AIR COMPRESSORS

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AIR COMPRESSORS

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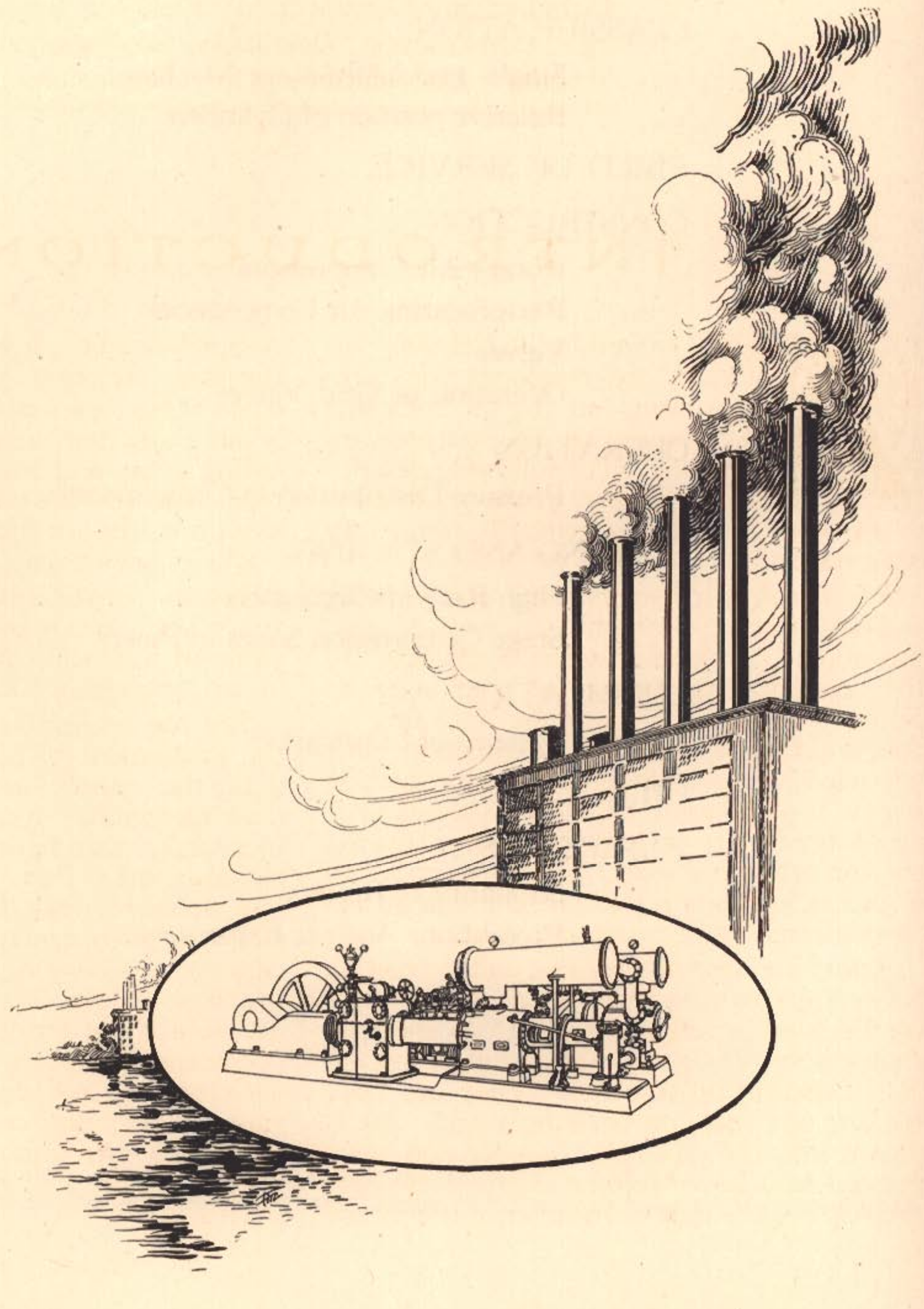


AIR COMPRESSORS

Introduction; Classification; Field of Service; Construction; Operation; Cooling and Staging; Lubrication; Oil; Explosions.

INTRODUCTION

AIR *compressors and blowing engines* are machines for compressing air to a sufficient pressure for the purpose intended. The following description applies, in the most part, to all types of machines generally termed air compressors.

Reciprocating air compressors and blowing engines are of a type in which the work of compression is performed within a cylinder by the reciprocating motion of a plunger or piston traveling in a straight line, first in one, and then in the opposite direction. Air admitted to the cylinder during the suction stroke, is compressed to a lesser volume and, consequently, to a higher pressure during the compression stroke. They are employed in producing compressed air, through an extended range of pressure and volume.

Rotary air compressors or so called positive blowers are of a type in which the work of compression is performed within an enclosed chamber by the continuous rotative motion of a close fitting impeller. They are used for low and medium pressure work. Air is drawn into the enclosed chamber and compressed to a lesser volume as the cycle progresses, but the part or member in the rotary compressor that corresponds to, and performs the same functions as the piston in the reciprocating compressor, has a rotary motion. While these machines differ from the reciprocating type, and from each other, in structural features, the temperatures involved for like pressures are the same.

There are, however, peculiarities of construction constituting subjects for special study that do not properly come within the scope of a general discussion of the subject of air compressor lubrication.

The fan or turbine of blower depends on the attainment of high air velocity to produce the desired increased pressure. The rotating member in such a machine is not in mechanical (air tight) contact with the stationary part. Fans are generally used for low pressure work but fans of the multi-stage type operated at high speed, are capable of delivering air at moderately high pressure (60 to 100 lb.). These machines are similar in form to the steam turbine, presenting like bearing problems when lubricated by the same kind of a system and operating under similar conditions of speed, pressure and surrounding temperature. This type of blower will not be discussed further in this paper.

The purpose of this paper is to treat of the construction, operation and lubrication of reciprocating air compressors but the rotary type compressor is also illustrated and briefly described.

Compressed air is a convenient medium for transmitting power to remote points for operating machines and for special purposes. Its extended use has promoted the development of the air compressor to its present state of perfection.

Air is often preferable to steam as a motive power as it is subject to slight loss from radiation or condensation and is therefore well adapted to intermittent operating conditions. Compressed air may be stored in metal tanks and kept available in large receivers and air pipe systems, being maintained at nearly constant pressure, during inoperative periods with minimum wastage.

The exhaust from air-tools presents no such difficulty as does steam, in fact it is often beneficial as it has a ventilating and refrigerating effect, relieving, to some extent, the heat in underground work.

Important uses of compressed air are found in the manufacturing arts, where it is used in aiding both physical and chemical processes, and in metallurgical and chemical industries.

Stages or staging in air compressor work refers to the separate operations performed on the air in compressing it to a higher pressure. This operation may be completed in one operation in one cylinder (called single stage compression) or it may be accomplished in part in two or more separate cylinders termed, generally, multi-stage compression or, specifically, two stage, three stage, etc., indicating the number of stages or cylinders in which the work of compression is completed.

CLASSIFICATION

CLASSIFICATIONS of air compressors are usually made with regard to their type, size, speed, delivery air pressure, piston action, stages, cooling, cylinder arrangement and drive.

Type: Air compressors are designed with their cylinders in a horizontal or vertical position or at an angle to each other.

Delivery air pressure: Machines that deliver air at low pressure (and usually in large volume) are termed blowers or blowing engines (the cylinder of which is usually called the "tub") while machines designed to deliver air at higher pressure are termed air compressors. There is no well defined dividing line between the two, beyond which, by reason of high pressure, a blower becomes known as a compressor or by reason of large air volume or decreased pressure a compressor may, properly, be called a blower.

Blowing engines are used in iron and steel plants, copper smelters, etc., and usually deliver a large volume of air at pressures ranging from 10 to 30 pounds per square inch. Blowing engines are necessarily large and operate at slow speed, from 30 to 60 r.p.m. The final delivery pressure is reached in one cylinder, single-stage compression.

Air compressors are designed to supply air at high pressure, up to 80 pounds, in one stage and up to 120 pounds usually in two stages, for general use, and to higher pressure, 400 to 500 pounds, for special purposes in two or more stages.

Special types of air compressors are used to compress air to exceptionally high pressures; 1000 to 5000 pounds, in three, four or more stages.

Single- and Multi-stage Machines

Stages: Compressors are termed single, two-stage, etc., according to the number of successive compression stages or cylinders in which the air is compressed in reaching the final delivery pressure.

Single-stage compressors, as a rule, operate at high speed and rarely deliver air at a pressure above 80 pounds. Collieries use large volumes of air compressed to a pressure of 60 to 80 pounds. Sometimes this work is done in one stage but more frequently two cylinders or stages are used.

Two-stage air compressors are advantageously used when air is to be delivered at pressures exceeding 40 pounds. Two-stage air compressors of small or medium size are used in connection with pneumatic tool operation in wood, iron and steel manufacture at a pressure of 100 to 120 pounds.

