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THE SULLIVAN AIR LIFT PUMPING SYSTEM.

1917

Sullivan Machinery Company

BULLETIN 71-C. CHICAGO, MARCH, 1917

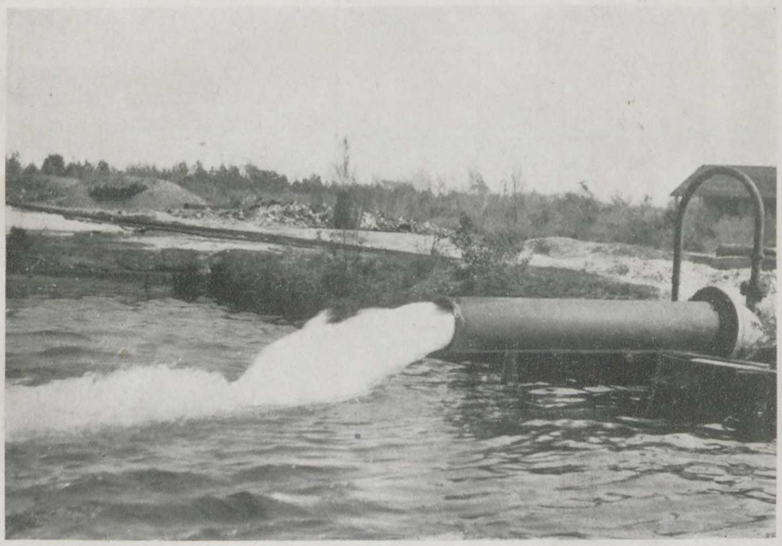
The Sullivan Air Lift Pumping System

Methods and Apparatus

PUMPING water from deep wells by means of compressed air has been practiced for many years, with varying degrees of success and efficiency. The purpose of this bulletin is to call attention to the important advantages of air lift pumping, when properly applied, and to show how Sullivan engineering and Sullivan equipment secure a high degree of effectiveness in this field.

The air lift department of this company embodies a separate corps of engineers, whose efforts are devoted solely to problems relating to pneumatic pumping, and whose experience in this field embraces nearly twenty-five years of manufacture and installation.

Those interested in securing water supply from deep wells are urged to submit their requirements and conditions to this department.

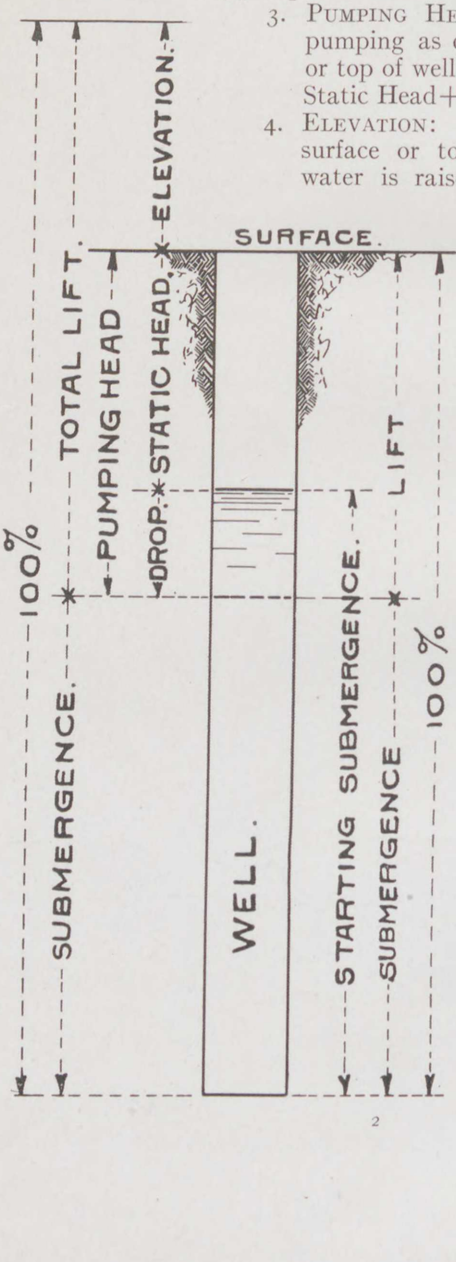


Well No. 3, Prairie Pebble Phosphate Company, Mulberry, Florida, pumped by the Air Lift, and flowing 4600 gallons per minute

Standard Terms Used in Air Lift Work

The sketch on this page illustrates the terms regularly used in referring to air lift pumping, and these terms and their application should be thoroughly understood as a preliminary to study of the subject. They are explained more fully below.

1. Static Head: Normal water level when not pumping, measured from surface or top of well casing.
2. Drop: Point to which the water level drops below the static head while being pumped.



3. Pumping Head: Level of water when pumping as compared to ground surface or top of well casing.
   Static Head + Drop = Pumping Head.
4. Elevation: Point above the ground surface or top of well casing to which water is raised.
5. Total Lift: Distance water is elevated, from level when pumping, to point of discharge, at an elevation, and includes:
   Elevation + Static Head + Drop = Total Lift.
6. Lift: Distance the water is elevated from level when pumping to point of discharge at surface, and includes:
   Static head + Drop = Lift (or pumping head).
7. Submergence: Distance below the pumping head at which the air picks up the water.
8. 100 per cent: The vertical distance the air travels with the water from point introduced to point discharged, and includes:
   Total Lift or Lift + Submergence = 100 per cent.
9. Starting Submergence: Distance below the static head at which the air picks up the water and includes:

Drop + Submergence = Starting Submergence.

Among the advantages of pneumatic pumping may be noted:

Advantages of the Air Lift

1. QUANTITY: More water can be secured from the same wells than by any other system.
2. QUALITY: Improvement in the character of the water, due to aeration, as to purity and solubility.
3. TEMPERATURE: Reduction in temperature, due to absorption of the heat in the water, by the air.
4. DURABILITY AND SIMPLICITY: There are no moving parts in the well.
5. The apparatus is always in order, and is not affected by mud, grit, floating sand or by long shut downs.
6. SUSTAINED EFFICIENCY.

These advantages may be explained more fully as follows:

Quantity

There is no question but that more water can be secured from a deep well with the air lift than with any other method of pumping, provided the conditions are proper for its use. This is especially true where it is desired to increase the yield from a flowing well; as, by mixing the ascending column of water with a small amount of air, the column is lightened and the head against the inflowing water reduced without in any way retarding the flow.

Quality

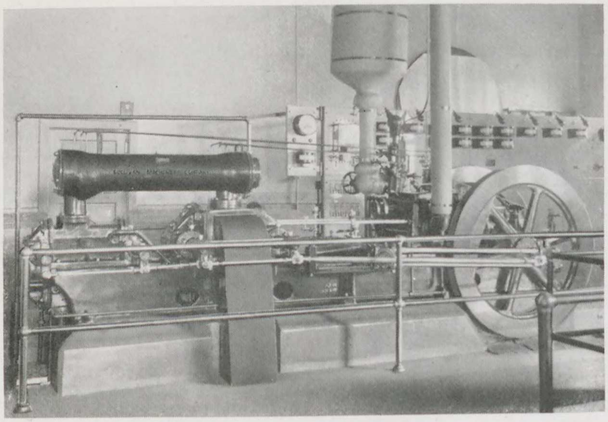
The deep wells of industrial and public ownership are found to be remarkably free from disease germs, as the casing, driven down to hard pan above the gravel formation, or into rock, shuts off contamination from the surface.

Gravel beds in or near a river may be made the source of a pure water supply by drilling wells and casing them low enough so that the water will pull down through the sand and gravel. The erosion of the river keeps the top of the infiltration bed clean.

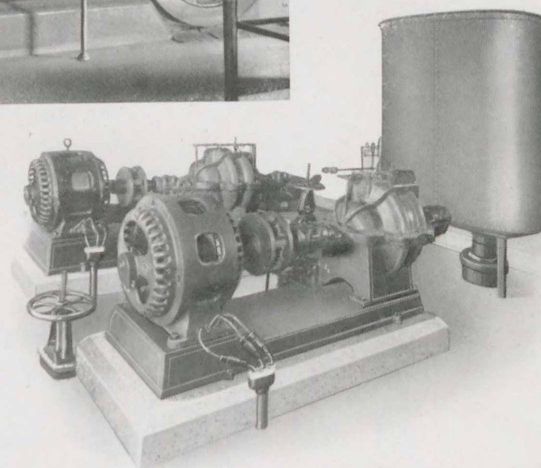
Aeration is acknowledged to be one of the principal methods for purifying water in filtration plants. If this occurs with air at low pressure, the perfect mixture of air and water in an air lift should and does cause much more complete purification.

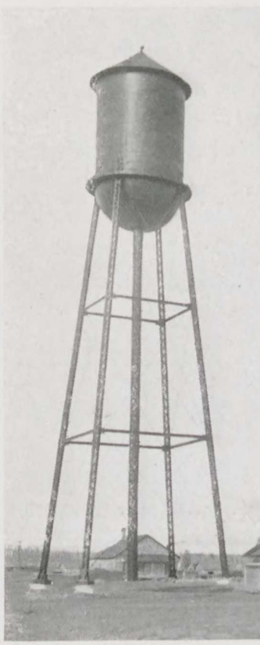
Free sulphur gas is encountered in many underground waters. This gas is almost entirely removed by the action of aeration in an air lift system, and the water from many sources of supply that is unfit for domestic use, on account of sulphur discoloration when pumped by a direct acting pump, is entirely freed from its odor and staining effects by the use of the air lift.

The aeration of water containing large quantities of iron causes a precipitation of this solid in the shape of a yellow mud, and while the freeing action is not as rapid as with sulphur, a large percentage of the iron can be eliminated by allowing time for settling.



Sullivan Air Lift Installation, Municipal Water Works, Buhl, Minnesota. The air Lift raises the water into a reservoir, from which it is forced into the stand-pipe or the mains by centrifugal pumps. The Compressor is a Sullivan " WB2," two-stage Machine

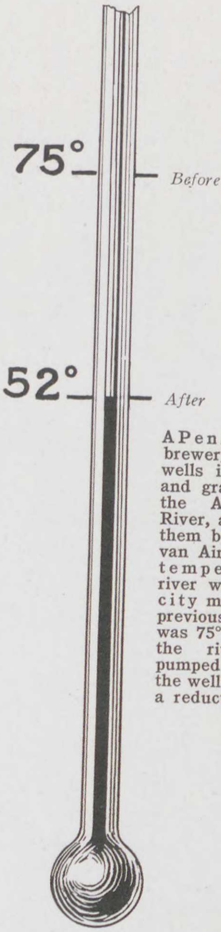




Most of the other solids contained in underground waters, if not thrown off altogether by aeration, are rendered easier of treatment. For instance, while practically as much scale will form in a boiler from water lifted with air as by other methods of pumping, yet the scale so formed will be more of the consistency of chalk than of the cement-like deposits of water not aerated.

Temperature

As heat is driven from air by compression, through re-expansion it must absorb heat from any material with which it may come in contact. The expansion of the air in the eduction pipe of the air lift absorbs heat from the water and lowers its temperature. If the water is naturally cold, the reduction will be slight, but if the temperature of the water is high, the reduction will be marked. This is a great advantage in water to be used for condensing purposes, as the reduction of a few degrees in the temperature of the water will make a great difference in the amount of coal used.



A Pennsylvania brewery sank three wells in the sand and gravel along the Allegheny River, and pumped them by the Sullivan Air Lift. The temperature of river water in the city mains (the previous source) was 75° F.; that of the river water pumped through the wells, 52° F., or a reduction of 23°.

Durability

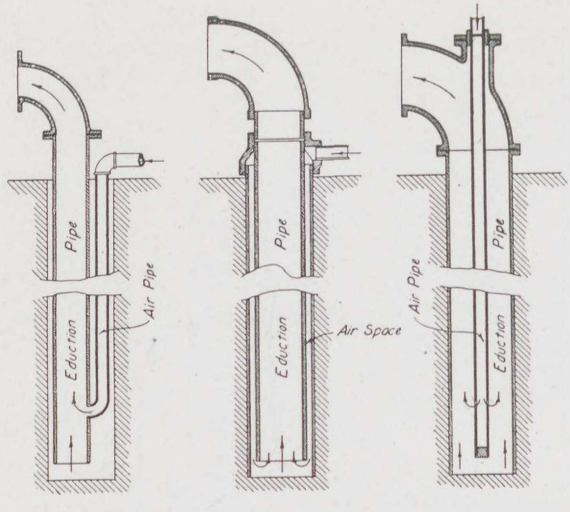
The air lift installation is more durable, and requires less attention and repairs than any other method of pumping. When once the well or wells are properly adjusted, the installation requires no further attention. The water never comes in contact with any moving parts and the machinery is in the power house directly under the eye of the engineer, avoiding all pulling of sucker rods, working barrels, et cetera.

Efficiency a New Idea

On account of the ease with which installations may be made, it is only in recent years that *efficiency* has been thought of in connection with air lift work.

As a general thing, manufacturers have sold compressors for this work upon the specifications of the customer, without making a thorough investigation of his requirements or advising him as to the best method of developing his supply. It has been so easy to turn the air loose in a well and get certain results, and there has been so little known of the laws governing this method of pumping, that haphazard installations have given it a reputation for inefficiency that is not warranted, and which a careful study of the subject will tend to remove.

When Dr. Pohlé worked out his theory of a submergence of sixty per cent and of alternate plugs of air and water, he secured an efficiency of from twenty to twenty-five per cent, which at that time was thought to be as high as could be depended upon. Since then, experiments



Sketches illustrating forms of " Straight " Air Lifts

and careful investigation as to methods of mixing air and water, proper proportioning of piping, et cetera, have almost doubled this figure; and increasingly satisfactory results are being secured by careful study of the laws governing this work, by the care in installation and the improved methods and equipment used by this company.

