-gallon tank and meter on the discharge-line of the circulating water from the air-compressor. Indicator-cards were

Fig. 1.AIR-INJECTION NOZZLE,
WELL NO. 1.*Fig. 2.*AIR-INJECTION NOZZLE,
WELL NO. 2.

taken at intervals from the air- and steam-cylinders of the compressor. In tests Nos. 4 and 6 the discharge from the well was similar to that obtained in tests No. 1 and 2; but in Nos. 3 and 5 it was in the form of a steady flow of spray, the air being thoroughly mixed with the water.

During April, 1912, after deepening and re-tubing, tests Nos. 7, 8, 9, 10, 11, 12 were made on well No. 2, using the air-injection nozzle shown in *Fig. 2*; the results are plotted graphically in

Fig. 3, and the velocities of the rising mixture are shown in *Fig. 4*. During this series the water lifted was measured in one of the 84,000-gallon tanks. The depth of the water-surface in the well below the derrick floor was measured every $\frac{1}{4}$ hour. The temperature of the air entering the compressor was recorded every 10 minutes, as was also the reading of the revolution-counter. The revolutions during each test remained very constant. It was impossible to take indicator-cards of the air-compressor during the tests, so on the 24th April a series was taken at the same

Fig. 3.

RESULTS OF TESTS NOS. 7-12.

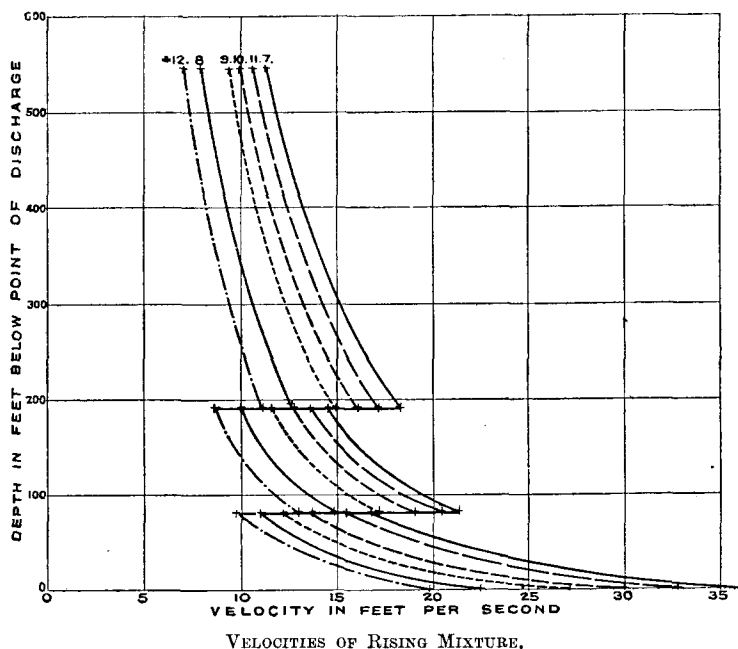
suction temperatures and at successive speeds commencing at the lowest and allowing 15 minutes at each speed before taking the cards. As the only outlet for the air both during the tests and at the time the cards were taken was to this one well, the horse-power indicated by the cards has been taken as being identical with that expended during the tests.

It will be noticed in *Fig. 3* that the points on the indicated horse-power curve lie very uniformly, the only change of curvature being at a speed of 36 revolutions per minute of the compressor. This

change of slope is accounted for by the fact that from 15 revolutions per minute—the lowest speed tried—up to 36 revolutions per minute the air-pressure at the well-head remained the same, but above this speed the air-pressure rose steadily with each increase of speed. The following points regarding the nature of the discharge were observed on the 11th April and during the tests, periods of discharge and rest being taken approximately with the watch.

At 19 Revolutions per Minute of the Compressor.—Water flowed in the form of fine spray and at high velocity for 25 seconds, followed

Fig. 4.



by a period of $1\frac{1}{4}$ minute during which there was no discharge but a slight roar could be heard, the sound rising and falling, growing louder each time until discharge took place, as if the mixture rose so far in the discharge-pipe, then the air broke through and the water fell back.