Three-stage air compressors deliver air at a pressure upward of 1000 pounds, used to help atomize the fuel charge in Diesel engines, for example. Two-stage machines are sometimes used for Diesel engines of 500 horse-power or less but most builders furnish three-stage compressors for even small ones, and for power units of more than 500 horse-power the air compressors are almost invariably three-stage.

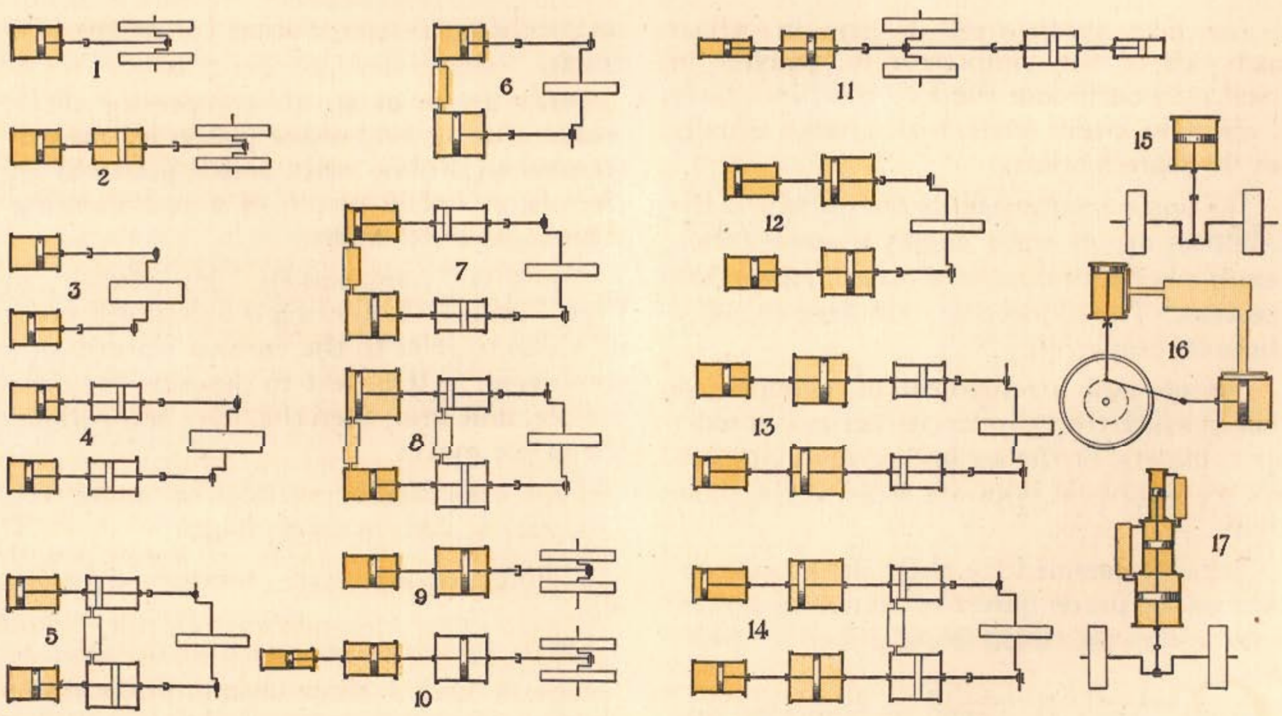
Four or more stages: Air compressors used for segregating oxygen from air generally have four cylinders and compress air to a pressure of 2000 to 3000 pounds. Compressors for charging torpedoes are usually four-orfive-stage machines, capable of compressing air to 5000 pounds.

Relative Positions of Cylinders

Cylinder arrangement: Compressors are called tandem, angle or duplex according to the relative position of the two or more air cylinders, and may comprise several cylinders arranged in tandem, angle or duplex order.

The tandem arrangement: The cylinders are in a straight line and the pistons have a common piston rod.

The duplex arrangement consists of two cylinders placed side by side when the cylinders act as successive stages as in a cross compound steam engine.



*Figs. 1 and 2—Typical combinations and cylinder arrangements of air compressors shown diagrammatically

* In all color illustrations, *red* indicates oil, *green* indicates water, and *yellow* indicates gas.

TABLE 1. TABULATION OF CYLINDER ARRANGEMENT, ETC.
AS SHOWN IN FIGURES 1 AND 2

	Type	No. Stages	Cylinder Arrangement		Drive
No. 1	Horizontal	Single	One		Crank
No. 2	"	"	"		Direct, Simple Engine
No. 3	"	"	Two	Duplex	Crank
No. 4	"	"	"	"	Direct, Twin Engine
No. 5	"	Two	"	"	" Cross Comp. Engine
No. 6	"	"	"	"	Crank
No. 7	"	"	"	"	Direct, Twin Engine
No. 8	"	"	"	"	" Cross Comp. Engine
No. 9	"	"	"	Tandem	Crank
No. 10	"	"	"	"	Direct, Simple Engine
No. 11	"	"	"	"	Opposed, Tandem Comp. Eng.
No. 12	"	"	Four	Duplex	Crank
No. 13	"	"	"	"	Direct, Twin Engine
No. 14	"	"	"	"	" Cross Comp. Engine
No. 15	Vertical	Single	One		Crank
No. 16	Angle	Two	Two		"
No. 17	Vertical	Three	Three		"

The twin arrangement is one in which each side of the compressor is complete in itself. In each case the two machines have a common crank shaft with cranks usually set 90 degrees apart.

The angle arrangement is one in which the cylinders are at right angles to each other, one in a horizontal and the other in a vertical position. The connecting rods often engage a common crank pin.

The opposed arrangement of cylinders is that in which the cylinders, either two or more air cylinders, or the air and power cylinders, are set in line on opposite sides of the main shaft.

Drive: Classified by their drive, connection to the prime mover or source of power, compressors are called crank driven or direct driven.

Crank driven is meant to comprise any manner of machine drive, (by means of belts, ropes, chains, or gears, as well as by coupling to a rotating shaft) that is transposed into reciprocating piston motion by means of a crank.

Direct driven in an air compressor drive, means that a compressor piston is, directly coupled to, in line with, and is actuated by the piston rod or piston of a reciprocating, steam, gas or oil engine.

Numerous combinations are shown in Figs. 1 and 2. Following is a desirable order in which to refer to the various features of a compressor. It is best to describe the compressor unit first, then the drive and perhaps the prime mover.

Type—horizontal, vertical or angle, etc.

Stage—single- or multi-stage.

Cylinder arrangement—tandem or duplex, etc.

Drive—crank driven or direct driven.

Figs. 1 and 2 show diagrammatically a number of compressors of different types, stages, cylinder arrangements and drives which, referred to in the order suggested, would be listed as in Table 1. It is obvious that many of the combinations of cylinder arrangements of the horizontal type shown may be duplicated in other types, therefore, they need not be shown. The ones most frequently met with are duplications, in the vertical form, of Nos. 1, 2, 3, 4 and 5, Fig. 1.

Piston action: Air compressors are single acting or double acting, i.e., they deliver air during one or both strokes of the piston, comprising a cycle or one revolution, referring to one cylinder only. A machine or unit may consist of one or more cylinders and may be either single acting or double acting.

Size: Compressors either single or multi-stage, are rated according to the volume of free air entering the first cylinder. A machine having a piston displacement of less than 1000 cubic feet per minute is termed small. One having a capacity greater than 1000 cubic feet per minute is called large. This classification is, of course, simply an arbitrary one for the purpose of mutual understanding when the term large, or small is used.

Speed: Air compressors operate at various speeds. Blowing engines are slow-speed machines, operating at 30 to 60 r.p.m. Large air compressors also operate at slow speed. Small compressors, particularly single-acting machines, usually operate at high speed, at from 100 to 300 r.p.m. and in some cases up to 400 r.p.m. or more. Vertical air compressors generally operate at higher speed than do horizontal compressors.

Cooling: Compressor cylinders may be air cooled or water jacketed. Blowing engines and low pressure, comparatively slow-speed compressors are air cooled. Air-brake compressors of low pressure and small volume, operating at moderate speed, are air cooled. Compressors for high speed, high-pressure work must be jacketed and a rapid circulation of clean, cool water maintained within the jacket to avoid overheating.

FIELD OF SERVICE

THE *field of service of air compressors* is extensive, including nearly every industry. One important use is that of furnishing the power medium to drilling machines and various types of pneumatic tools and machines, and for this purpose, they are found widely distributed, in mining, quarrying, tunnelling, construction work and the manufacturing industries.

Compressed air is extensively used in connection with conveying material, by haulage, hoisting, pumping and direct propulsion by means of a jet of air. In traffic systems it plays an important part in air-brake and signal control systems. It is generally used for starting internal combustion engines of medium and large size; and to assist in atomizing the fuel in Diesel and oil engines and in furnaces using liquid fuel.

CONSTRUCTION

B*LOWING engines:* The tub of direct-connected blowing engines is always in tandem with the power unit. The power unit may be either a steam or gas engine. It is becoming quite general practice to utilize some of the by-product gas from iron works' blast furnaces as fuel for these large, gas-engine operated blowing units, after it has been thoroughly washed and purified.