"Straight" Air Lift

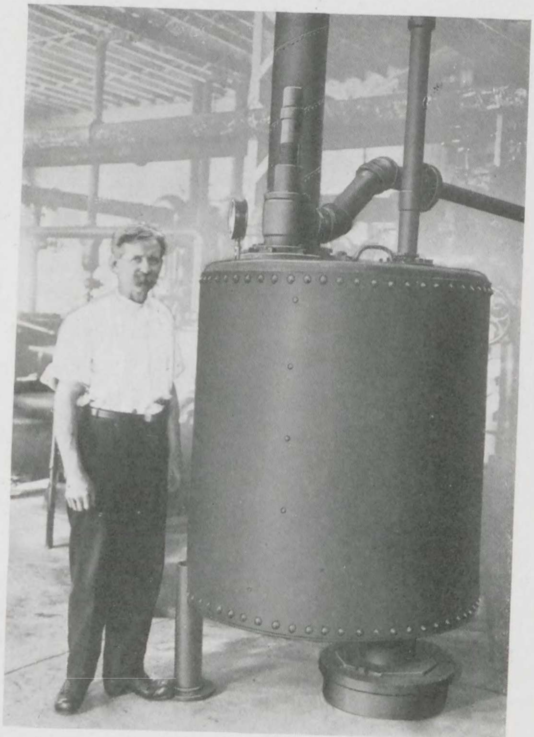
A discharge consisting of alternate plugs of air and water is a common result of most forms of air lift in which open-end piping is used, and which is generally termed the "straight air" system. Although at times, a more or less constant discharge is secured, this is considered one of the vagaries of the system and the cause is not thoroughly understood.

Types of "Straight" Air Lift

There are three general systems of "straight air" pumping.

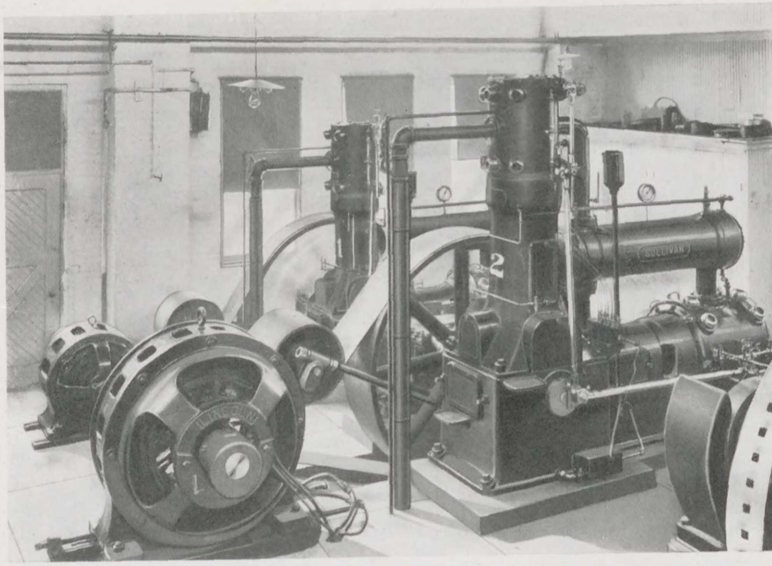
1. The Outside System. (See "A" in the cut above) in which the air is carried down outside of the eduction pipe, into which it is connected a short distance above the bottom.
2. The Central Pipe System. (Sketch "C") in which the air is carried down through a pipe suspended inside the eduction pipe and allowed to discharge into the water through an open end.
3. The Reservoir System. (Sketch "B") in which an eduction pipe is suspended in a casing, allowing the air to pass down between the two and mix with the water at the bottom of the eduction pipe.

In all of these systems the principle is much the same. Pressure is built up in the air passage until it is sufficient to overcome the head due to submergence, when a large bubble of air passes into the eduction pipe. This flow of air from the pipe temporarily reduces the air pressure, through wire drawing; so that the weight of water in the well outside of the eduction and air pipes, which is due to submergence, shuts the air off and a plug of water follows the plug of air up into the eduction pipe, until the compressor has had time to build up the air pressure and another plug of air breaks through. This combat of the air and water pressure becomes rhythmic in its action, forming a succession of air bubbles and water plugs in the eduction pipe, and is the cause of the "plugging" or unequal discharges found with this class of air lift installations.

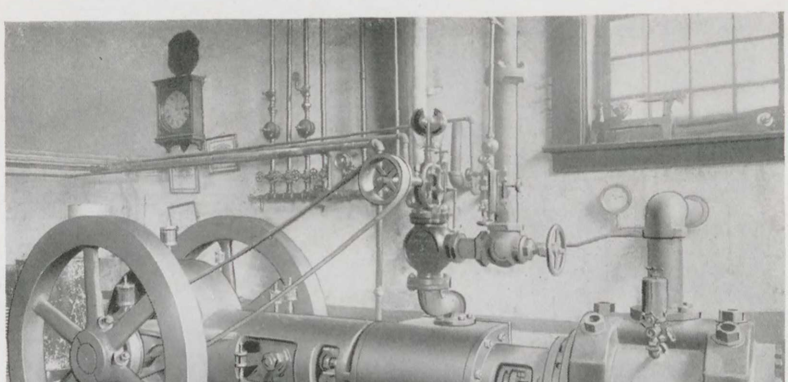


The theory of the air lift and the reason for submergence, are, that by mixing the water with air in the discharge, the water is made lighter, so that the pressure of the column of air and water in the bottom of the eduction pipe is less per square inch than that of the solid water

Maywood, Ill., City Water Works and one of the Sullivan Air Lift Boosters. There are two wells, pumped by Sullivan Foot Pieces, Boosters and Sullivan Angle Compound Air Compressors, see page 8. Flow, 1400 gallons per minute; lift, 250–300 feet. Elevated discharge from boosters, 20 feet.



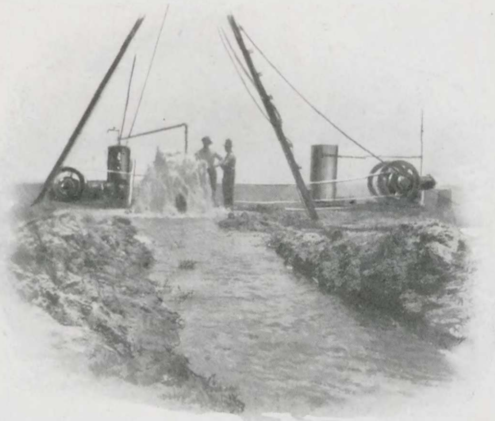
Two Sullivan "WJ3" Angle Compound Air Compressors with short belt, motor drive, in City Water Works, Maywood, Illinois. (See page 7) No. 1 Compressor has a capacity of 628 cubic feet of free air per minute; No. 2, 886 feet.



Sullivan "WA 4" Single-Stage, Steam Driven Air Compressor, pumping water at Fort Pitt Brewing Company's Plant, Sharpsburg, Pa.

outside, in the well, or in the rock, gravel or sand strata; and an upward flow is thus created.

The air lift should be a perfect expansion pump, but unfortunately there are other natural laws that take effect which prevent this in ordinary "straight air" installations.



An Open-Air Air Lift Plant, pumping water from a deep well for irrigation in New Mexico

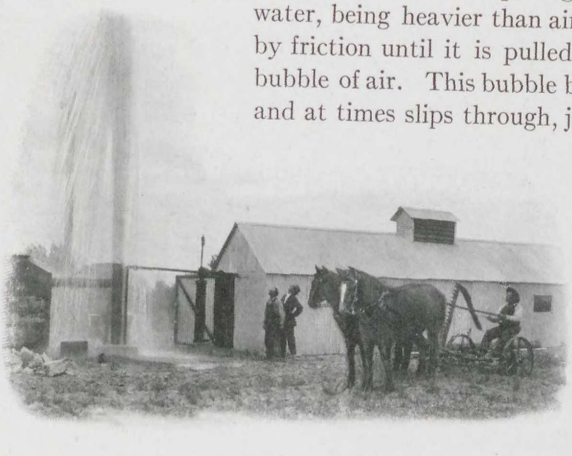
The following are some of the conditions responsible for low efficiency in open end pipe air lifts.

Reasons for Low Efficiency

1. The difference in pressure between the air and water where the former enters the eduction pipe is small, and the air flows into the water at a low velocity. In the open end pipe lift, the air must travel some distance towards the surface in the eduction line, before it can expand sufficiently to form a plug and carry the water with it. This means a loss in submergence.

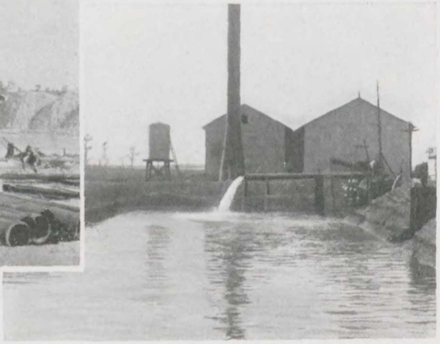
2. As the bubble of air travels towards the surface and the pressure above decreases, it must expand, and being confined in the pipe, can only do this in a vertical direction—resulting in increased velocity and friction and a greater displacement in the eduction pipe.

3. Owing to well known laws, the flow at the point of contact between a gas or liquid and the walls of the passage is retarded, and water, being heavier than air, is retarded more by friction until it is pulled back around the bubble of air. This bubble becomes elongated and at times slips through, joining the preceding bubble and leaving the water behind. This slippage represents loss of efficiency and is manifested by variations in the plugging discharge.



Flow from a Sullivan Air Lift installation in the California Oil Fields

Drilling No. 9 Well, 16-in. in diameter, for Prairie Pebble Phosphate Co., Southard Contracting Company, Contractors



Well No. 10, and Receiving Basin, Mulberry, Florida

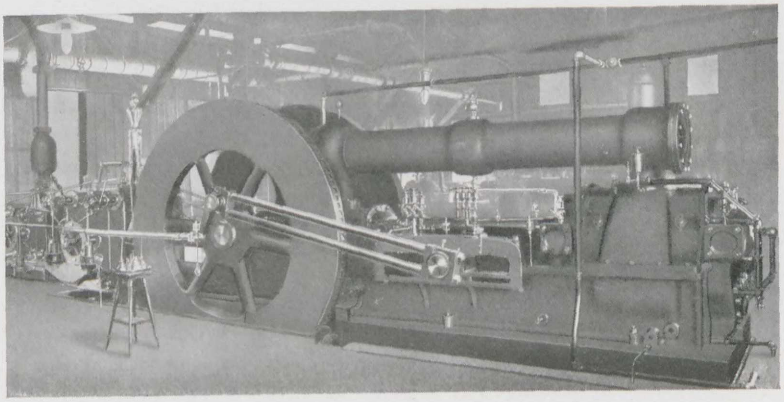
4. The air, like any confined gas, is always seeking a chance to escape, and any inequalities in the flow passage or abrupt changes in direction of flow, offer the opportunity sought, resulting in a still further slippage.

Requirements for Efficient Air Lift

These disadvantages can be overcome: and the best results are obtained by the following methods:

1. Means should be provided to secure a complete mixture of the air and water, forming an emulsion at the point at which the air is injected into the water. Then each particular small bubble of air will start its lifting effect at once.

2. A Venturi or throat should be provided just above the mixer. This will increase the velocity, give a jet effect at this point, insure



Sullivan 2450-foot Tandem Corliss Air Compressor used for Air Lift Pumping in Plant of Prairie Pebble Phosphate Company a more thorough mixture of the air and water, and exert a continuous upward pressure upon the ascending column.

3. The eduction pipe should be arranged to allow proper expansion of the air so far as possible and to prevent excessive velocity as the point of discharge is approached.

4. An absolutely smooth passage for the air and water is essential. Even the swirl caused by the recess in a coupling, occurring as often as it does in a long string of pipe, will cause a considerable loss.

5. Proper proportioning of air and water pipes for the work to be done is very important.

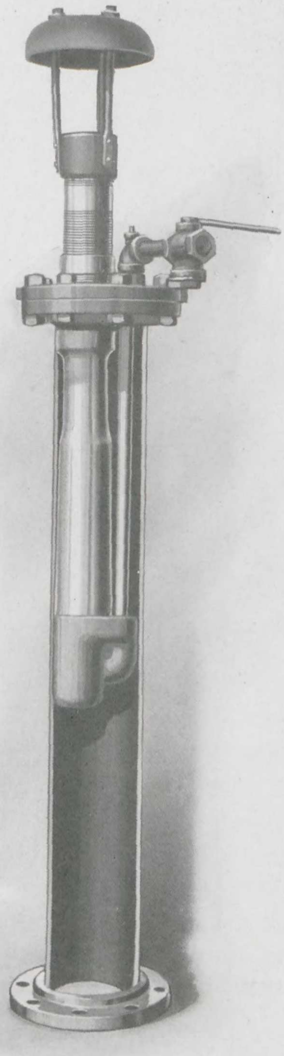
Detailed Description of the Sullivan Air Lift Pumps and Well Tops

The Sullivan Air Lift Pumps, described below and illustrated on pages 11 to 14, will be seen to embody exactly the principles expressed above; and the satisfaction they have given in actual practice under a wide range of working conditions, bears out the claim made for them, that they comprise the most efficient apparatus yet devised for raising water by air lift methods. Tables of dimensions and weights appear on page 27.