At 28 Revolutions per Minute of the Compressor.—Discharge in the form of fine spray for 35 seconds, followed by a period of 30 seconds during which there was no discharge and the air-pressure in the receiver rose from 130 to 132 lbs. per square inch. On reaching

this latter pressure discharge took place for $1\frac{1}{2}$ second followed by a pause for $1\frac{1}{2}$ second, then discharge for $1\frac{1}{2}$ second and again a pause of 1 second before the cycle commenced again.

At 30 Revolutions per Minute of the Compressor.—Discharge in the form of spray at high velocity for 20 seconds, then three periods of alternate 1-second pause and discharge (6 seconds in all), pause 17 seconds, discharge 2 seconds, pause 1 second, discharge 1 second, pause 3 seconds, discharge 3 seconds, pause 1 second; the cycle then commencing again with a discharge for 20 seconds.

At 32 Revolutions per Minute of the Compressor.—Alternate periods of 2 seconds discharge and 1 second pauses for a total period of 30 seconds, followed by alternate periods of 1 second flow and pauses of 4 seconds during the next 30 seconds.

At 35½ Revolutions per Minute of the Compressor.—A regular succession of periods of flow for 2 seconds with intervals of 1 second.

At 40 Revolutions per Minute of the Compressor.—Discharge almost continuous though varying considerably in velocity.

At 45 Revolutions per Minute.—To all appearances practically the same as at 40 revolutions per minute as far as can be observed with the naked eye.

At 50 Revolutions per Minute.—Discharge in the form of a heavy spray at high velocity, with a $\frac{1}{2}$ second pause every 30 seconds or so.

The total times taken by the above cycles were checked more than once and found to remain reasonably constant, though the length of the intervals stated to be 1 second and less are, of course, only approximate.

The wells were started flowing at least 2 hours before each test, with the compressor running at the same speed as during the test, so that all conditions remained constant throughout, with one exception, when the lift was found to increase slightly during the first $\frac{1}{2}$ hour, so that in this case the test was prolonged $\frac{1}{2}$ hour and the first readings discarded. In the test with the compressor running at 30.7 revolutions per minute the water-level in the well rose 2 feet during the interval between each period of 20 seconds of discharge and fell again when the discharge took place.

The total cost of the installation less that of the wells was \$52,500, \$35,200 being that of the pumping-station complete, \$13,350 that of the 6-inch main, and the balance for the primary storage-tank. These figures are given so that any person interested in comparing the cost may add interest and depreciation charges to the operating costs given below.

Operating Costs for 5 Months.

| | \$ |
|---|-------------------|
| Wages | 1,290.75 |
| Fuel at 50 cents per bl. | 1,291.75 |
| Make-up feed-water, say 5 per cent. of total evaporated | 50.00 |
| Oil, waste, paint, small tools and other sundries | 348.72 |
| Insurance | 91.65 |
| Electric light | 30.00 |
| Total | <u>\$3,102.87</u> |

| | |
|---|------------------------------|
| Total quantity of water pumped | 30,364,565 imperial gallons. |
| Static head on main-line pump | 835 feet. |
| Average lift from wells | 245 " |
| Total lift | 1,080 " |
| Duty in millions of foot-gallons | 32,793.73 |
| Output expressed as a percentage of the total capacity. | 57 per cent. |

In conclusion, the Author wishes to express his indebtedness to Mr. Chevalier for arranging the boiler tests and lending most of the scientific instruments; also to Messrs. G. T. McKinney, J. H. Mudie, and S. W. Duhig, for their assistance throughout the tests.

The original Paper, filed in the Library, is accompanied by four drawings and nine diagrams, from which the Figures in the text have been selected.

APPENDIX.

TESTS OF AIR-LIFT PUMPS.