Blowing engines are sometimes crank driven and operated by large electric motors on the main shaft. Such machines are found in iron and steel mills that are thoroughly "electrified" and also in smelters for copper and other ores, where water power is available, operated by belt or rope drive from the water wheel or by an electric motor as described.

Fig. 3 shows a horizontal blowing engine driven by a cross compound steam engine. This arrangement permits of the use of two blowing cylinders, "tubs," which are placed

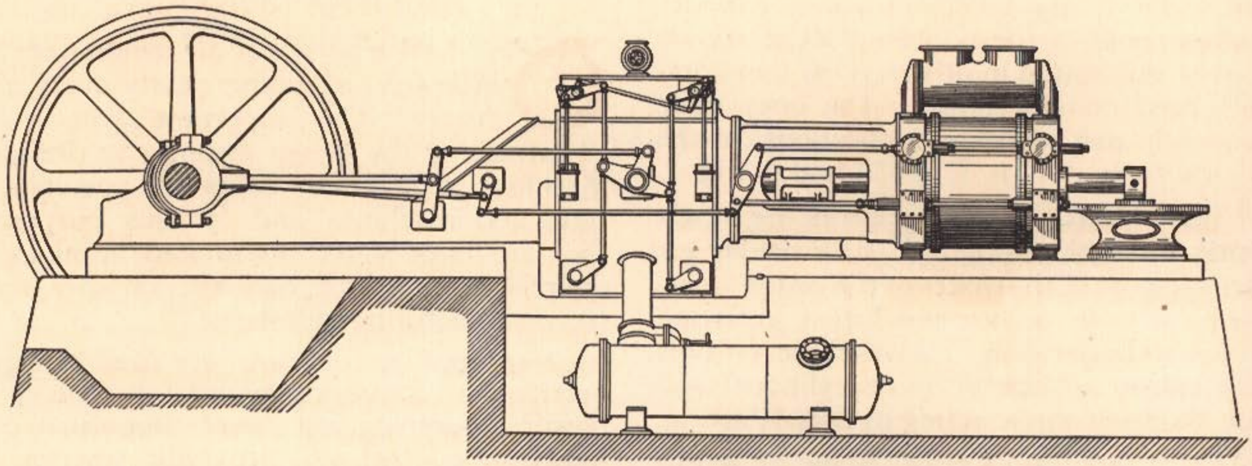


Fig. 3—Twin blowing tubs tandem with the cylinders of a cross compound steam engine

tandem, in line with the steam cylinders. The blowing-tub rod is directly connected to the steam-piston rod. The blowing tub may be placed between the steam cylinder and the crank. The tandem arrangement of cylinders is also used in vertical blowing engines, the blowing tub being placed either above or below the steam cylinder.

Fig. 4 shows a blowing tub connected to a gas engine.

Gas engines for this work are nearly always of the horizontal, double acting, two stroke type, giving a power impulse for every stroke of the piston and the tandem arrangement of the power cylinder and blowing tub is always employed.

Blowing tubs are always double acting. Air is taken into the cylinder on one side of the piston while compression and delivery is taking place on the other side, on each stroke. The piston must, therefore, be entirely enclosed in the cylinder.

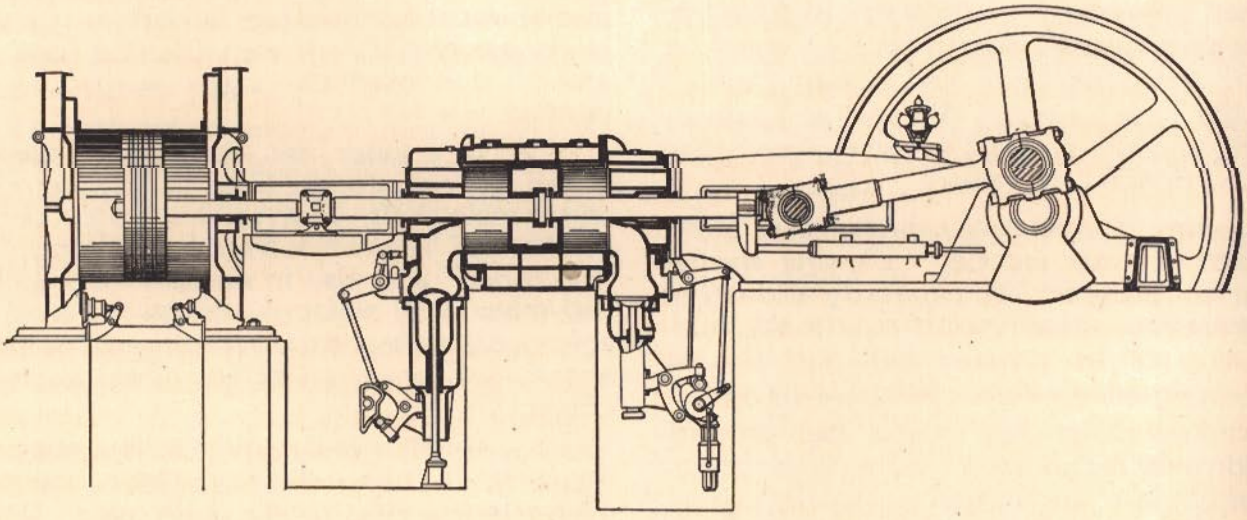


Fig. 4—Sectional view of a tandem blowing unit, operated by a double acting gas engine

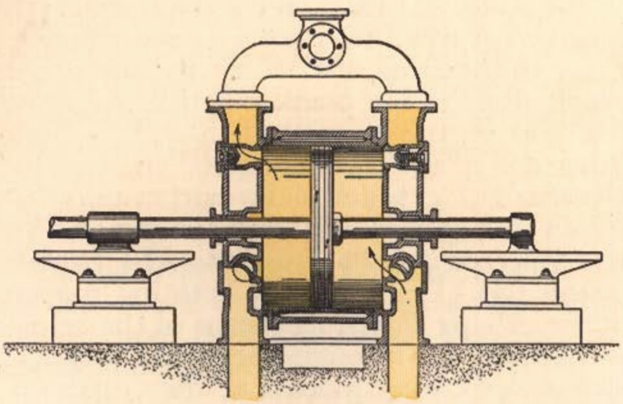


Fig. 5—Air cylinder, valves and piston supports

Fig. 5 is a sectional view of the air cylinder of a blowing engine with corliss inlet valves and poppet discharge valves.

Rotary Air Compressors

Rotary compressors consist of one or more rotating parts fitting closely within a circular, or part circular casting. Fig. 6 shows a section through one such compressor of a design that is perhaps as easily described and understood as any machine of this type. It consists of two comparatively long tooth spur gears in mesh, that fit closely within a casing, both at their periphery and ends.

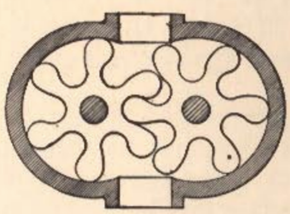


Fig. 6—Gear type blower

It is apparent that air may occupy all of the space between the teeth except where they are in mesh. When the gears are rotated, air may enter at one of the openings in the casing and be trapped (enclosed) between two adjacent teeth and the side of the casing and be carried around with the gear until displaced, forced out of the space, by the entrance of a tooth of the other gear. With gears of comparatively fine pitch the volume of air contained between any two teeth is small so that the air discharge is nearly constant and there is no extreme pulsation. The action is continuous so that no inlet or outlet check (non-return) valves are necessary although such a valve is often connected at the discharge side to prevent the air from escaping back through the machine, when shut down. Stuffing boxes are provided at the shaft to prevent leakage at that point.

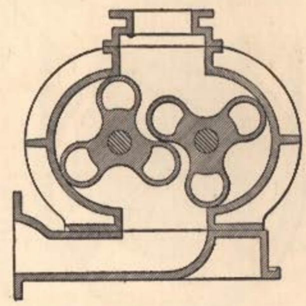


Fig. 7—Three-lobe blower

Designs are numerous but the general principles involved are the same and all of the foregoing applies, in general, to all compressors of this class. Fig. 7 can be recognized as having gears or cams with three teeth or lobes each. Other designs (Fig. 8) have cams with only two lobes. Another construction is shown in Fig. 9. This consists of a circular drum working within a circular casing of considerably larger bore than the diameter of the drum. The position of the drum is eccentric to the bore of the casing, leaving a crescent shaped space between them. The drum has four radial slots (A) fitted with blades (B) capable of movement within the slots toward and away from the center. These blades are held outward (by through pins C) with their outward edges against the inside bore of the casing so as to form a practically air-tight joint.

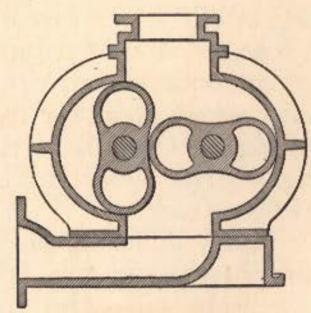


Fig. 8—Two-lobe blower

The operation of Fig. 9 is described as follows: Air occupies the spaces formed by adjacent blades, the body of the drum and the casing. By observation it is apparent that this space is greater at the lower portion of the casing than at the upper part. The air originally occupying the larger space when compressed into the smaller, as the drum is rotated, is, therefore, of relatively higher pressure. Air enters at D and is discharged at E, as the drum is rotated. The space is diminished as the side of the drum approaches the side of the casing—the blades in turn receding into the slots in the drum, correspondingly. The air is compressed as the space is diminished and discharge takes place when the leading blade uncovers or passes the discharge opening.