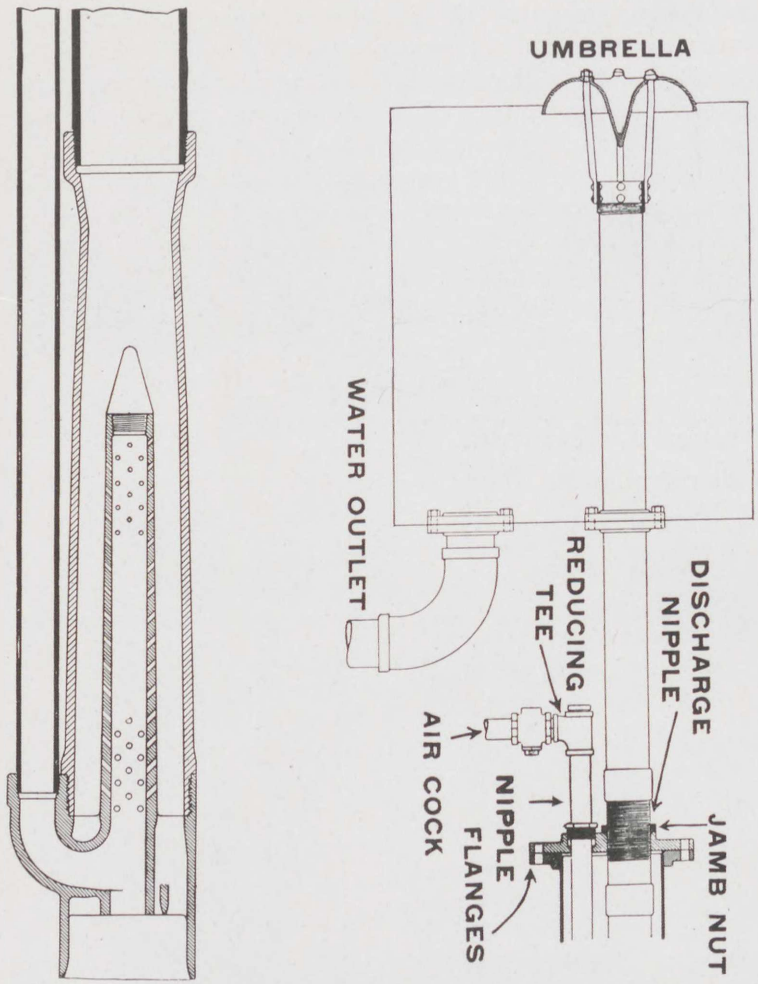
The Sullivan Standard Air Lift Foot Piece

(Outside Air Line)

The Sullivan Standard Pump or Foot Piece, illustrated on this page, is made



Sullivan Standard Foot Piece and Well Top, showing relative location of casing, flanges, et cetera



Sullivan Standard Air Lift Pump and Umbrella Well Top, with casing flanges and connections

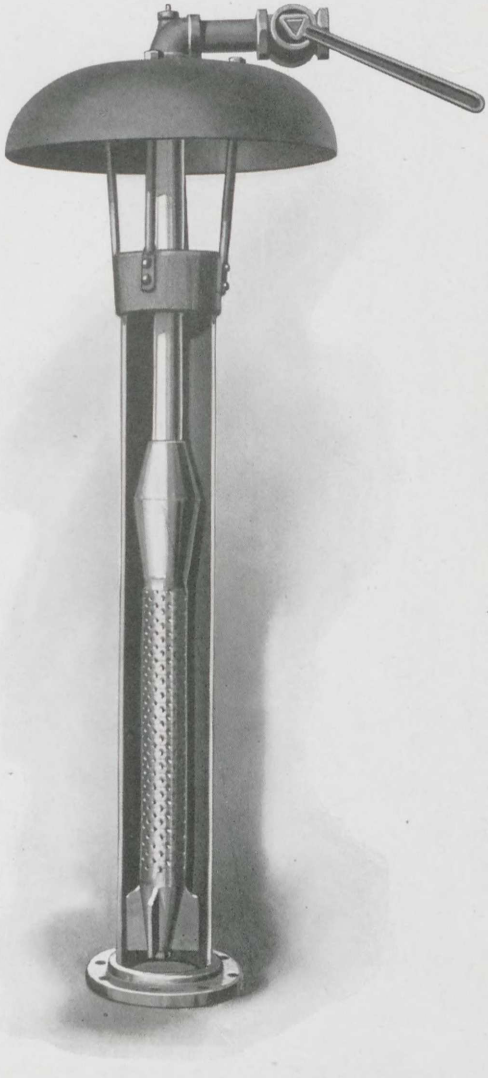
of bronze, with an air passage, leading from the outside, terminating in a perforated vertical tube below a Venturi or throat, so that the air is broken up into small jets, insuring a perfect mixture, or emulsion, of the air and water, and increasing the velocity in the throat to produce an ejector effect. By having a large number of holes in the mixing tube, a mixture containing more or less air, depending upon the lift, is made automatically, without change in the pump. An opening just below the mixing tube permits sand or scale, lodging in the tube when pumping is stopped, to drop through and not plug the perforations.

The Sullivan Standard Well Top

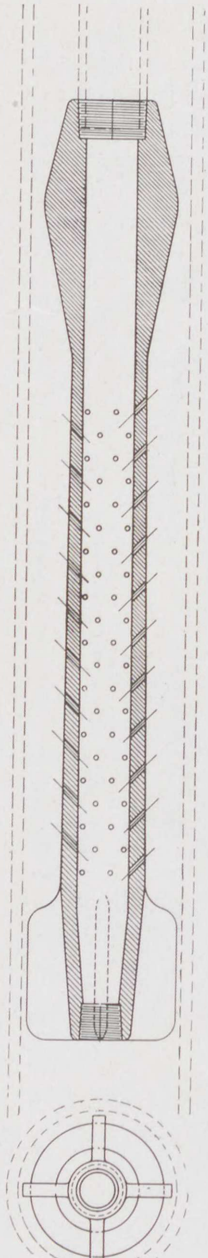
The Sullivan Standard Well Top (see pages 11 and 12) consists of flanges to seal the top of the casing, a water discharge nipple and umbrella separator, with jamb nut, and also with stuffing box for the air line, with air line nipple, back outlet elbow for gauge connection, and adjusting mine cock.

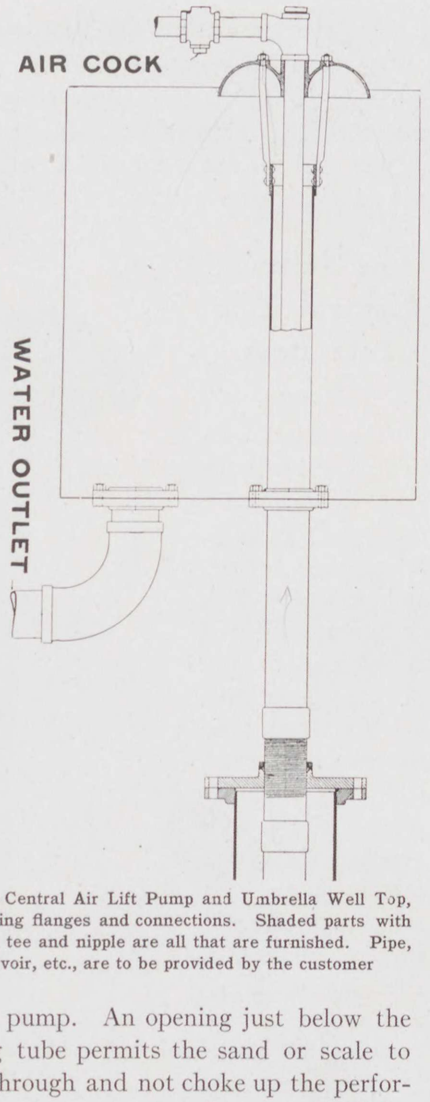
The Sullivan Central Air Lift Foot Piece

The Sullivan Central Pump or Foot Piece, illustrated on this page, is made of bronze, and consists of a perforated tube. It is suspended from the central air pipe, below a throat, and has wings to center it in the discharge pipe. The air is broken up into small jets by the perforations, insuring a perfect mixture, or emulsion, of the air and water, and increasing the velocity in the throat to produce an ejector effect. By having a large number of holes in the mixing tube, the mixture is automatically made to contain more or less air, depending upon the lift, without change



Sullivan Central Foot Piece and Umbrella Well Top; the flange shown at the foot of this cut and at the foot of the cut on page 11, is not a part of the equipment



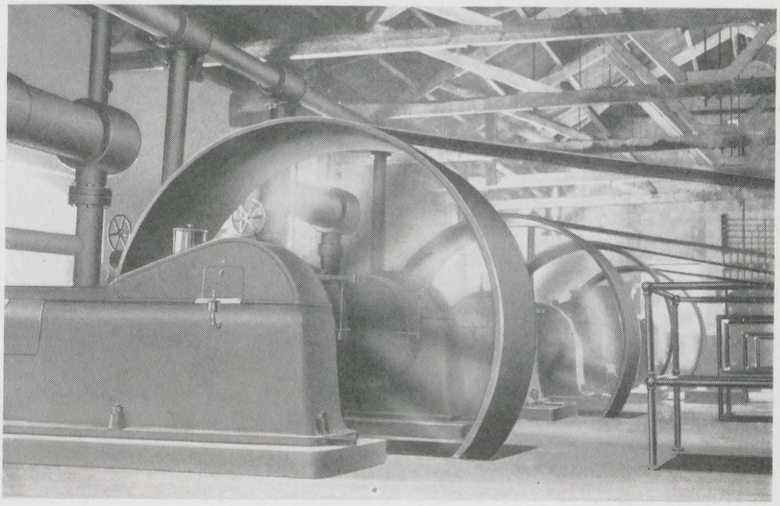


Sullivan Central Air Lift Pump and Umbrella Well Top, with casing flanges and connections. Shaded parts with air cock, tee and nipple are all that are furnished. Pipe, reservoir, etc., are to be provided by the customer

in the pump. An opening just below the mixing tube permits the sand or scale to drop through and not choke up the perforations when pumping is stopped. This foot piece, being suspended upon the central air line, can be raised or lowered without changing the discharge pipe.

The Sullivan Central Well Top

The well top for the central pump or foot piece, as shown here and also on page 13, consists of flanges to seal the top of the casing, a water discharge nipple with jamb nut, and an umbrella sepa-



Sullivan Belted Air Compressors operating Air Lifts for mill service at a well-known mine in Mexico

rator, having an opening in the top for suspending the air line; and is equipped with stuffing box, nipple, back outlet elbow for gauge connections and regulating mine cock.

NOTE: This head may also be made up with a back outlet elbow on the discharge for suspending the air line, when it is necessary to carry the discharge to an elevation.

Ratio of Lift to Submergence

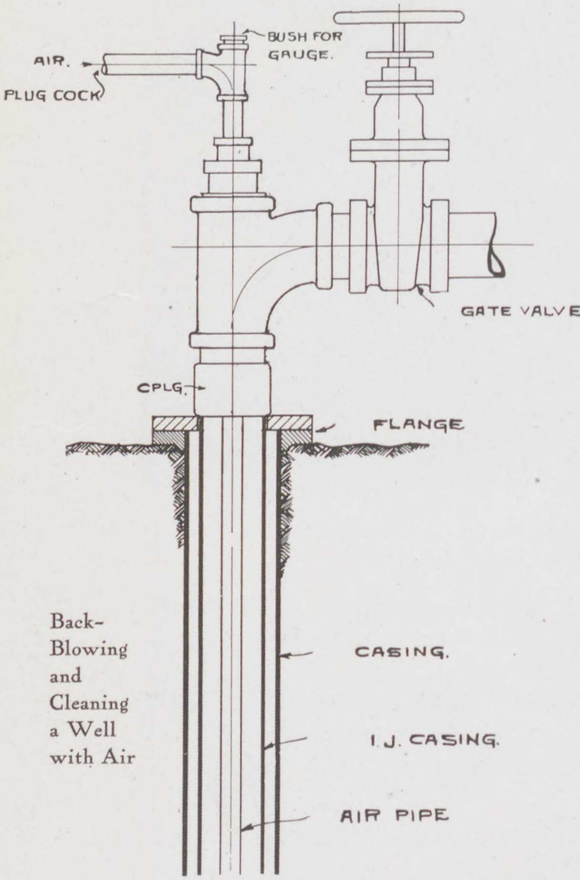
In actual practice, it has been found that the submergence may be varied with the lift, shorter lifts requiring a greater percentage of submergence. While there is no definite division line, the following proportion of submergence to lift will be found effective:

For lifts up to 50 feet	70 to 66 per cent submergence
50 to 100 feet	66 to 55 per cent submergence
100 to 200 feet	55 to 50 per cent submergence
200 to 300 feet	50 to 43 per cent submergence
300 to 400 feet	43 to 40 per cent submergence
400 to 500 feet	40 to 33 per cent submergence

Proportioning of Piping

It will be readily understood that the diameter of the water discharge or eduction pipe is of prime importance to secure the best efficiency, and must bear a relation not only to the amount of water to be handled, but also to the amount of air; so that for an equal amount of water the pipe size may vary with the lift and also with

Back-Blowing and Cleaning a Well with Air



Arrangement of piping a well for back-blowing

the percentage of submergence, as both factors change the amount of air. If the pipe is too large, then there is slippage of the air past the water, unless more air is used to keep up the velocity; or if too small a pipe is used, undue friction will increase the power needed.

Each separate well or group of wells is an engineering problem that should be carefully studied, and the most complete data obtainable should be furnished, so that a system can be designed to cover all points.

The standard practice of well drillers is to equip gravel and sand wells with a strainer, designed to shut out the sand from the working barrel of a deep well pump. In time, these strainers become clogged with sand and the flow into the well is thus reduced. By a system of *back-blowing*, the output from such wells can be permanently increased.