Temperature of mixture on leaving the well 70° F. in all cases.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|-------------------|-------------------|-------------------|-------------|-------------|-------------|
| 1. Number of experiment | . | . | . | . | . | . |
| 2. Number of well tested | . | . | . | . | . | . |
| 3. Date | 15 July, 1911 | 18 July, 1911 | 4 Nov. 1911 | 7 Nov. 1911 | 8 Nov. 1911 | 9 Nov. 1911 |
| 4. Duration of test | 5½ hours | 4 hours | 2 hours | 6 hours | 8 hours | 6 hours |
| 5. Total length of discharge pipe above air-injection footpiece | 452 | 608 | 481 | 481 | 481 | 481 |
| 6. Lift in feet when pumping | 242 | 210 | 236 | 229 | 236 | 228 |
| 7. Submersion | 210 | 398 | 245 | 252 | 245 | 253 |
| 8. Ratio $\frac{\text{lift}}{\text{submersion}}$ | 0.87 | 1.89 | 1.04 | 1.10 | 1.03 | 1.11 |
| 9. Water lifted per minute (Imperial gallons) | 108.7 | 140.5 | 218.9 | 178.1 | 220.25 | 171.75 |
| 10. Water lifted per minute (cubic feet) | 17.39 | 22.48 | 35.02 | 28.50 | 35.24 | 27.48 |
| 11. Revolutions per minute of air-compressor | 44.0 | 39.6 | 66.7 | 41.1 | 73.7 | 39.5 |
| 12. Cubic feet of free air discharged per revolution | 5 | 5 | 5 | 5 | 5 | 5 |
| 13. Average temperature of air suction | 109.0 | 92.0 | 61.5 | 65.2 | 65.8 | .. |
| 14. Cubic feet of air at 70° F. and 29.25 Bar, used per minute | 204.9 | 190.0 | 339.5 | 207.3 | 372.4 | 201.5 |
| 15. Cubic feet of air per cubic feet of water | 11.7 | 8.5 | 9.7 | 7.3 | 10.6 | 7.3 |
| 16. Gauge pressure of air at well head | 102.3 | 174.0 | 136.0 | 109.0 | 119.0 | 109.0 |
| 17. Power equivalent to water raised | 7.97 | 8.94 | 15.65 | 12.36 | 15.75 | 11.86 |
| 18. I.H.P. of air-compressor | 35.5 ¹ | 31.2 ¹ | 69.0 ¹ | 36.7 | 69.9 | 35.2 |
| 19. Efficiency percentage of air-lift $\frac{\text{water HP.}}{\text{air HP.}}$ | 22.5 | 28.6 | 22.6 | 33.6 | 22.5 | 33.7 |

¹ Calculated, not indicated.

TESTS OF AIR-LIFT PUMPS.

| | 7 | 8 | 9 | 10 | 11 | 12 |
|---|----------------|----------------|----------------|----------------|----------------|----------------|
| 1. Number of experiment | | | | | | |
| 2. Number of well tested | 2 | 2 | 2 | 2 | 2 | 2 |
| 3. Date | 12 April, 1912 | 17 April, 1912 | 18 April, 1912 | 19 April, 1912 | 22 April, 1912 | 23 April, 1912 |
| 4. Duration of test | 2½ hours | 2 hours | 2 hours | 2 hours | 2 hours | 2 hours |
| 5. Total length of discharge pipe above air-injection footpiece . | 547 | 547 | 547 | 547 | 547 | 547 |
| 6. Lift in feet when not pumping | 252 | 252 | 252 | 252 | 252 | 249 |
| " " when pumping | 263 | 257 | 256 | 260 | 262 | 249 |
| 7. Submersion | 284 | 290 | 291 | 287 | 285 | 298 |
| 8. Ratio $\frac{\text{submersion}}{\text{lift}}$ | 1.08 | 1.13 | 1.135 | 1.10 | 1.085 | 1.19 |
| 9. Water lifted per minute (Imperial gallons). | 209.4 | 158.0 | 185.0 | 187.5 | 203.0 | 138.0 |
| 10. Water lifted per minute (cubic feet) | 33.51 | 25.30 | 29.61 | 30.0 | 32.48 | 22.1 |
| 11. Average revolutions per minute of air-compressor | 55.2 | 34.4 | 40.9 | 46.4 | 51.5 | 30.7 |
| 12. Volume of free air discharged per revolution (cubic feet). | 5 | 5 | 5 | 5 | 5 | 5 |
| 13. Average temperature of air suction | 57.4 | 71.5 | 64.9 | 62.9 | 75.3 | 79.6 |
| 14. Volume of air at 70° F. and 29.25 Bar. used per minute. | 283.0 | 172.0 | 206.0 | 235.0 | 255.5 | 151.0 |
| 15. Cubic feet of air per cubic feet of water | 8.45 | 6.80 | 6.96 | 7.83 | 7.85 | 6.86 |
| 16. Gauge pressure of air at well head | 145.8 | 131.0 | 136.0 | 138.0 | 142.5 | 131.0 |
| 17. Power equivalent to water raised | 16.70 | 12.3 | 14.35 | 15.35 | 16.10 | 10.40 |
| 18. I.H.P. of air-compressor | 57.7 | 33.6 | 40.8 | 47.5 | 53.4 | 30.0 |
| 19. Efficiency percentage of air-lift $\frac{\text{water HP.}}{\text{air HP.}}$ | 28.9 | 36.6 | 35.2 | 32.3 | 30.2 | 34.7 |