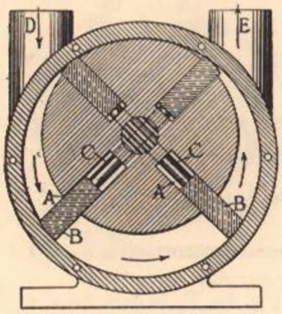


Fig. 9—Drum and blade type blower

Governing factors: In every machine of this type it is necessary to have the gears, cams or drum members, form a close contact within the casing—bore and ends—in order to be reasonably air tight (like the piston within the cylinder in a compressor of the reciprocating type) but from the nature of the design a packing ring (corresponding in effect to a piston ring) cannot be used. Close, accurate fitting with the correct grade of oil is depended upon to form an air seal and avoid excessive friction and air leakage. Unequal expansion must also be guarded against to avoid friction and wear and possible seizure.

The volume of air delivered increases in proportion to the operating speed. With adequate jacketing (cooling), air compressors of the rotating type may be run at high speed.

Reciprocating Air Compressors

Large reciprocating compressors are almost always double-acting, being provided with inlet and discharge valves in the cylinder heads at each end of the cylinder.

Fig. 10 is a side view, partly in section, of a horizontal single stage, double acting, crank-driven air compressor having corliss inlet valves and poppet discharge valves.

The pulley (A) fixed on the main shaft (B) is driven by a belt from some source of power. Fixed in the crank disk (C) on the end of the crank shaft is the crank pin (D), engaging one end of the connecting rod (E). The other end of the connecting rod engages the crosshead (F), which slides horizontally between the guides (G) and the piston (H) is connected to the crosshead (F) by the piston rod (J). Thus the rotating motion of the driving shafts, by means of the crank, is transformed through the connecting rod into reciprocating motion at the crosshead, piston rod and piston.

The piston (H) in all double-acting compressors, is fixed on a piston rod (J) which passes through a stuffing box (K) in the cylinder head (L) at the end of the cylinder. The weight of the piston is sometimes carried by external piston rod supports or crossheads, which slide on horizontal guides (as in Figs. 3 and 5). Sometimes the tail rod support is omitted, in which case the piston must slide on the bottom of the cylinder, increasing the difficulty of its lubrication.

Piston rings (M) are fitted to the piston, designed to spring outward against the cylinder wall, to prevent the escape of air past the piston, from one side to the other, without causing excessive friction.

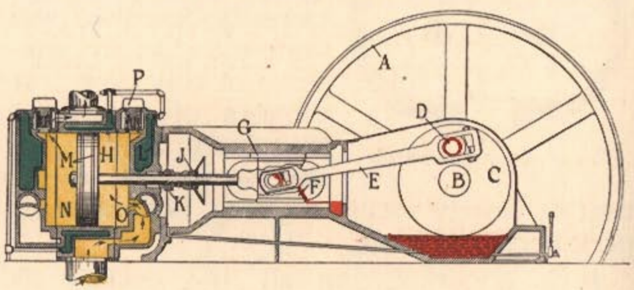


Fig. 10—Section of a crank-driven compressor

The piston rod of the compressor may be directly connected to the piston of a steam or gas engine, as in Fig. 3, in which the motion of the power piston is transmitted directly to the blowing tub piston, or, as in Fig. 10, to a crosshead and crank, as described.

A packing or stuffing box (K) is fitted to the cylinder head (L) and around the piston rod (J) in order to allow free motion of the piston rod and at the same time prevent leakage of air from the cylinder.

Valves

The two sets of valves on compressors are termed suction or inlet valves, and discharge valves, and may be either mechanically operated or automatic.

Mechanically operated valves, are so called because they are connected with, and actuated by, some moving part of the machine, usually an eccentric fixed on the main shaft. In operation they are so timed as to open and close at the right time in relation to the piston stroke.

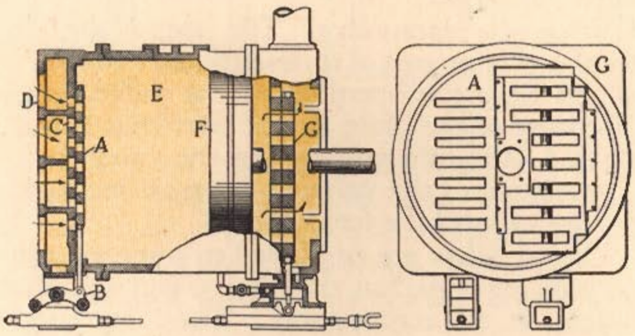


Fig. 11—Blowing tub fitted with grid valves

Automatic valves depend on a difference in air pressure on the two sides of the valve for their action. The difference in pressure may be slight, which is desirable in the case of the inlet valves, or considerable in case of spring loaded discharge valves.

The types of valves employed by the principal manufacturers of air compressors and blowing engines are of the grid, poppet, corliss, plate, flap and leather disk types. The determining factors being the volume, pressure and the condition of the air to be dealt with. There has always been a general preference for mechanically operated inlet valves with automatic discharge valves, but the tendency toward high rotative speed is bringing about the use of automatic valves for both the inlet and discharge. Blowing engines are frequently equipped with positively operated grid valves of various forms which take their motion from the main shaft. This type of valve is not employed on air compressors.

Grid valves (Fig. 11) are used on blowing tubs exclusively. A grid valve is a large plate regularly slotted or perforated, working on a similarly slotted stationary seat. When in one extreme position, the openings in the valve and those in the seat register, permitting air to pass freely through. When in the other extreme position the openings in the valve are opposite the bars or seats between the openings in the stationary part and the bars of the valve are, likewise, opposite the openings in the stationary part or seat, so that air cannot pass.

The Operation of Grid Valves

Referring to the part sectional view, Fig. 11, the slotted suction valve (A) is operated by means of a lever (B) and a valve stem. The openings in the valve (A), as shown, do not exactly coincide with the openings (C) in the cylinder head (D), because the operating mechanism has begun to close the valve. A small movement of the valve, by this construction, gives a large port opening which permits a large volume of air to easily enter the cylinder (E) as the piston (F) moves, in the direction indicated by the arrow on the piston rod.

In a similar manner the discharge valve (G) is timed to open when the air in the cylinder has been compressed to the desired pressure. The compressed air is forced out of the cylinder through the port openings in the valve and the cylinder head, by the movement of the piston (F). Fig. 11 shows, in section, only the inlet valve (A) at the left and the discharge valve (G) at the right. The blowing tub is, however, equipped with both inlet and discharge valves in each cylinder head.

Plate valves (Fig. 12) are employed in both blowing engines and air compressors. They vary in design but all are automatically operated, i. e., opened and closed by a difference in air pressure acting on the two sides. The plate valve has recently been highly developed, so that it will operate satisfactorily at high speed and quick reversals.

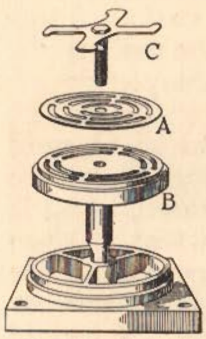


Fig. 12—Detail plate valve

A plate valve consists of a thin, flexible, slotted, steel disk or plate (A—Fig. 12), which closes the openings in the valve seat (B) when the plate rests on the seat. A spider or cross piece (C), bolted through its center to the valve seat (B) holds the plate (A) in a central position, allowing the flexible plate enough freedom of motion to lift off the seat. With a slight difference in air pressure in one direction the plate lifts off its seat and the air passes through the openings or slots in the valve seat (B) and the valve (A). Some discharge valves are spring loaded, that is, the plate is held against the seat by a spring until there is sufficient air pressure to lift the valve against the action of the spring.

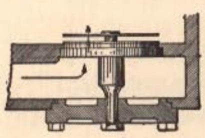


Fig. 13—Valve assembled

Fig. 13 is a sectional view of a plate valve assembled and attached to a cylinder head. The main feature of this design is the large port area or openings obtained, with relatively slight valve movement.

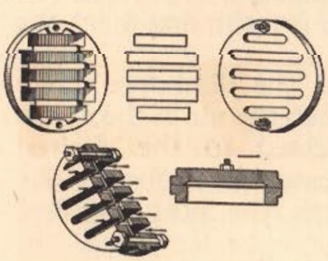


Fig. 14—The feather valve

Fig. 14 shows another form of plate valve that is used for either inlet or discharge. This is known as the FEATHER (U. S. Reg.) valve. It is made up of a number of individual flexible steel strips that close the opening in the valve seat. These strips or valves are held in place by a guard plate that permits motion by flexture only. This construction is suitable for relatively high speed and is practically noiseless in operation.