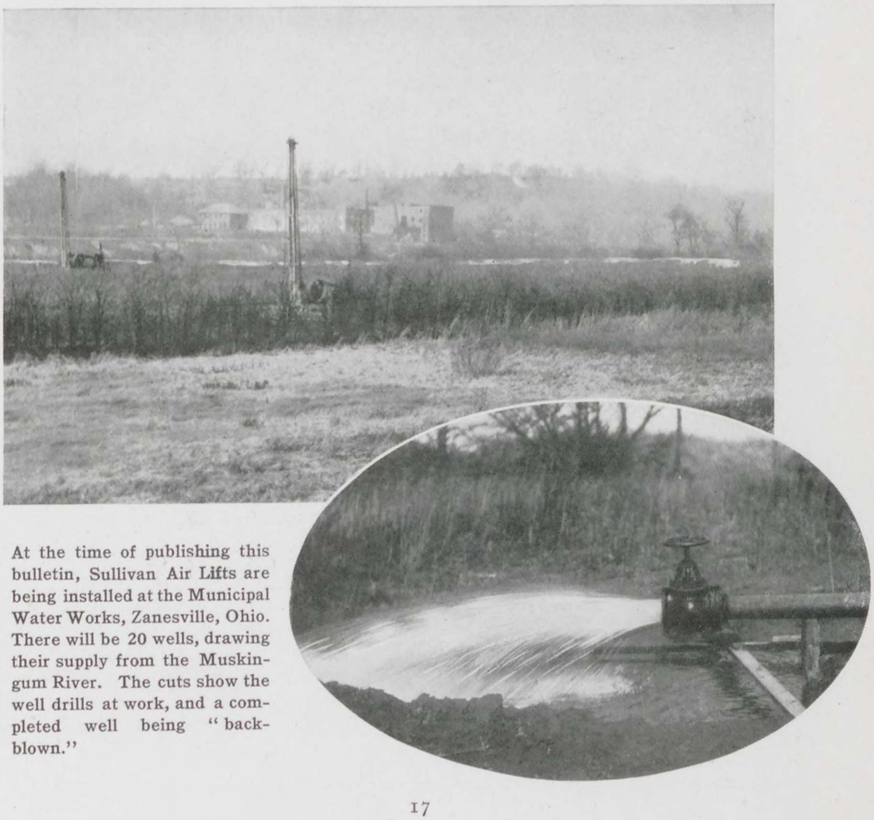
The correct strainer for wells of this class, pumped by the air lift, is a perforated screen with openings of a suitable size to admit the fine material into the well, from which it can be pumped, and to hold back the coarser particles, so as to form a natural gravel filter bed outside of the artificial one.

The force available for getting water into a well is the head, due to the difference between the static level in the water strata outside the well and the pumping level in the well, minus friction due to the strata and screen. Therefore, the more this friction can be reduced, the greater will be the flow, providing of course, that an abundance of water is available.

"Back-blowing" can be applied to all wells. The top of the well casing should be sealed; next, by closing the discharge pipe while the air lift is in operation, the air will be forced through the foot piece and will drive the water ahead of it out through the strainer and float the finer sand. Then, by opening the discharge, the flow will resume its course toward the surface and bring a portion of the floating sand with it. By a repetition of this operation and by increasing the back pressure if necessary, all of the fine sand immediately outside of the strainer will be drawn into the well and discharged at the surface, and the coarser gravel will be collected outside of the screen in such quantities as to shut off the sand and increase the flow into the well, without changing the piping in the well. This process may be repeated at any time, so that the screen and adjacent strata can be kept clear.

When wells are drilled in rock, the action of the drilling tool forces the cuttings back into the crevices in the rock. These may be loosened and pumped out of the well in the same manner.

In the case of wells in fine material and quicksand it is often possible to set a strainer in the sand and drill auxiliary holes alongside the well down to the top of the strainer. Then foreign gravel may be



At the time of publishing this bulletin, Sullivan Air Lifts are being installed at the Municipal Water Works, Zanesville, Ohio. There will be 20 wells, drawing their supply from the Muskingum River. The cuts show the well drills at work, and a completed well being "back-blown."

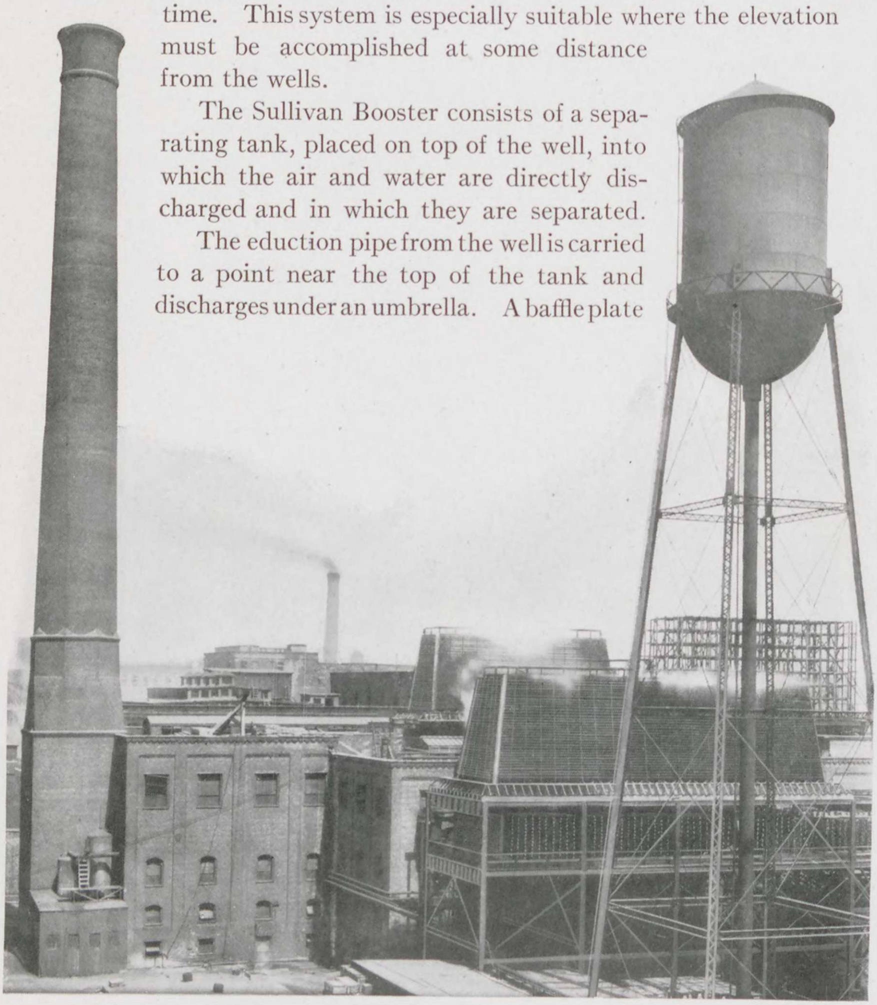
dropped down, which will roll in alongside of the screen and take the place of the sand pumped out—often increasing the yield four-fold, by affording, outside of the gravel bed, a larger area through which the water may leave the sand.

The Sullivan Booster System for Elevated Discharge

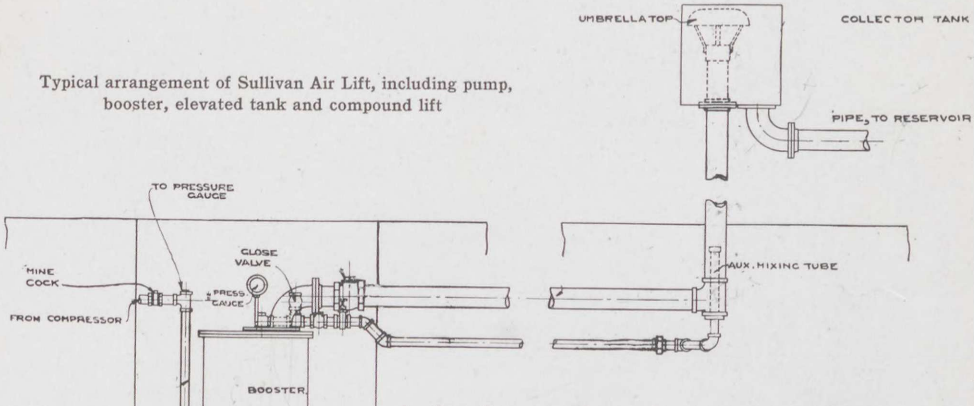
By means of the Sullivan "Booster" System (illustrated on pages 19 and following), the water may be lifted to an elevation above the surface by using the air employed in the air lift proper a second time. This system is especially suitable where the elevation must be accomplished at some distance from the wells.

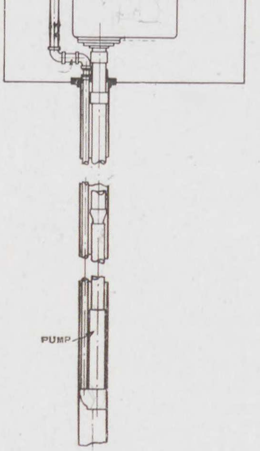
The Sullivan Booster consists of a separating tank, placed on top of the well, into which the air and water are directly discharged and in which they are separated.

The eduction pipe from the well is carried to a point near the top of the tank and discharges under an umbrella. A baffle plate



Power house and storage tank of Morris & Company, Union Stock Yards, Chicago





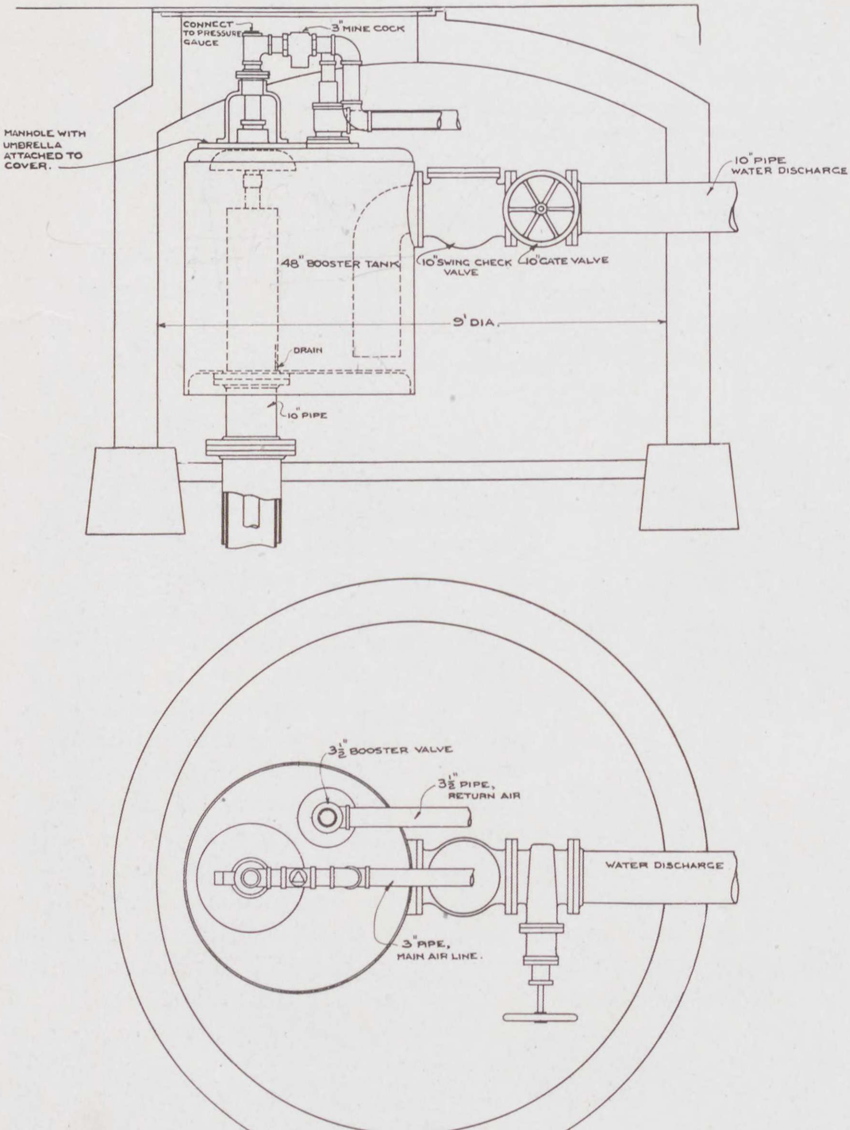
Typical arrangement of Sullivan Air Lift, including pump, booster, elevated tank and compound lift

is placed across the tank to prevent surging. The end of the discharge leading from the booster extends down from the top, or the side near the top, to within a short distance of the bottom, so that the pressure upon the surface of the water forces it directly into the discharge with the least amount of friction. Immediately over the discharge from the well, is constructed a manhole and a removable plate that carries the umbrella. With the standard pump, this plate can be removed and a temporary connection made to the well discharge for back-blowing and cleaning the well, without removing the booster, keeping it free from sand or drillings.

The Central Pump and air line, when this installation is used, are installed through this opening after the booster is in place and suspended in the eduction pipe by means of the manhole plate, which affords an easy means of raising or lowering the pump without disturbing any other part of the equipment.

The vent valve is a circular slide valve made of bronze and operated by the water in the booster, through the use of a diving bell, non-leaking float and rod; and is adjusted from the outside by means of a spring under a cap in order to maintain the necessary pressure to force the water to the required head.

The principle involved in the operation of the booster is as follows: The velocity of water and air in an air lift is always greatest as it nears the point of discharge. This is demonstrated by the force of the discharge into the atmosphere. By discharging into a closed tank, the kinetic energy of the column of water and air under arrested



Elevation and Plan Views of Sullivan Booster installation in Concrete Chamber, with Piping Connections

motion is used to recompress the air and a certain amount of the power originally expended is returned.

Compressed air under ordinary air lift conditions is wasteful if used to force water horizontally, as the air, being lighter than water, goes to the top of the pipe and fails to bring the water with it.

With the use of a booster, the air does not follow the water but is held in the tank, building up pressure to force the solid body of water through the horizontal and vertical lines.

The booster is usually set in a pit below the ground level and enclosed in a brick or concrete dry well, but may be located at any convenient point, as provision is made for automatic drainage back into the well when pumping is stopped.