TESTS OF AIR-LIFT PUMPS.

Average velocities in feet per second.

| Tubing. | Test No. 1. | Test No. 2. |
|--|-------------|-------------|
| Rising mixture at bottom of 3-inch | 14.45 | 12.5 |
| " " " top of 3-inch | 25.80 | 19.4 |
| " " " bottom of $3\frac{1}{2}$ -inch | 18.95 | 14.25 |
| " " " top of $3\frac{1}{2}$ -inch | 31.60 | 26.40 |
| " " " bottom of 4-inch | 24.20 | 20.20 |
| " " " top of 4-inch | 42.50 | 40.50 |
| Air in air main | 40.5 | 23.3 |

| Tubing. | Test No. 3. | Test No. 4. | Test No. 5. | Test No. 6. |
|---|-------------|-------------|-------------|-------------|
| Rising mixture at bottom of 4-inch | 12.9 | 10.0 | 14.4 | 9.7 |
| " " " top of 4-inch | 22.5 | 16.8 | 26.0 | 15.5 |
| " " " bottom of $4\frac{1}{2}$ -inch | 17.8 | 13.2 | 20.6 | 12.2 |
| " " " top of $4\frac{1}{2}$ -inch | 26.7 | 18.5 | 30.0 | 17.4 |
| " " " bottom of $5\frac{3}{16}$ -inch | 20.1 | 13.9 | 22.5 | 13.1 |
| " " " top of $5\frac{3}{16}$ -inch | 30.2 | 20.2 | 34.0 | 19.2 |
| " " " bottom of $5\frac{5}{8}$ -inch | 25.6 | 17.2 | 28.9 | 16.3 |
| " " " top of $5\frac{5}{8}$ -inch | 36.2 | 22.6 | 39.4 | 22.1 |
| Air in air main | 38.2 | 28.4 | 47.5 | 27.6 |

| Tubing. | Test No. 7. | Test No. 8. | Test No. 9. | Test No. 10. | Test No. 11. | Test No. 12. |
|---|-------------|-------------|-------------|--------------|--------------|--------------|
| Rising mixture at bottom of 4-inch | 11.2 | 8.0 | 9.4 | 9.9 | 10.6 | 7.10 |
| " " " top of 4-inch | 18.2 | 12.6 | 14.7 | 16.0 | 17.1 | 11.1 |
| " " " bottom of $4\frac{1}{2}$ -inch | 14.4 | 10.0 | 11.6 | 12.7 | 13.6 | 8.8 |
| " " " top of $4\frac{1}{2}$ -inch | 22.2 | 14.8 | 17.3 | 19.0 | 20.4 | 12.9 |
| " " " bottom of $5\frac{3}{16}$ -inch | 6.7 | 11.1 | 12.0 | 13.7 | 15.4 | 9.8 |
| " " " top of $5\frac{3}{16}$ -inch | 36.0 | 22.5 | 26.9 | 30.0 | 32.9 | 19.7 |
| Air in air main | 40.5 | 27.0 | 31.5 | 35.4 | 37.5 | 23.8 |