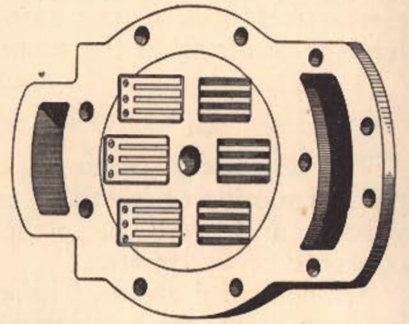


Fig. 15—Finger type valve

Finger valves: Fig. 15, is an illustration of the "finger" valve, a modification of a plate valve. The plate is slotted for the greater part of its length into "fingers" which close the openings in the valve seat. The base of the plate, or the part that is not slotted, is rigidly attached to the valve seat. The motion of the valve or fingers is through flexure beyond the fixed end.

Corliss valves are employed to some extent on blowing tubs, but they find a wider application in air compressors. They are used mainly as inlet valves, but they are sometimes used as both inlet and discharge valves on blowing tubs.

A corliss valve is, part-cylindrical in form, relatively long and of small diameter and is usually made of cast iron. In its simplest form, the central portion (A—Fig. 16) is cut away to form a passageway for the air. The cylindrical ends (B) fit into the bored valve chamber that acts as the bearing for the ends and the seat for the valve.

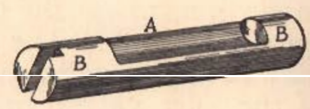


Fig. 16—A Corliss valve

The valve is accurately fitted into this bored chamber and is given a rocking or oscillating motion by the valve gear actuated from the main shaft.

The motion of the valve causes the port in the passageway, from the inlet pipethrough the valve chamber to the cylinder, to be opened and closed at the proper time, thus allowing air to enter the cylinder during the suction stroke and cutting off the air supply just before the compression stroke begins.

The poppet valve (Fig. 17) is the most commonly used type of air compressor discharge valve. The thimble shaped valve (A) has a straight line motion within a cylindrical guide (B) in the direction of, and away from, the valve seat. The spring (C) holds the valve on its seat (D) until the air pressure is sufficient to lift the valve off its seat. The air then passes out through the openings (E) in the cylindrical guide (B). These valves are of unit construction and the valve and seat may be removed from the cylinder head intact. This facilitates regrinding and cleaning the valve and seat.

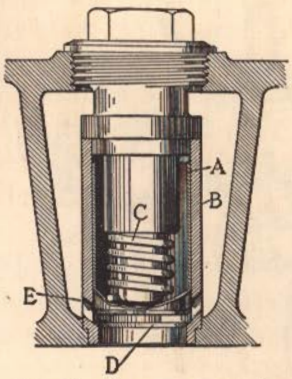


Fig. 17—Poppet type valve

Flap and leather disk valves were at one time quite generally used on blowing tubs.

Flap valves consist of plates that swing on hinges. Discharge flap valves open against the action of a spring.

Leather disk valves are disks of leather mounted between a convex plate (facing the seat) and a flat valve seat. The leather valve is kept in place by a bolt through its center and when opened by the passage of air it is forced against a convex plate.

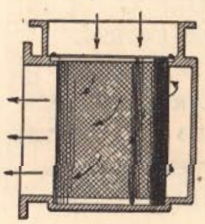


Fig. 18—Strainer

Air strainers (Fig. 18) should be fitted to air intake pipes when the air is laden with grit as it sometimes is. The strainer may be made of wire gauze screen, and may also contain cotton, wool, or fibre, as a medium to retain the impurities. If such impurities reach the compressor they will adhere to the oil film and the mass will bake together, form an objectionable deposit resulting in the necessity of shutting down the machine for frequent cleaning of the valves, otherwise explosions may occur.

If the intake air temperature is high, more power will be required to deliver a given volume of compressed air and higher temperature is also produced in the compressor making lubrication difficult. The intake air should therefore be taken from a cool place outside of the compression room and should be as clean as possible.

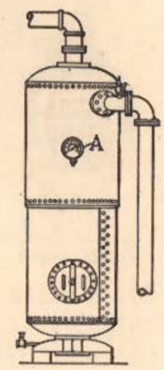


Fig. 19—Receiver

Receivers (Fig. 19) minimize the pulsating effect of the strokes of the compressor piston and prevent rapid fluctuations of pressure, i.e., to act as reservoirs of power and as equalizers, storing up air when the demand decreases and giving it up when the demand suddenly exceeds the supply. They also afford an opportunity for the air to cool somewhat and deposit the moisture with which it is more or less saturated, before passing out in the lines. Receivers are sometimes fitted with coils or pipes through which cold water is circulated to assist in cooling the air. Such receivers are called "intercoolers" or "aftercoolers" dependent upon their position in relation to the compressor.

An intercooler (Fig. 20) is a chamber in which the hot, compressed air comes in contact with tubes (A) through which cooling water is circulated. The water absorbs heat from the air, reducing it to approximately the temperature of the cooling water, in an efficient intercooler. The air then passes from the intercooler to the next stage or cylinder to be further compressed. Intercoolers may be placed between the cylinders of compressors of any number of stages and in order to still

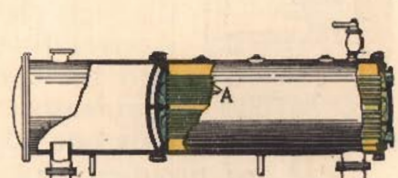


Fig. 20—Horizontal intercooler

further reduce the heat of compression an aftercooler of similar construction is sometimes used.

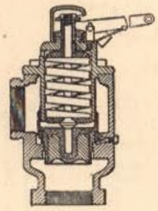


Fig. 21—Spring safety valve

Pressure gages: A pressure gage (A.—Fig. 19) is used to indicate the air pressure within a receiver or other enclosure.

Safety valves are automatic escape or relief valves that lift when acted upon by a pressure for which they are set or adjusted. A safety valve (Fig. 21) is fitted to receivers and sometimes to cylinder heads, in order to prevent the air pressure rising beyond a predetermined point. If air is not drawn from the receiver for use and the compressor continues to deliver to it, the pressure will, of course, build up in the receiver and must be allowed some escape.

Safety valves are sometimes placed in the compressor cylinder heads to relieve the cylinder of excessive pressure. If for any reason the discharge valves fail to act the relief valves are opened by the air pressure, when it rises slightly above the normal discharge pressure, allowing the air to be discharged to the atmosphere.

Check valves are so designed as to allow flow in one direction but prevent a return flow. A check valve (Fig. 22) should be fitted in the air pipe line between the compressor and the receiver. This check valve prevents the high pressure air in the receiver from blowing back into the compressor if, for any reason, the compressor discharge valves are out of order.

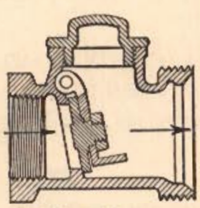


Fig. 22—Check valve

Speed and pressure regulators are usually used to automatically regulate the action of compressors. The usual intermittent operation of machines using compressed air, causes rapid and extreme changes in the demand for air and, as a result, considerable fluctuation in the receiver pressure. It therefore, becomes necessary to supply air rapidly when the demand is great and to cut down or stop the supply altogether when there is little or no demand in order to keep the receiver pressure nearly constant and avoid wasting air, and consequently power, by "blowing" at the safety valve.

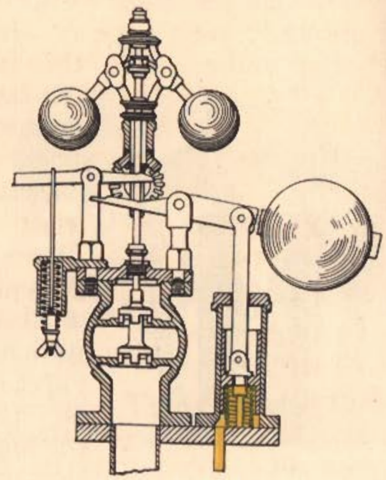


Fig. 23—A throttling governor

The speed governor (Fig. 23) limits the speed of the compressor through its source of power, such as a steam or gas engine and the governor may in turn be controlled by the air pressure in the receiver. When the pressure in the receiver falls the governor allows the compressor to "speed up" which brings about an increased delivery of compressed air to supply the increased demand and build up the pressure in the receiver. On the other hand if the pressure in the receiver rises too high, the governor brings about a "slowing down" of the compressor, decreasing the supply of air.

Unloaders: At times, the demand for air may cease entirely for a short period. It is not desirable to allow the compressor to come to a standstill during these periods, consequently provision is made to discontinue the delivery of compressed air and "unload" or take the work off the air cylinder. When "unloaded" the compressor continues to operate but consumes only enough power to overcome the friction, no useful work being done. Such devices are called unloaders.

Their action may be described as follows: As the demand for air decreases the speed governor slows down the speed of the compressor. Then if the demand ceases altogether the unloading mechanism acts, either closing the intake air valves so that no air can enter the cylinder to be compressed (A—Fig. 24) or holding them open so that the air may escape without being compressed, (B—Fig. 24) or else opening the discharge valves admitting the air at receiver pressure at each end of the cylinder at the same time (C—Fig. 24). The pressure on each side of the piston being equal, no useful work is performed, so that the compressor takes only enough power to overcome the friction of the machine while continued in motion.