It will readily be seen, therefore, that with this arrangement, any number of wells may discharge into a common delivery pipe. This constitutes a great advantage when the elevation to be reached is at some distance from a well or group of wells. A check valve should be installed in the discharge line immediately outside of the booster.

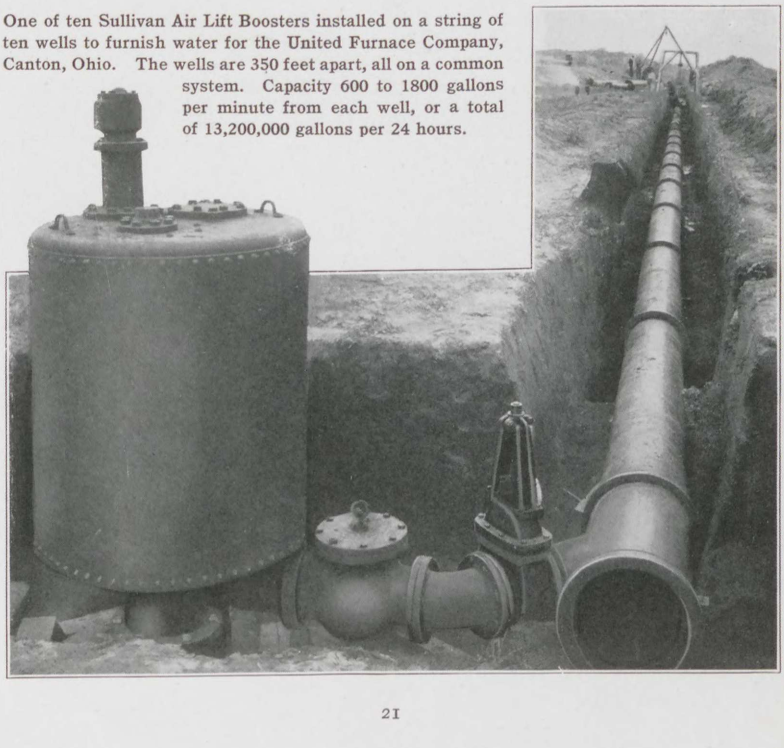
The engineer operates the complete plant from the compressor, no change being required after the adjustment has once been made. Varying the speed of the compressor secures a greater or less amount of water.

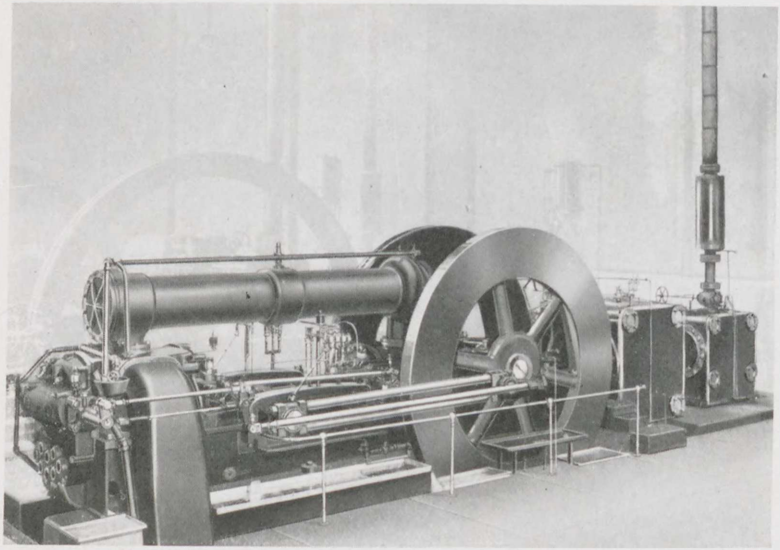
There are three ways in which the air escaping from the booster may be employed.

1. It may be allowed to escape through the vent valve to the atmosphere.

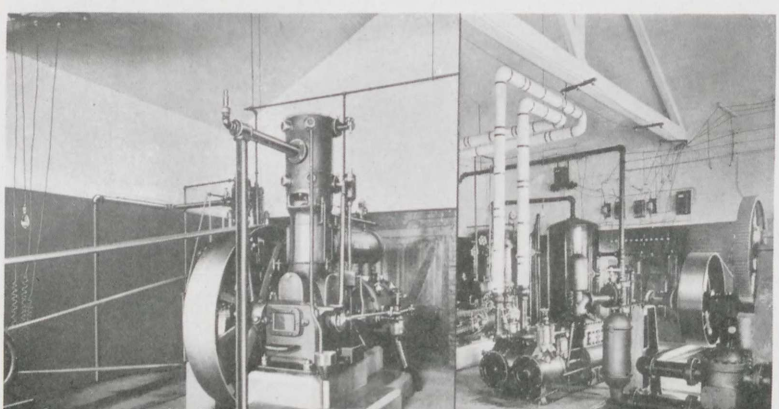
2. It may be returned to the intake of the compressor. The

One of ten Sullivan Air Lift Boosters installed on a string of ten wells to furnish water for the United Furnace Company, Canton, Ohio. The wells are 350 feet apart, all on a common system. Capacity 600 to 1800 gallons per minute from each well, or a total of 13,200,000 gallons per 24 hours.

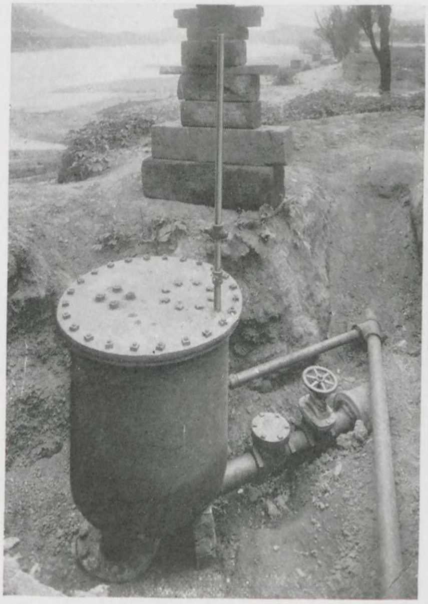




Sullivan " WC " Tandem Corliss Compound Two Stage Air Compressor used for Air Lift pumping at packing house of Morris & Company, Chicago. (See page 18.) This Compressor has a rated capacity of 2450 cubic feet of free air per minute



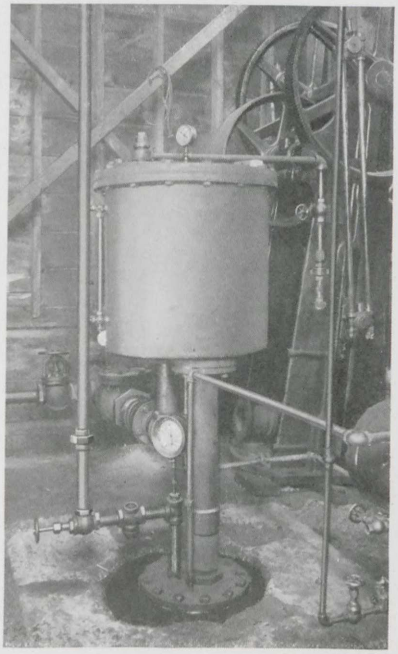
Sullivan " WJ3," Angle-Compound Air Compressor in the Municipal Water Works at Dickinson, North Dakota



Sullivan Booster on one of three wells at Sharpsburg, Pa. Horizontal discharge line 1350 ft. long; final elevation, 25 ft.

fact that this return air is at a lower temperature than atmospheric air and at a slightly greater pressure, secures a decided gain in volumetric efficiency.

3. Where the water is discharged at an elevation above the surface, either near or at some distance from the well or wells, a greater gain is secured by discharging the air from the booster or boosters through a mixing tube in the base of the riser pipe, lightening the water discharge column and reducing the head.

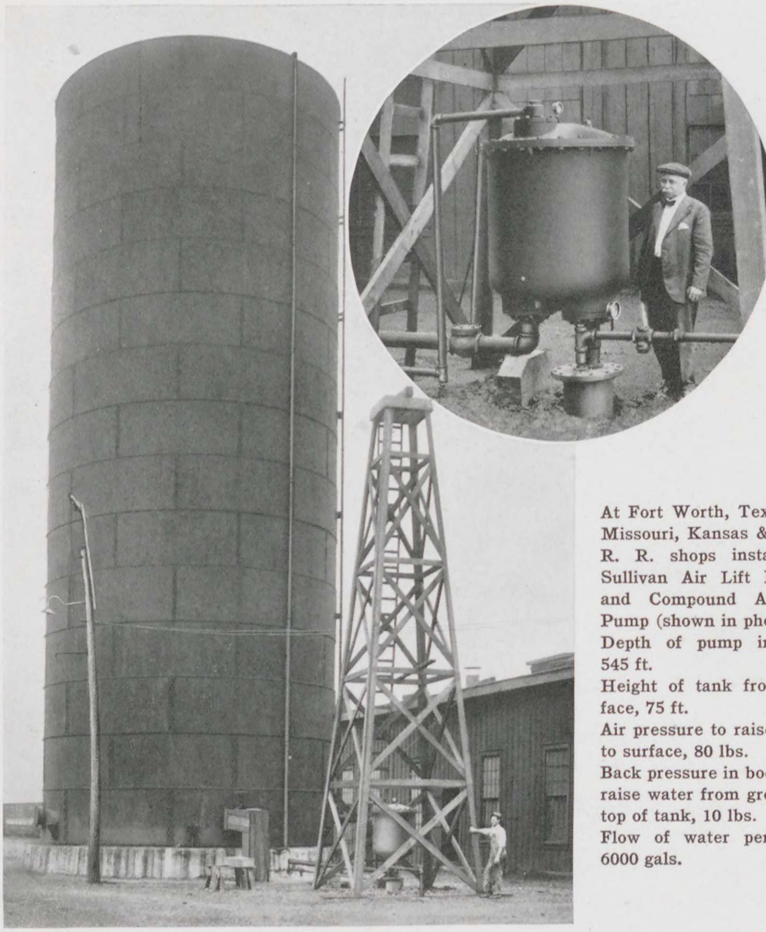


Sullivan Booster on a well at Rubsam and Hormann Brewing Co., Staten Island. N.Y.; discarded deep well pump in background. This plant gives 55 gallons per minute instead of 30 gallons, (capacity of old pump) and requires only 13¾ H. P. as compared with 20. At the same plant, a Sullivan Air Lift Booster was substituted for an Air Lift of another system. The flow in gallons per minute was increased from 50 to 100, with 20 per cent less air.

The accompanying illustrations and notes show some of the installations of this character that have been made by this company. More detailed reports on these and many other similar booster plants are also available.

The Air Lift for Acids and Chemicals

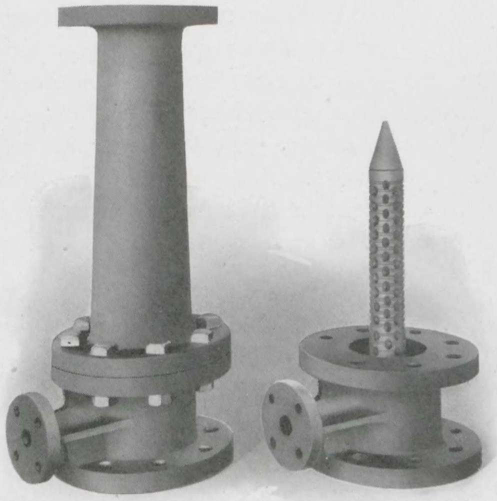
The air lift is admirably adapted for pumping acids, slimes, pulps and other solutions containing chemicals which rapidly eat out the working parts of mechanical pumps. For service in connection with Pachuca tanks, flotation and other wet ore dressing systems, the air lift is very desirable. Advantages secured in handling such liquids by this method, as embodied in Sullivan practice, include



At Fort Worth, Texas, the Missouri, Kansas & Texas R. R. shops installed a Sullivan Air Lift Booster and Compound Air Lift Pump (shown in photo).
Depth of pump in well, 545 ft.
Height of tank from surface, 75 ft.
Air pressure to raise water to surface, 80 lbs.
Back pressure in booster to raise water from ground to top of tank, 10 lbs.
Flow of water per hour, 6000 gals.

(1) length of service, (2) absence of repairs, (3) cheapness of renewals, (4) variation in capacity; to which may be added (5) high efficiency on lifts of any height and of varying submergence, (6) solutions carried horizontally as well as vertically, (7) any number of lifts handled from a central power plant, (8) simplicity and sustained effectiveness, (9) apparatus furnished in any materials necessary to resist chemical action.

This company has installed numerous pumps for service such as is described above, made of various acid-resistant materials, such as hard or soft lead, cast iron or steel, bronze, rubber, etc. Sullivan Acid Pumps are designed to work satisfactorily under low submergence. The following data should be furnished in order to permit estimates to be submitted.



Sullivan Air Lift Acid Pump, supplied as desired in cast iron or cast steel

1. Temperature of liquid.

2. Specific gravity of liquid.

3. Material of which the pump is to be made.

4. Kind of acid to be pumped.

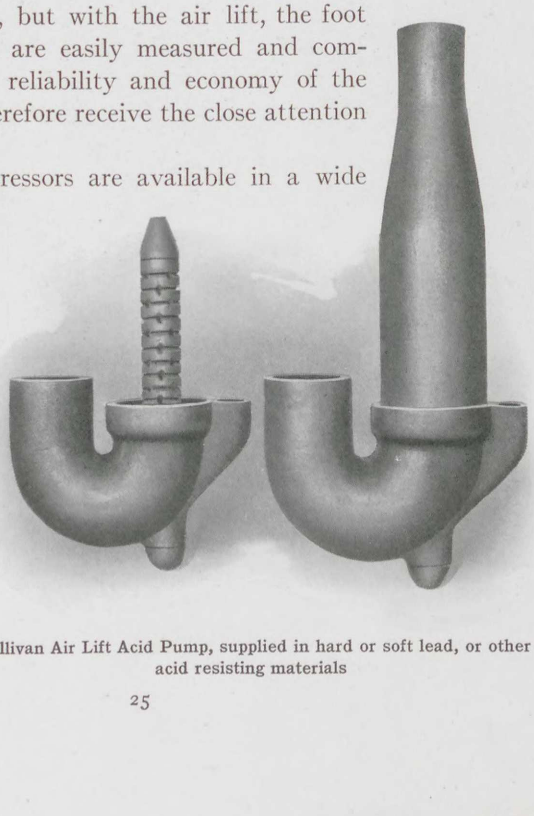
5. Lift in feet.