Their application is not limited to variable speed machines but is adapted to the complete automatic control of constant-speed crank-driven compressors as well. The compressor speed may be maintained constant, and the unloading device depended upon to stop air delivery when the predetermined pressure is reached.

Modulated unloaders: Some motor-driven air compressors, equipped with corliss inlet valves, are governed by closing the inlet valve before the end of the stroke (D—Fig. 24). This admits a variable amount of air to be compressed and is equivalent to the variable cut-off in steam engines, or to changing the length of the compression stroke.

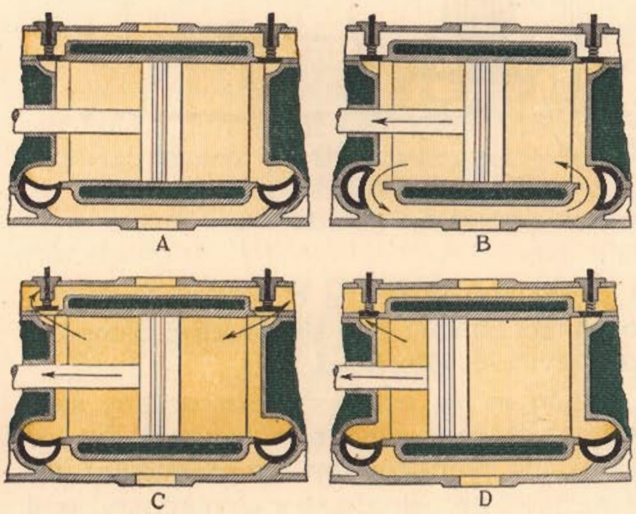


Fig. 24—The action of the four unloaders

Recapitulation: The supply of air may be diminished or stopped by any of the following means:

- Reducing the speed of the compressor;
- Keeping the inlet valves closed;
- Keeping the inlet valves open;
- Keeping the discharge valves open;
- Allowing the inlet valves to open during part of the suction stroke;
- Allowing escape at a safety valve.

OPERATION

THE *operation of air compressors* and blowing engines is identical and both may be described as follows:

The piston motion during the suction stroke (at one end of the cylinder), is away from one cylinder head and simultaneously (during the compression stroke at the opposite end of the cylinder), toward the other cylinder head. The first mentioned stroke creates a partial vacuum in the cylinder (N—Fig. 10) at the end of the cylinder from which the piston (H) is receding, allowing air to enter through the air inlet duct and valve of whatever type or design. This is termed the suction stroke with regard to the end of the cylinder under consideration. When the piston reaches the end of this stroke the inlet valve (O) closes. On its return stroke the piston compresses the air, trapped in the cylinder, to the discharge pressure so that it forces open the discharge valve (P). This is termed the compression stroke. When the piston reaches the end of this compression stroke and the compressed air has been discharged, the discharge valve (P) closes and the inlet valve (O) is again opened allowing a fresh charge of air to enter the cylinder during the next suction stroke, and the operation described is repeated.

While the operation described is taking place on one side of the piston (H) a similar set of events occur on the other side of the piston, the timing of the events being opposite, that is, air is being drawn in on one side of the piston, while compression is taking place on the other. The machine is therefore, double acting, delivering a "charge" of compressed air at each stroke of the piston and is single stage, having only one cylinder.

Operation of two stage compressors: Fig. 25 illustrates the operating principle of a two cylinder, double acting, two stage air compressor with an intercooler and after-cooler. The type in this case is horizontal and the cylinder arrangement is tandem, the cylinders being placed in a straight line formation. The motion of the piston is understood to be from left to right and the course of the air is shown by the arrows.

Action in the first cylinder: Air at atmospheric pressure enters through the air filter (A) and pipe (L) into the cylinder (M) through the open inlet valve (N). At the end of the suction stroke the inlet valve (N) is closed and the cylinder (M) is filled with air at atmospheric pressure. In a similar manner the cylinder was filled with air on the opposite side of the piston on its previous stroke and the motion of the piston compressed the air trapped in that end of the cylinder until the discharge valve (P) opened automatically allowing the compressed air to pass through the passage to the intercooler (C). So much of the operation is similar to (in fact is) that of a single-stage compressor previously described.

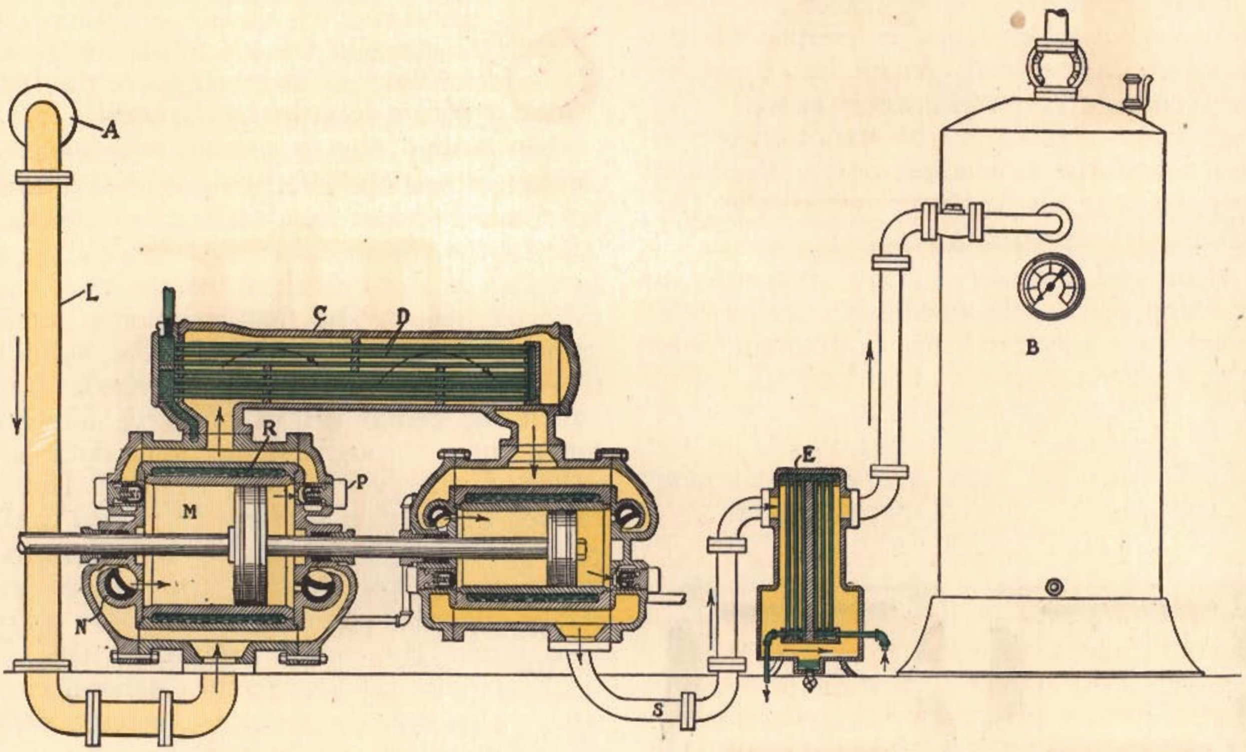


Fig. 25—Section of a two-stage compressor in which the course of the air may be traced

Action in the second cylinder or any subsequent stage is similar except that the air enters the cylinder from the intercooler (C) at a higher pressure (above atmosphere) and is discharged at a still higher pressure in a manner similar to that described, which in this case is the final delivery pressure.

Cooling: The air entering the intercooler has been heated by the act of compression but some of the heat has been absorbed by the water in the water jacket (R). In passing through the intercooler on its way to the second stage cylinder it comes in contact with pipes (D) through which cooling water is being circulated and a large part of the heat of compression is absorbed by the cooling water. The temperature of the air on entering the second-stage cylinder may, therefore, be approximately that of the cooling water. Leaving the second-stage cylinder by way of a pipe (S), the air is usually conducted to an aftercooler (E). Here the heat generated during the final stage of compression is removed by the cooling water as the air comes in contact with the cooling coils. The cooled high pressure air then passes to the receiver (B) where it is stored until drawn off for use as required.

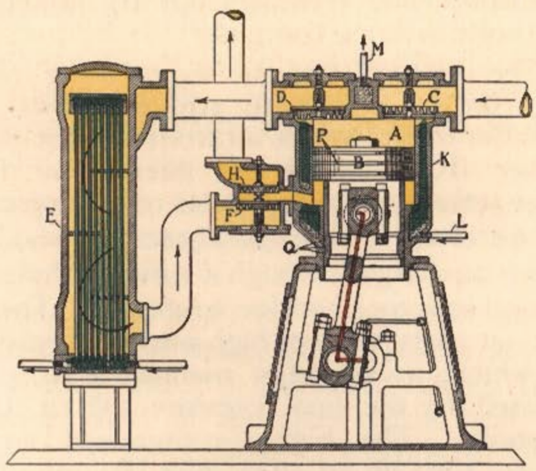


Fig. 26—Two-stage differential-piston machine

A two-stage vertical compressor which is single-cylinder, single-acting and of the enclosed type, with plate valves, is shown in section in Fig. 26. The piston (B) moving downward creates a partial vacuum in the top portion of the cylinder (A). This action automatically opens the inlet valve (C) and allows the cylinder to fill with air at atmospheric pressure. The piston (B) returning on its upward stroke discharges the air through the low pressure discharge valve (D) as the pressure in the cylinder equals the first stage discharge pressure. The charge of compressed air passes through the intercooler (E) and enters the lower portion of the cylinder below the larger end of the differential piston, through the inlet valve (F) as the piston moves upward. This cylinder space is in the form of an annular ring between the cylinder wall and the trunk type piston (B).

The piston moving downward compresses the air trapped in the lower portion of the cylinder driving it out through the discharge valve (H) to a receiver or the service line.

Machines of this type, built in two or more stages, are frequently used to atomize and assist in injecting the fuel into the cylinders of Diesel engines (at approximately 1000 pounds) and for starting the engine. For this purpose they are usually built as a part of the engine and are driven from the main crank shaft.

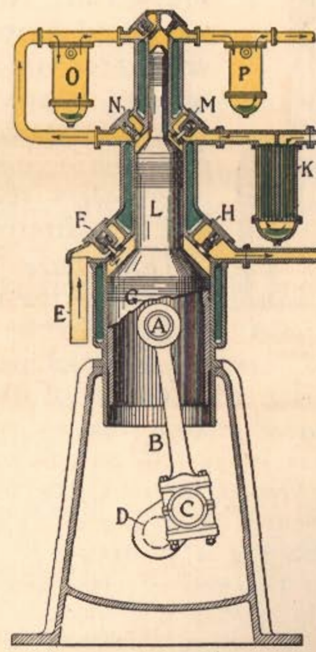


Fig. 27—Three-stages, single acting compressor

A three-stage compressor is shown in Fig. 27. The cylinders are in a vertical position with the smallest at the top. A three diameter trunk piston is made to suit this cylinder construction and each piston or section is equipped with piston rings.

To the piston pin (A) is fitted the small end of a connecting rod (B) the other end engaging the crank pin (C) of the compressor crank on the engine crank shaft (D). The revolving crank shaft gives motion to the crank and through the connecting rod, a reciprocating motion to the piston. Water, within the cylinder jackets and pipes in the coolers reduces the temperature of the compressed air. Atomized or vaporized lubricating oil and water vapor condenses and, nearly all, separates from the compressed air in the separators in the intercoolers (K and O) and the aftercooler (P).

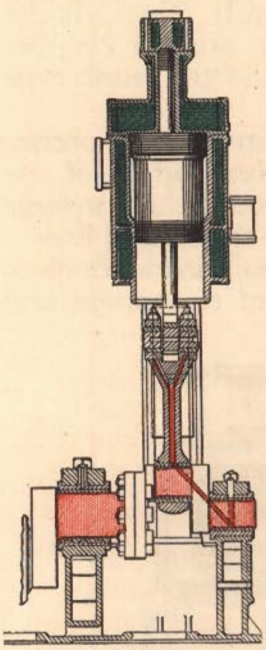


Fig. 28—Three stages in a modified form

Three-stage operation: Air enters the large first-stage cylinder through the air inlet passage (E) and valve (F) by reason of the partial vacuum created within the cylinder when the piston (G) is moved downward. When the piston is moved upward the inlet valve (F) closes and the air in the cylinder is compressed, (reaching a pressure of about 60 pounds) near the end of the piston stroke. This pressure causes the discharge valve (H) to open and the compressed air is discharged into the first-stage cooler (K) in which the air is cooled by contact with the cooling coils. The moisture and oil vapor condenses and separates out by falling to the bottom of the container.

The piston (L) of the second-stage cylinder, on its downward stroke, allows the cylinder to receive the air from the first-stage cooler (K), through its inlet valve (M) after which it is compressed on the upward stroke of the piston (to about 220 pounds) and is discharged through a valve (N) into the second intercooler and separator (O). Thence the air goes to the high-pressure cylinder in which, in a similar manner, it is compressed to the final pressure (about 1000 pounds). The highly compressed air is passed through an aftercooler (P) and often through a non-return valve to an air reservoir.

A modified form: It has been found, with the arrangement of cylinders described, that by reason of the partial vacuum in the first-stage cylinder during the suction stroke, there is a tendency to draw oil-laden vapor from the crank case past the piston, into the first-stage cylinder where it causes carbon trouble. To overcome this the second stage cylinder and piston is sometimes placed below, with the first-stage next above, and the last-stage at the top as shown in Fig. 28. Since the air pressure in the second-stage cylinder is always higher than that in the crank case, no crank case vapor can be drawn past the piston into this cylinder.

Pressure Distribution in Compressors

	Air pressure lb. per sq. in.
Two stage (to 1000 lb.)	
Leaving the first stage	120 to 150
Leaving the second stage	800 to 1000
Three stage (to 1000 lb.)	
Leaving the first stage	40 to 60
Leaving the second stage	120 to 220
Leaving the third stage	800 to 1000

COOLING AND STAGING

THE *principle involved* in the act of compressing air, or other gas, is that the heat of compression is equivalent to the work performed in increasing the pressure—heat and work being related and convertible values. Therefore, when air is compressed its temperature increases as its pressure is increased.

Compressors require jacket cooling to moderate the temperature if air is delivered at high pressure.

Means of cooling: Air compressor cylinders and cylinder heads are as a rule jacketed and cooling water is circulated within the jacket to carry off as much of the heat of compression as possible. Referring to Fig. 26, cooling water enters the water jacket (K) at the bottom through a pipe (L) and comes in contact with the wall of the cylinder (A) and the cylinder head. The water having absorbed some of the heat of compression is discharged through an overflow outlet (M) and may be wasted or passed to a cooling tower, tank or pond, whence it may be recirculated within the water jacket.

High Rate of Circulation

Rapid circulation of the cooling water is desirable and is sometimes produced by means of a circulating pump, in this way securing the cooling effect of a large volume of water.

Cooling effect limited: Only a small per cent of the total volume of the highly compressed air, delivered at each stroke, can come in contact with the water-cooled cylinder during the short period of compression. This limitation does not permit of much cooling effect on the air, the absorption of much of the heat of compression by the cooling water. It does, however, limit the temperature of the cylinder wall and heads to a reasonable degree.

Staging is a means of limiting the temperature range per cylinder. When air is compressed to a high pressure in a single stage, the power loss is great, due to the high temperature developed. To reduce the loss as much as possible, in high pressure compression, the final pressure is reached by two or more stages and intercooling. The air is first compressed to a moderate pressure in one cylinder and, on its way to the next cylinder, this slightly compressed air is passed through an intercooler where the temperature is considerably lowered and the volume or bulk correspondingly reduced, effecting a saving in power.

Stage Compression Saves in Power

By means of staging and intercooling it is possible to effect a great saving in the power necessary to perform the work of compression. For example, it will require about 20 per cent more power to compress a given amount of air to 100 pounds pressure in one stage than in a two-stage machine.

A modification or exception: If the compressed air is to be used at once and very near the compressor, there will be no material advantage in cooling the air, particularly in after-cooling it, because the hot air, on account of the heat it contains, occupies a larger volume than when cooled and will do more work. There is a saving, therefore, in allowing the air to remain hot until used whenever possible. The air is, however, generally used at a distance from the compressor and cools to atmospheric temperature in transit and the volume is correspondingly reduced and more work in the form of more air is required to supply the volume lost by cooling.

LUBRICATION

THE *object of internal lubrication* in air compressors is to provide a complete oil film on all frictional surfaces, and also to form an oil-sealing film to assist in preventing air leakage past the piston.

Oil is sometimes applied by means of an air compressor sight feed lubricator (Fig. 29) attached, in a vertical position, to the air cylinder. It consists essentially of an oil container (A), a feed regulating valve (B), and a ball check (C). In operation, the main valve (D) is open wide, and the regulating valve (B) is adjusted to the desired rate of oil feed. The oil thus admitted to the air cylinder is distributed over its walls, and the frictional surfaces of the valves.

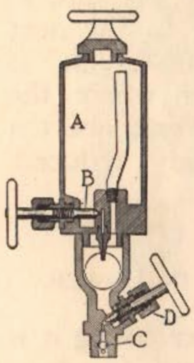


Fig. 29—Sight feed cup lubricator

Another method of cylinder lubrication is by means of the mechanical force feed lubricator (Fig. 35), having positive oil feeds. The number of feeds required depends upon the size of the compressor and the thoroughness of distribution of the oil desired. With such a lubricator the oil feed, once adjusted, remains constant and permits regulation for a minimum rate of feed, avoiding the possibility of accidental overfeeding.

Feeding oil direct: As a rule, it is best to feed the oil sparingly, uniformly, and directly to the frictional surfaces. In horizontal blower or compressor cylinders, the lubricating oil is introduced either through one lead at the center of the cylinder, at the top, or through three leads at three points, one at the top and one at each side below the highest point. The oil is spread by the piston and forms a complete sealing and lubricating film. The latter method is preferred.