6. Submergence in feet.

7. Pounds to be pumped per minute.

The question of an air compressor for air lift work is one that should receive careful attention, because the efficiency of the machine, under this class of work, is immediately demonstrated. When compressed air is used for manufacturing purposes, it is frequently difficult to check up the amount of work done, but with the air lift, the foot pounds of work done are easily measured and comparisons made. The reliability and economy of the compressor should therefore receive the close attention of the engineer.

Sullivan air compressors are available in a wide range of styles, pressures, capacities and for operation by steam, belt, electric motor, et cetera. Some of these styles are shown in the accompanying illustrations. Bulletins on Sullivan air compressors will be furnished on request.

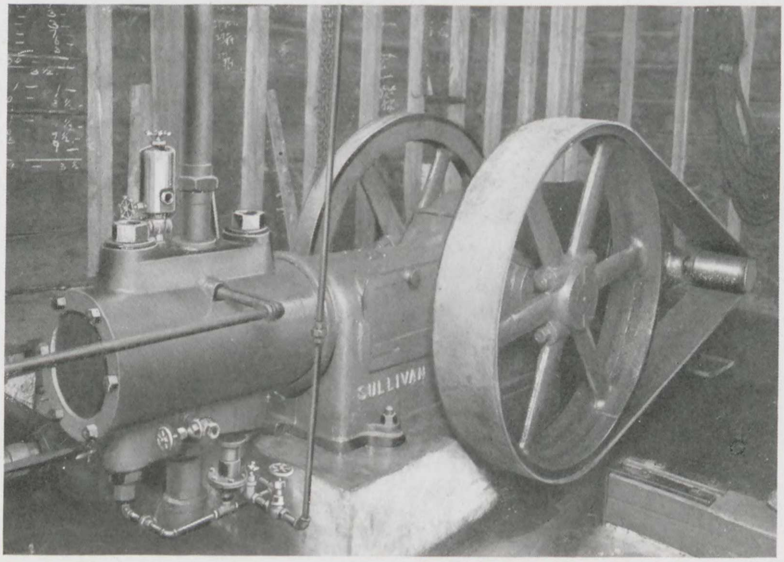


Sullivan Air Lift Acid Pump, supplied in hard or soft lead, or other acid resisting materials

Separating Head for Acid Pumping

In the latter pages of this bulletin will be found tables of pipe sizes and specifications, air compressor data and other reference material, that are required in air lift calculations. It is hoped that their publication here may prove of assistance to intending purchasers.

NOTE. This company reserves the right to alter its machines and apparatus, and to furnish them, when so altered, without reference to the illustrations or reading matter contained in the present bulletin.



Sullivan "WG-3" Single Stage, Belted Air Compressor operating the Sullivan Air Lift Booster shown on page 23. This plant has since been enlarged by the addition of a Sullivan Angle-Compound Compressor of 445 feet capacity.

Sullivan Standard Air Lift Pumps

General Code Word, *Obarma*

Size Discharge, Inches	Approx. Capacity Gallons per Min.	Diameter Well Head, Inches	Approx. Shipping Weight, Pounds	Code Word for Complete Pump
1	5	4	65	*Obermans*
1¼	10	4	75	*Obarmare*
1½	20	4	85	*Obarmati*
2	50	6	125	*Obarmes*
2½	75	6	135	*Obarment*
3	100–150	6	150	*Obarmetur*
3½	150–200	8	175	*Obarmo*
4	200–300	8	185	*Obarmori*
4½	300–350	8	200	*Obba*
5	350–500	10	250	*Obbarum*
6	500–800	10	300	*Obbis*
7	800–1500	12	350	*Obdidi*

High Lift Pachuca Tanks at a Mexican Mine
Solutions handled by the Air Lift.

Sullivan Central Air Lift Pumps

General Code Word, *Obdormio*

Size Discharge, Inches	Approx. Capacity Gallons per Min.	Diameter Well Head, Inches	Approx. Shipping Weight, Pounds	Code Word for Complete Pump
1	Capacity determined by size of air line and effective discharge area.	2	25	*Obduca*
1¼		2	30	*Obducant*
1½		3	35	*Obducatur*
2		3	40	*Obducer*
2½		4	45	*Obducetis*
3		4	50	*Obducis*
3½		5	55	*Obducitus*
4		6	60	*Obduxit*
4½		6	65	*Obediens*
5		7	75	*Obedietur*
6		8	100	*Obedio*
7		9	125	*Obedivi*
8		10	150	*Obedivist*
9		11	175	*Obeor*
10		12	200	*Obequito*
11		13	225	*Obesitae*
12		14	250	*Obesae*
13		16	275	*Obesis*
14		18	300	*Obeso*
15		18	325	*Obesum*

Sullivan Boosters

General Code Word, *Oblecta*

Diameter, Inches	Height, Inches	Capacity Gallons, per Minute	Approx. Shipping Weight, Pounds	Code Word for Booster Complete
24	24	50–100	800	*Oblidere*
30	30	100–200	1500	*Oblidetus*
36	36	200–400	2000	*Oblidis*
42	42	400–600	1500	*Oblidunt*
48	48	600–800	2000	*Oblisi*

Boosters will be made of cast iron up to the 36-inch size; larger, of boiler plate, riveted.

Inlet and discharge flanges are furnished to suit specifications.

Equipment.—The prices of complete pumps include the Foot Piece, Companion Flange, Made-up Flange, Bolts and Gasket, Umbrella Separator or Long Sweep Elbow, Nipples, Gauge Connection and Mine-Cock Adjusting Valve. With the Standard and Central Pumps are also furnished a Long Threaded Discharge Nipple with Jamb Nut and a Back Outlet Elbow. With the Standard Pump only, one Air Line Stuffing Box. When well casing is used as discharge with the Central pump, no flanges will be supplied.

Pipe Tables, for Reference *

Standard Pipe—Black and Galvanized

All Weights and Dimensions are Nominal

Size	Diameters		Thickness	Weight per foot		Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings		Diameter	Length	Weight
⅛	.405	.269	.068	.244	.245	27	.562	⅞	.029
¼	.540	.364	.088	.424	.425	18	.685	1	.043
⅜	.675	.493	.091	.567	.568	18	.848	1⅛	.070
½	.840	.622	.109	.850	.852	14	1.024	1⅜	.116
¾	1.050	.824	.113	1 130	1.134	14	1.281	1⅝	.209
1	1.315	1.049	.133	1.678	1.684	11½	1.576	1⅞	.343
1¼	1.660	1.380	.140	2.272	2.281	11½	1.950	2⅛	.535
1½	1.900	1.610	.145	2 717	2.731	11½	2 218	2⅜	.743
2	2.375	2.067	.154	3.652	3.678	11½	2.760	2⅝	1.208
2½	2.875	2.469	.203	5.793	5.819	8	3.276	2⅞	1.720
3	3.500	3.068	.216	7.575	7.616	8	3.948	3⅛	2.498
3½	4.000	3.548	.226	9.109	9.202	8	4.591	3⅝	4 241
4	4.500	4.026	.237	10.790	10.889	8	5.091	3⅝	4.741
4½	5.000	4.506	.247	12.538	12.642	8	5.591	3⅝	5.241
5	5.563	5.047	.258	14.617	14.810	8	6.296	4⅛	8.091
6	6.625	6.065	.280	18.974	19.185	8	7.358	4⅛	9.554
7	7.625	7 023	.301	23.544	23 769	8	8.358	4⅛	10.932
8	8.625	8.071	.277	24.696	25.000	8	9.358	4⅝	13.905
8	8.625	7 981	.322	28.554	28 809	8	9.358	4⅝	13.905
9	9.625	8.941	.342	33 907	34.188	8	10.358	5⅛	17.236
10	10.750	10.192	.279	31 201	32.000	8	11.721	6⅛	29.877
10	10.750	10.136	.307	34.240	35.000	8	11.721	6⅛	29.877
10	10.750	10.020	.365	40.483	41.132	8	11.721	6⅛	29.877
11	11.750	11.000	.375	45.557	46.247	8	12.721	6⅛	32.550
12	12.750	12.090	.330	43.773	45.000	8	13.958	6⅛	43.098
12	12.750	12.000	.375	49.562	50.706	8	13.958	6⅛	43.098
13	14.000	13.250	.375	54 568	55.824	8	15.208	6⅛	47.152
14	15.000	14.250	.375	58 573	60.375	8	16 446	6⅛	59.493
15	16.000	15.250	.375	62.579	64 500	8	17 446	6⅛	63.294

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise ordered.

Taper of threads is ¾ inch diameter per foot length for all sizes.

The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

On sizes made in more than one weight, weight desired must be specified.

Drive Pipe

All Weights and Dimensions are Nominal

Size	Diameters		Thickness	Weight per foot		Threads per inch	Couplings		
	External	Internal		Plain ends	Threads and couplings		Diameter	Length	Weight
2	2.375	2.067	.154	3 652	3.730	11½	2.923	3⅝	2.380
2½	2.875	2.469	.203	5 793	5.906	8	3.486	4⅛	3.748
3	3.500	3 068	.216	7.575	7.705	8	4.111	4⅛	4.493
3½	4.000	3 548	.226	9.109	9.294	8	4.723	4⅛	5.973
4	4.500	4.026	.237	10 790	10.995	8	5.223	4⅛	6 740
4½	5.000	4.506	.247	12 538	12.758	8	5.723	4⅛	7.439
5	5.563	5.047	.258	14 617	14.989	8	6.410	5⅛	11.871
6	6.625	6.065	.280	18.974	19 408	8	7.473	5⅛	13.956
7	7 625	7.023	.301	23.544	24.021	8	8.474	5⅛	15.955
8	8 625	8 071	.277	24 696	25.495	8	9.588	6⅛	24.343
8	8.625	7 981	.322	28.554	29.303	8	9.588	6⅛	24.343
8	8 625	7 917	.354	31 270	32.334	8	9.882	6⅛	31.320
9	9 625	8.941	.342	33 907	34.711	8	10.588	6⅛	27.035
10	10 750	10.192	.279	31.201	32 631	8	11 950	6⅝	40.108
10	10.750	10.136	.307	34.240	35 628	8	11.950	6⅝	40.108
10	10 750	10.020	.365	40.483	41.785	8	11.950	6⅝	40 108
11	11.750	11.000	.375	45.557	46 953	8	12 950	6⅝	43.664
12	12.750	12.090	.330	43.773	45.358	8	13.950	6⅝	47.220
12	12.750	12.000	.375	49.562	51 067	8	13 950	6⅝	47.220
13	14.000	13.250	375	54.568	56 849	8	15 438	7⅛	66.024
14	15 000	14.250	375	58 573	61.005	8	16.438	7⅛	70 533
15	16 000	15 250	.375	62.579	65 161	8	17.438	7⅛	75 043
17 O.D.	17 000	16.214	393	69 704	73.000	8	18.675	7⅛	91.746
18 O.D.	18 000	17 182	.409	76 840	81 000	8	19.913	7⅛	109 669
20 O.D.	20 000	19 182	409	85 577	90 000	8	21.913	7⅛	121.298

The permissible variation in weight is 5 per cent above and 5 per cent below.

Furnished with threads and couplings and in random lengths unless otherwise ordered.

Taper of threads is ¾ inch from 2 inches to 5 inches, and 3/16 inch from 6 inches to 20 inches.

The weight per foot of pipe with threads and couplings is based on a length of 20 feet, including the coupling, but shipping lengths of small sizes will usually average less than 20 feet.

All weights given in pounds. All dimensions given in inches.

On sizes made in more than one weight, weight desired must be specified.

*(From Book of Standards, National Tube Co.)

Pipe Tables, (Continued)

Inserted Joint Casing*

All Weights and Dimensions are Nominal

Size	Diameters		Thickness	Weight per foot plain ends	Threads per inch	Joint	
	External	Internal				Length of Joint —"L"	Diameter of joint —"D"
2	2.250	2.050	.100	2.296	14	.967	2.340
2¼	2.500	2.284	.108	2.759	14	.992	2.606
2½	2.750	2.524	.113	3.182	14	1.017	2.866
2¾	3.000	2.768	.116	3.572	14	1.042	3.122
3	3.250	3.010	.120	4.011	14	1.067	3.380
3¼	3.500	3.250	.125	4.505	14	1.092	3.640
3½	3.750	3.492	.129	4.988	14	1.117	3.898
3¾	4.000	3.732	.134	5.532	14	1.142	4.158
4	4.250	3.974	.138	6.060	14	1.167	4.416
4¼	4.500	4.216	.142	6.609	14	1.192	4 674
4½	4.750	4.460	.145	7.131	14	1.217	4.930
4¾	5.000	4.696	.152	7.870	14	1.242	5.194
5	5.250	4.944	.153	8.328	14	1.267	5.446
5³⁄₁₆	5.500	5.192	.154	8.792	14	1.292	5.698
5⅝	6.000	5.672	.164	10.222	14	1.342	6.218
5⅝	6.000	5.620	.190	11.789	11½	1.373	6.246
6¼	6.625	6.287	.169	11.652	14	1.405	6.853
6⅝	7.000	6.652	.174	12.685	14	1.442	7.238
7¼	7.625	7.263	.181	14.390	14	1.505	7.877
7⅝	8.000	7.628	.186	15.522	11½	1.573	8.238
8¼	8.625	8 249	.188	16.940	11½	1.636	8.867
8⅝	9.000	8.608	.196	18.429	11½	1.673	9.258
9⅝	10.000	9.582	.209	21.855	11½	1.773	10.284
10⅝	11.000	10.552	.224	25.780	11½	1.873	11.314
11⅝	12.000	11.514	.243	30.512	11½	1.973	12.352
12½	13.000	12.482	.259	35.243	11½	2.073	13.384
13½	14.000	13.448	.276	40.454	11½	2.173	14.418
14½	15 000	14.418	.291	45.714	11½	2.273	15.448
15½	16 000	15.396	.302	50 632	11½	2.373	16.470

The permissible variation in weight is 5 per cent above and 5 per cent below.
Furnished in random lengths unless otherwise ordered.
Regular taper of threads is ⅜ inch diameter per foot length for all sizes, but will furnish ¼ inch, ½ inch, or ⅝ inch taper if so ordered.
All weights given in pounds. All dimensions given in inches.
On sizes made in more than one weight or thread, weight and number of threads desired must be specified.
Thickness of walls make it impracticable to cut threads of coarser pitch than shown on table.

*(From Book of Standards, National Tube Co.)

Decimal Parts of an Inch*

Decimals of an Inch for Each 1/64th

1/32	1/64	Decimal	Fraction	1/32	1/64	Decimal	Fraction
	1	.015625			33	.515625	
1	2	.03125		17	34	.53125	
	3	.046875			35	.546875	
2	4	.0625	1/16	18	36	.5625	9/16
	5	.078125			37	.578125	
3	6	.09375		19	38	.59375	
	7	.109375			39	.609375	
4	8	.125	1/8	20	40	.625	5/8
	9	.140625			41	.640625	
5	10	.15625		21	42	.65625	
	11	.171875			43	.671875	
6	12	.1875	3/16	22	44	.6875	11/16
	13	.203125			45	.703125	
7	14	.21875		23	46	.71875	
	15	.234375			47	.734375	
8	16	.25	1/4	24	48	.75	3/4
	17	.265625			49	.765625	
9	18	.28125		25	50	.78125	
	19	.296875			51	.796875	
10	20	.3125	5/16	26	52	.8125	13/16
	21	.328125			53	.828125	
11	22	.34375		27	54	.84375	
	23	.359375			55	.859375	
12	24	.375	3/8	28	56	.875	7/8
	25	.390625			57	.890625	
13	26	.40625		29	58	.90625	
	27	.421875			59	.921875	
14	28	.4375	7/16	30	60	.9375	15/16
	29	.453125			61	.953125	
15	30	.46875		31	62	.96875	
	31	.484375			63	.984375	
16	32	.5	1/2	32	64	1	1

Mechanical, Electrical and Heat Equivalents*

One Horse Power is equal to: 746 Watts, 0.746 K. W., 33,000 ft.-lbs. per minute, 550 ft.-lbs. per second, 2,545 heat-units per hour, 42.4 heat-units per minute, 0.707 heat-units per second, 0.175 lbs. carbon oxidized per hour, 2.64 lbs. water evaporated per hour from and at 212° F.

Contents in Cu. Ft. and U. S. Gallons of Pipes and Cylinders of various inside diameters and one foot in length. *

(1 gallon = 231 cubic inches. 1 cubic foot = 7.4805 gallons.)

Diameter in inches	For 1 ft. in length: Cubic feet, also area in square feet	For 1 ft. in length: U. S. gallons	Diameter in inches	For 1 ft. in length: Cubic feet, also area in square feet	For 1 ft. in length: U. S. gallons	Diameter in inches	For 1 ft. in length: Cubic feet, also area in square feet	For 1 ft. in length: U. S. gallons
1/4	.0003	.0025	6 3/4	.2485	1.859	19	1.969	14.73
5/16	.0005	.0040	7	.2673	1.999	19 1/2	2.074	15 51
3/8	.0008	.0057	7 1/4	.2867	2.145	20	2.182	16.32
7/16	.0010	.0078	7 1/2	.3068	2.295	20 1/2	2.292	17.15
1/2	.0014	.0102	7 3/4	.3276	2.450	21	2.405	17 99
9/16	.0017	.0129	8	.3491	2.611	21 1/2	2.521	18.86
5/8	.0021	.0159	8 1/4	.3712	2.777	22	2.640	19.75
11/16	.0026	.0193	8 1/2	.3941	2.948	22 1/2	2.761	20.66
3/4	.0031	.0230	8 3/4	.4176	3.125	23	2.885	21.58
13/16	.0036	.0269	9	.4418	3.305	23 1/2	3.012	22.53
7/8	.0042	.0312	9 1/4	.4667	3.491	24	3.142	23.50
15/16	.0048	.0359	9 1/2	.4922	3.682	25	3 409	25.50
1	.0055	.0408	9 3/4	.5185	3.879	26	3.687	27.58
1 1/4	.0085	.0638	10	.5454	4.080	27	3.976	29.74
1 1/2	.0123	.0918	10 1/4	.5730	4.286	28	4.276	31.99
1 3/4	.0167	.1249	10 1/2	.6013	4.498	29	4.587	34.31
2	.0218	.1632	10 3/4	.6303	4.715	30	4.909	36.72
2 1/4	.0276	.2066	11	.6600	4.937	31	5.241	39.21
2 1/2	.0341	.2550	11 1/4	.6903	5.164	32	5.585	41.78
2 3/4	.0412	.3085	11 1/2	.7213	5.396	33	5.940	44.43
3	.0491	.3672	11 3/4	.7530	5.633	34	6.305	47.16
3 1/4	.0576	.4309	12	.7854	5.875	35	6.681	49.98
3 1/2	.0668	.4998	12 1/2	.8522	6.375	36	7.069	52.88
3 3/4	.0767	.5738	13	.9218	6.895	37	7.467	55.86
4	.0873	6528	13 1/2	.9940	7.436	38	7.876	58.92
4 1/4	.0985	.7369	14	1.069	7.997	39	8.296	62.06
4 1/2	.1104	.8263	14 1/2	1.147	8.578	40	8.727	65.28
4 3/4	.1231	.9206	15	1.227	9.180	41	9.168	68.[illegible]8
5	.1364	1.020	15 1/2	1.310	9.801	42	9.621	71.97
5 1/4	.1503	1.125	16	1.396	10.44	43	10.085	75.44
5 1/2	.1650	1.234	16 1/2	1.485	11.11	44	10.559	78.99
5 3/4	.1803	1.349	17	1.576	11.79	45	11.045	82.62
6	.1963	1.469	17 1/2	1.670	12.49	46	11.541	86.33
6 1/4	.2131	1.594	18	1.767	13.22	47	12.048	90.13
6 1/2	.2304	1 724	18 1/2	1.867	13.96	48	12 566	94.00

To find the capacity of pipes greater than the largest given in the table, look in the table for a pipe of one-half the given size, and multiply its capacity by 4; or one of one-third its size, and multiply its capacity by 9, etc.

To find the weight of water in any of the given sizes, multiply the capacity in cubic feet by $62\frac{1}{2}$ or the capacity in gallons by $8\frac{1}{3}$, or, if a more accurate result is required, by the weight of a cubic foot of water at the actual temperature in the pipe.

Given the dimensions of a cylinder in inches, to find its capacity in U.S. gallons: Square the diameter, multiply by the length and by 0.0034. If d = diameter, l = length, gallons = $\frac{d^2 \times 0.7854 \times l}{231} = 0.0034\, d^2 l$.

If D and L are in feet, gallons = $5.875\, D^2 L$.

Cylindrical Vessels, Tanks and Cisterns; Diameter in Feet and Inches. Area in square feet and Capacity in U. S. Gallons for one ft. in depth. *

(1 gallon = 231 cubic inches = 1 cubic foot/7.4805 = 0.13368 cubic foot.)

Diameter, ft.	in.	Area, square feet	Gallons, 1 foot depth	Diameter, ft.	in.	Area, square feet	Gallons, 1 foot depth	Diameter, ft.	in.	Area, square feet	Gallons, 1 foot depth
1	0	.785	5.87	5	8	25.22	188 66	19	0	283.53	2120.9
1	1	.922	6 89	5	9	25.97	194.25	19	3	291.04	2177.1
1	2	1.069	8 00	5	10	26.73	199 92	19	6	298.65	2234 0
1	3	1.227	9.18	5	11	27.49	205.67	19	9	306.35	2291.7
1	4	1.396	10.44	6	0	28.27	211.51	20	0	314.16	2350.1
1	5	1.576	11.79	6	3	30.68	229.50	20	3	322.06	2409.2
1	6	1.767	13.22	6	6	33.18	248.23	20	6	330 06	2469 1
1	7	1.969	14.73	6	9	35 78	267.69	20	9	338.16	2529 6
1	8	2.182	16.32	7	0	38.48	287.88	21	0	346.36	2591 0
1	9	2.405	17.99	7	3	41.28	308.81	21	3	354.66	2653 0
1	10	2.640	19.75	7	6	44.18	330.48	21	6	363.05	2715 8
1	11	2.885	21.58	7	9	47.17	352.88	21	9	371.54	2779.3
2	0	3.142	23.50	8	0	50.27	376.01	22	0	380.13	2843.6
2	1	3.409	25.50	8	3	53.46	399.88	22	3	388 82	2908.6
2	2	3.687	27.58	8	6	56.75	424.48	22	6	397.61	2974 3
2	3	3.976	29.74	8	9	60.13	449.82	22	9	406.49	3040 8
2	4	4.276	31.99	9	0	63.62	475.89	23	0	415.48	3108 0
2	5	4.587	34.31	9	3	67.20	502.70	23	3	424.56	3175.9
2	6	4.909	36.72	9	6	70.88	530.24	23	6	433.74	3244 6
2	7	5.241	39.21	9	9	74.66	558.51	23	9	443.01	3314 0
2	8	5.585	41.78	10	0	78.54	587.52	24	0	452.39	3384.1
2	9	5.940	44.43	10	3	82.52	617.26	24	3	461 86	3455 0
2	10	6.305	47.16	10	6	86.59	647.74	24	6	471.44	3526 6
2	11	6.681	49.98	10	9	90.76	678.95	24	9	481.11	3598.9
3	0	7.069	52.88	11	0	95.03	710.90	25	0	490.87	3672 0
3	1	7.467	55.86	11	3	99.40	743.58	25	3	500 74	3745 8
3	2	7.876	58.92	11	6	103.87	776.99	25	6	510 71	3820 3
3	3	8.296	62.06	11	9	108.43	811.14	25	9	520.77	3895 6
3	4	8.727	65.28	12	0	113.10	846.03	26	0	530 93	3971 6
3	5	9.168	68.58	12	3	117 86	881.65	26	3	541 19	4048 4
3	6	9.621	71.97	12	6	122 72	918.00	26	6	551 55	4125 9
3	7	10.085	75.44	12	9	127 68	955.09	26	9	562 00	4204.1
3	8	10.559	78.99	13	0	132.73	992.91	27	0	572.56	4283 0
3	9	11.045	82.62	13	3	137.89	1031.5	27	3	583.21	4362.7
3	10	11.541	86.33	13	6	143.14	1070 8	27	6	593 96	4443.1
3	11	12.048	90.13	13	9	148.49	1110.8	27	9	604 81	4524.3
4	0	12.566	94.00	14	0	153.94	1151.5	28	0	615.75	4606.2
4	1	13.095	97.96	14	3	159.48	1193.0	28	3	626 80	4688 8
4	2	13.635	102.00	14	6	165.13	1235.3	28	6	637 94	4772 1
4	3	14.186	106.12	14	9	170 87	1278.2	28	9	649.18	4856.2
4	4	14.748	110.32	15	0	176.71	1321.9	29	0	660 52	4941.0
4	5	15.321	114.61	15	3	182 65	1366.4	29	3	671.96	5026 6
4	6	15 90	118.97	15	6	188.69	1411 5	29	6	683 49	5112.9
4	7	16 50	123.42	15	9	194 83	1457.4	29	9	695.13	5199.9
4	8	17 10	127.95	16	0	201.06	1504.1	30	0	706 86	5287.7
4	9	17 72	132 56	16	3	207.39	1551.4	30	3	718 69	5376 2
4	10	18 35	137 25	16	6	213 82	1599.5	30	6	730 62	5465.4
4	11	18 99	142 02	16	9	220 35	1648 4	30	9	742 64	5555.4
5	0	19 63	146 88	17	0	226 98	1697.9	31	0	754 77	5646.1
5	1	20 29	151 82	17	3	233 71	1748 2	31	3	766.99	5737 5
5	2	20 97	156 83	17	6	240 53	1799 3	31	6	779.31	5829.7
5	3	21 65	161 93	17	9	247.45	1851.1	31	9	791.73	5922.6
5	4	22 34	167.12	18	0	254 47	1903.6	32	0	804 25	6016.2
5	5	23 04	172 38	18	3	261 59	1956.8	32	3	816 86	6110.6
5	6	23 76	177 72	18	6	268 80	2010 8	32	6	829 58	6205 7
5	7	24 48	183 15	18	9	276 12	2065 5	32	9	842 39	6301 5

*(From Book of Standards, National Tube Co.

Loss in Water Pressure in Pipes, due to Friction

For Each 100 Feet of Length in Different Size Clean Iron Pipes, Discharging Given Quantities of Water per Minute
Also Velocity of Flow in Pipe, in Feet per Second

Gallons Discharged per Minute	¾ INCH		1 INCH		1¼ INCH		1½ INCH		2 INCH		2½ INCH		3 INCH		4 INCH		6 INCH		8 INCH		Gallons Discharged per Minute
	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	Veloc. in Pipe in Feet per Second	Friction Loss in Pounds	
20	14.5	50.4	8.17	12.3	5.22	4.07	3.63	1.66	2.04	0.42											20
25	18.1	78.0	10.2	19.0	6.53	6.40	4.54	2.62			1.63	0.21	1.13	0.10							25
30			12.3	27.5	7.84	9.15	5.45	3.75	3.06	0.91											30
35			14.3	37.0	9.14	12.4	6.36	5.05													35
40			16.3	48.0	10.4	16.1	7.26	6.52	4.09	1.60											40
45					11.7	20.2	8.17	8.15													45
50					13.1	24.9	9.08	10.0	5.11	2.44	3.26	0.81	2.27	0.35	1.28	0.09					50
75					19.6	56.1	13.6	22.4	7.66	5.32	4.90	1.80	3.40	0.74							75
100							18.2	39 0	10.2	9.46	6.53	3.20	4.54	1.31	2.55	0.33	1.13	0.05			100
125									12.8	14.9	8.16	4.89	5.67	1.99							125
150									15.3	21.2	9.80	7.00	6.81	2.85	3.83	0.69	1.70	0.10			150
175									17.1	28.1	11.4	9.46	7.94	3.85							175
200									20.4	37.5	13.1	12.48	9.08	5.02	5.11	1.22	2.27	0.17			200
250											16.3	19.66	11.3	7.76	6.39	1.89	2.84	0.26	1.59	0.07	250
300											19.6	28.06	13.6	11.2	7.66	2.66	3.40	0.37			300
350													15.9	15.2	8.94	3.65	3.97	0.50			350
400													18.2	19.5	10.2	4.73	4.54	0.65			400
450													20.4	25.0	11.5	6.01	5.11	0.81			450
500													22.7	30.8	12.8	7.43	5.67	0.96	3.19	0.25	500
750																	8.51	2.21	4.79	0.53	750
1000																	11.3	3.88	6.38	0.94	1000
1250																			7.97	1.46	1250
1500																			9.57	2.09	1500

Loss of Air Pressure in Pipes, due to Friction; Applies to all Pressures and for Volumes up to 3000 Cu. Ft. of Free Air

Divide the number corresponding to the diameter of the pipe and volume in cu. ft. of free air by the ratio of compressions from free air. The result is the loss in pounds per sq. inch in 1000 feet of pipe. *See example.

Cubic Feet of Free Air per Minute	Diameter of Pipe in Inches								
	½	¾	1	1¼	1½	2	2½	3	3½
6	43.5	5.7	1.4	.4					
12	173.	22.8	5.3	1.5					
24	753.	91.	21.	5.9	2.2				
48		362.	85.	23.5	8.5	2.			
75			200.	57.	21.	4.9	1.6		
100			373.	92.	37.5	8.7	2.7		
125				163.	59.	13.6	4.4		
150				230.	83.5	19.5	6.3	2.3	
200				368.	150.	35.	10.8	3.7	
250					216.	54.5	17.7	6.4	2.9
300					338.	79.	25.3	9.3	4.2
	2	2½	3	3½	4	4½	5	6	7
350	105.	33.	12.7	5.5	2.7				
400	140.	45.	14.8	7.1	3.6	1.9			
450	174.	55.	20.7	9.4	4.1	2.3			
500	216.	68.	26.	11.1	5.6	2.9	1.7		
600	316.	100.	37.	16.6	7.3	4.	2.5		
700		133.	51.	21.8	10.9	5.8	3.4		
800		172.	59.	29.	14.3	7.5	4.4	1.8	
900		219.	83.	38.	16.5	9.2	5.4	2.2	
1000		272.	104.	44.	22.	11.7	6.8	2.8	1.4
1200		400.	148.	67.	29.	16.	9.6	3.9	1.9
1400			204.	87.	44.	23.	14.	5.5	2.6
1600			236.	114.	57.	30.	18.	7.1	3.1
1800			332.	150.	66.	35.	22.	8.8	4.3
2100				196.	98.	52.	30.	12.5	5.9
2400				266.	117.	65.	38.	15.5	7.7
2700					149.	82.	49.	19.5	9.8
3000					201.	100.	60.	24.	12.

*Example:

What is the loss of pressure and the terminal pressure with 350 cu. ft. of free air compressed to 90 lbs.? Initial gauge pressure passing through 500 ft. of 2 in. pipe.

From the table it will be seen that the number corresponding to the diameter of pipe and the volume mentioned is 105.

$\frac{90 + 14.7}{14.7} = 7.1$ Atmospheres or Compressions.

$\frac{1000'}{500'} = 2 \qquad \frac{105.}{2} = 52.5 \qquad \frac{52.5}{7.1} = 7.4$ Lbs. Loss.

90 Lbs. Initial − 7.4 Lbs. Loss = 82.6 Lbs. Terminal pressure.

This table is adapted from Elmo G. Harris' Formula in Compressed Air. McGraw-Hill Book Co., 1910.

$$f = c \frac{l}{d^5} \times \frac{(Va)^2}{r}$$

f = Loss of pressure per sq. inch.
c = An experimental coefficient.
l = Length of pipe in feet.
d = Diameter of pipe in inches.
Va = Cubic feet of free air passing per second.
r = Ratio of compressions from free air.

Values for "C" Used

d = in.	½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7
c =	1.47	1.21	1.35	1.16	1.02	1	.95	.9	.86	.825	.775	.715	.825	.8

Horsepower (Theoretical) Required to Compress 100 Cu. Ft. Free Air to Various Pressures

Gauge Pressure	Single-Stage	Two-Stage	Saving of Two-Stage Over Single-Stage Compression	
			Horsepower	Per Cent
5	1.97			
10	3.61			
15	5.02			
20	6.28			
25	7.44			
30	8.45			
35	9.41			
40	10.30			
45	11.13			
50	11.92	10.65	1.28	10.70
55	12.67	11.25	1.42	11.22
60	13.37	11.81	1.57	11.72
65	14.05	12.34	1.71	12.18
70	14.70	12.84	1.85	12.61
75	15.32	13.32	2.00	13.04
80	15.91	13.77	2.13	13.40
85	16.48	14.21	2.27	13.77
90	17.04	14.63	2.41	14.12
95	17.57	15.03	2.54	14.45
100	18.09	15.42	2.67	14.77
110	19.08	16.15	2.93	15.36
120	20.01	16.83	3.18	15.90
130	20.90	17.46	3.43	16.42
140	21.74	18.07	3.67	16.89
150	22.55	18.64	3.91	17.33
160	23.32	19.26	4.06	17.40
170	24.06	19.78	4.29	17.80
180	24.77	20.27	4.51	18.18
190	25.46	20.74	4.70	18.46
200	26.12	21.19	4.93	18.88
210		21.54		
220		21.96		
230		22.37		
240		22.76		
250		23.03		
260		23.28		
270		23.84		
280		24.19		
290		24.53		
300		24.85		
350		26.35		
400		27.65		
450		28.85		
500		29.97		

Flow of Air Through an Orifice in Cubic Feet of Free Air per Minute

Flowing from a Round Hole in a Receiver into the Atmosphere

These quantities are correct only for an orifice with countersunk edges and are not correct for a hole with straight edges.*

RECEIVER GAUGE PRESSURE

Diameter of Orifice Inches	2 Pounds	5 Pounds	10 Pounds	15 Pounds	20 Pounds	25 Pounds	30 Pounds	35 Pounds	40 Pounds	45 Pounds	50 Pounds	60 Pounds	70 Pounds	80 Pounds	90 Pounds	100 Pounds	125 Pounds
1/64	.038	.0597	.0842	.103	.119	.133	.156	.173	.19	.208	.225	.26	.295	.33	.364	.40	.486
1/32	.153	.242	.342	.418	.485	.54	.632	.71	.77	.843	.914	1.05	1.19	1.33	1.47	1.61	1.97
1/16	.647	.965	1.36	1.67	1.93	2.16	2.52	2.80	3.07	3.36	3.64	4.2	4.76	5.32	5.87	6.45	7.85
1/8	2.435	3.86	5.45	6.65	7.7	8.6	10.	11.2	12.27	13.4	14.50	10.8	19.	21.2	23.50	25.8	31.4
1/4	9.74	15.40	21.8	26.70	30.8	34.5	40.	44.7	49.09	53.8	58.2	67.	76.	85.	94.	103.	125.
3/8	21.95	34.60	49.	60.	69.	77.	90.	100.	110.45	121.	130.	151.	171.	191.	211.	231.	282.
1/2	39.00	61.60	87.	107.	123.	138.	161.	179.	196.35	215.	232.	268.	304.	340.	376.	412.	502.
5/8	61.00	96.50	136.	167.	193.	216.	252.	280.	306.80	336.	364.	420.	476.	532.	587.	645.	785.
3/4	87.60	133.	196.	240.	277.	310.	362.	400.	441.79	482.	522.	604.	685.	765.	843.	925.	
7/8	119.50	189.	267.	326.	378.	422.	493.	550.	601.32	658.	710.	622.	930.	1004.			
1	156.	247.	350.	427.	494.	550.	645.	715.	785.40	860.	930.						
1 1/4	242.	384.	543.	665.	770.	860.	1000.										
1 1/2	350.	550.	780.	960.													
2	625.	985.															

* See Bulletin 58-L. page 18.

Cylinder Piston Displacements in Cubic Feet per Revolution, of Double Acting Cylinders

Diam. in Inches	STROKE IN INCHES															Diam. in Inches
	6	7	8	10	12	14	16	18	20	22	24	30	36	42	48	
6	.195	.229	.261	.327	.392	.458	.523	....	....	....	....	....	....	....	....	6
7	.267	.311	.356	.445	.534	.624	.712	....	....	....	....	....	....	....	....	7
8	.349	.407	.465	.581	.698	.814	.930	1.04	1.16	1.27	1.39	1.74	....	....	....	8
9	.442	.515	.588	.736	.883	1.030	1.177	1.32	1.47	1.61	1.76	2.20	....	....	....	9
10	.545	.636	.727	.909	1.090	1.272	1.454	1.63	1.81	2.00	2.18	2.72	3.27	....	....	10
11	.659	.769	.879	1.099	1.319	1.539	1.759	1.97	2.19	2.41	2.63	3.29	3.95	....	....	11
12	.785	.916	1.047	1.308	1.571	1.832	2.094	2.35	2.61	2.87	3.14	3.92	4.71	5.49	....	12
13	....	1.075	1.228	1.536	1.843	2.150	2.457	2.76	3.07	3.37	3.68	4.60	5.53	6.45	....	13
14	....	1.247	1.425	1.781	2.137	2.494	2.850	3.20	3.56	3.91	4.27	5.34	6.41	7.48	8.55	14
15	....	....	1.636	2.045	2.454	2.803	3.272	3.68	4.09	4.49	4.90	6.13	7.36	8.58	9.81	15
16	....	....	1.861	2.327	2.792	3.257	3.723	4.18	4.65	5.12	5.58	6.98	8.37	9.77	11.16	16
17	....	....	....	2.629	3.152	3.677	4.203	4.72	5.25	5.77	6.30	7.88	9.45	11.03	12.60	17
18	....	....	....	2.945	3.534	4.123	4.712	5.30	5.89	6.47	7.06	8.83	10.60	12.36	14.13	18
19	....	....	....	....	3.937	4.593	5.250	5.90	6.56	7.21	7.87	9.84	11.81	13.78	15.75	19
20	....	....	....	....	4.363	5.090	5.817	6.54	7.27	7.99	8.72	10.90	13.08	15.27	17.45	20
21	....	....	....	....	....	5.612	6.413	7.21	8.01	8.81	9.62	12.02	14.43	16.83	19.24	21
22	....	....	....	....	....	6.159	7.037	7.91	8.79	9.67	10.55	13.19	15.83	18.47	21.11	22
23	....	....	....	....	....	....	7.693	8.65	9.61	10.57	11.54	14.42	17.31	20.19	23.08	23
24	....	....	....	....	....	....	8.377	9.42	10.47	11.52	12.56	15.70	18.84	21.98	25.12	24
25	....	....	....	....	....	....	9.090	10.22	11.36	12.49	13.63	17.04	20.44	23.85	27.26	25
26	....	....	....	....	....	....	9.830	11.06	12.29	13.51	14.74	18.43	22.12	25.80	29.49	26
27	....	....	....	....	....	....	10.602	11.92	13.25	14.57	15.90	19.88	23.85	27.83	31.80	27
28	....	....	....	....	....	....	11.402	12.82	14.25	15.67	17.10	21.38	25.65	29.93	34.20	28
29	....	....	....	....	....	....	....	13.75	15.28	16.81	18.34	22.93	27.51	32.10	36.68	29
30	....	....	....	....	....	....	....	14.72	16.36	17.99	19.63	24.54	29.44	34.35	39.26	30
31	....	....	....	....	....	....	....	15.72	17.47	19.21	20.96	26.20	31.44	36.68	41.92	31
32	....	....	....	....	....	....	....	16.75	18.61	20.47	22.34	27.92	33.51	39.09	44.68	32
33	....	....	....	....	....	....	....	....	....	21.77	23.75	29.69	35.63	41.57	47.51	33
34	....	....	....	....	....	....	....	....	....	23.11	25.22	31.52	37.83	44.13	50.44	34
35	....	....	....	....	....	....	....	....	....	....	26.72	33.40	40.08	46.76	53.45	35
36	....	....	....	....	....	....	....	....	....	....	28.27	35.34	42.40	49.47	56.54	36
37	....	....	....	....	....	....	....	....	....	....	....	37.33	44.79	52.26	59.72	37
38	....	....	....	....	....	....	....	....	....	....	....	39.37	47.25	55.12	63.00	38
39	....	....	....	....	....	....	....	....	....	....	....	41.47	49.77	58.06	66.36	39
40	....	....	....	....	....	....	....	....	....	....	....	43.63	52.35	61.08	69.80	40
42	....	....	....	....	....	....	....	....	....	....	....	....	....	67.34	76.96	42
44	....	....	....	....	....	....	....	....	....	....	....	....	....	73.89	84.46	44

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