In vertical cylinders, lubricating oil is introduced at two points, front and back, or at several points, evenly spaced, around the cylinder. Each oil inlet to the cylinder should be fed by an individual oil pump, so that each feed is controlled with certainty. If one oil lead is branched to several inlets to the cylinder, the oil will take the path of least resistance and flood some parts while other parts may be "starved."

Single-acting trunk pistons may be lubricated by means of the splash system whereby a moving part of the machine dips into the oil in the crank case, producing an oil spray that reaches all parts. It is of greatest importance that a constant oil level be maintained in the crank case, for if the oil level is too low the oil spray will be insufficient and some of the parts will be "starved." If the oil level is too high, there will be too much splash and an excessive supply of oil will work past the piston rings. This will result in the carbonization of the oil under the extreme heat of compression. Carbon accumulating on the discharge valves causes them to stick, especially if the air is dirty.

Valve lubrication requirements differ with different types of valves.

Grid valves of blowing engines are large and have extensive surfaces which must be directly lubricated by introducing the oil

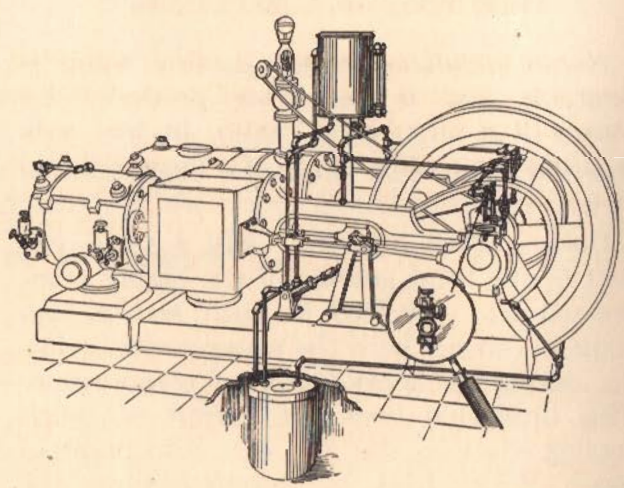


Fig. 30—A circulation lubrication system

at several points, uniformly but sparingly, so that the oil finds its way all over the entire surface.

Plate valves require no lubrication.

Corliss valves, of blowing engines and compressors, need lubrication on all rubbing surfaces, particularly at their ends. The oil must be introduced as directly as possible and uniformly. The practice of fitting grease cups to supply grease to the valve ends is not to be recommended, partly because grease does not spread readily over the rubbing surfaces and partly because it bakes together with the impurities in the intake air, forming a pasty, sludgy or varnish-like deposit, some of which may reach the valve chamber, and even the cylinder, causing excessive friction and wear.

Poppet valves and valve stems usually get sufficient lubrication from the oil carried by the air.

Flap valves require no lubrication except at the hinges. These hinges are oiled by means of feed pipes passing through the cylinder head.

Leather disk valves need no lubrication, but the leathers must be kept in good condition.

Systems of Lubrication

The external lubrication of an air compressor is accomplished by one or some combination of the following systems.

Circulation lubrication (Fig. 30). Oil is circulated through the bearings, drains into a sump and is returned by a pump which may supply oil to the bearings direct or through a gravity head tank. The oil may be delivered to the bearings under pressure or through controllable sight feed adjustments without pressure inside of the bearings.

Vertical air compressors employing this system of lubrication may operate at high speed, owing to the efficiency of the pressure circulation oiling system and to their vertical construction. This system is illustrated in Fig. 26. Oil is forced under pressure to the main bearings, crankpin bearing and piston pin bearing, and is splashed on the cylinder wall and lubricates the lower part of the trunk piston. Usually, sufficient oil passes the lower part of the trunk piston to lubricate the top portion also.

Care should be taken that the piston rings (P) and oil scraper rings (Q) on the lower part of the trunk piston are in good order and dowel-pinned so that they wear to a fit with the cylinder and keep oil and compression tight.

The oil pressure should not exceed 15 pounds because excessive oil pressure may cause too much oil spray to form and too much oil is likely to pass the piston.

When the unloader-governor operates by throttling the intake air, the high vacuum created in the cylinder tends to draw the oil into the cylinder past the piston rings. Splash guards fitted over the crank webs and tight piston rings will tend to prevent this and assist materially in reducing the oil consumption.

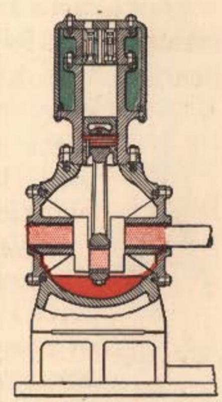


Fig. 31—Splash lubrication

Splash lubrication: Oil contained in an enclosed chamber is splashed to parts requiring lubrication by the dip of a moving part of the machine (Fig. 31). Fig. 10 is also a splash lubricated air compressor in which the rim of the crank disk (C) dips into the oil in the crank pit producing an oil spray, reaching all parts. If the oil level is too low, too little oil spray will be formed and some of the parts will be "starved" but if the oil level is too high, too much oil spray will be formed and oil will pass the piston and accumulate and carbonize upon the discharge valves. It is therefore important that the correct oil level be maintained.

Ring lubrication: (Fig. 32) Oil contained in the lower part of the bearing housing is carried to the rotating shaft through the motion of chains, rings or collars which roll or revolve with the shaft and dip into the oil. A ring-oiled bearing is shown in Fig. 32.

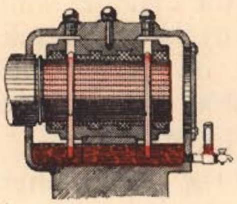


Fig. 32—Ring oiler

Drop feed lubrication: Oil contained in individual or multi-feed drop oilers (Fig. 33) is supplied at a regulated rate. Small parts, or those not subject to severe operating conditions, are served by this means.

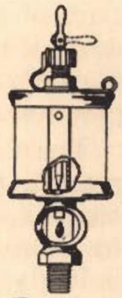


Fig. 33—Drop feed oiler

Hand lubrication: Oil from an oil can (Fig. 34) is applied to the bearings by hand at intervals Only the most minor parts may be satisfactorily left to this method of oil application.

Fig. 34—Hand oiler

Mechanical force feed lubrication: Oil contained in a lubricator is forced to the moving parts by one or more plunger pumps driven by the engine or machine. Fig. 35 shows a four feed (T & K) lubricator of this type. Mechanical force-feed lubricators may be used to supply the internal parts, as described under internal lubrication, as well as external parts such as main bearings, crank and piston pins, etc.

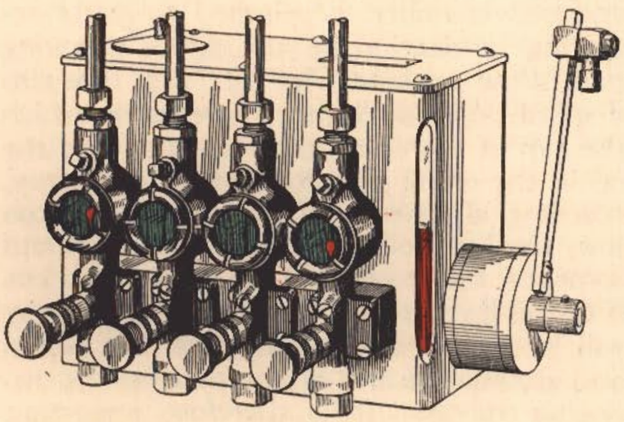


Fig. 35—A mechanical force feed lubricator

Grease lubrication: Grease is applied through specially designed cups (Fig. 36) or by hand. This is the means of lubrication sometimes used in place of drop feed or hand oiling.

Fig. 36—A cup for grease

OIL

THE *quality of the oil* used for the lubrication of air compressors, more particularly for the internal lubrication of cylinder and valve surfaces, is an important factor in their operation. In order to insure absolute safety in the operation, freedom from the carbonaceous deposits and the minimum of frictional losses or air leakage, it is imperative that lubricating oil be of the highest possible quality, without free carbon and its vaporizing tendencies reduced to the minimum.

Oil remains in the cylinder of an air compressor a long time because it is not overheated as in an internal combustion engine nor washed away as in a steam engine. Very little oil, therefore, is required if it is of the correct quality. The rate at which compressor oil should be fed is only about 10 per cent of the rate that steam cylinder oil is fed to a steam cylinder of the same size.

The correct quality oil will resist the oxidizing effect of the heated compressed air, and the correct body will spread and maintain a complete oil film, preventing air leakage or frictional loss.

Oil too heavy in body will not spread readily over the rubbing surfaces and there will be considerable "oil drag" on the piston, resulting in excessive friction loss and air leakage, because the oil film is not complete. Furthermore, impurities in the air will more readily cling to the heavy oil and bake into a carbonaceous deposit on the piston, discharge valves and valve spindles.

Oil too light in body must be used in excess to form and maintain the necessary oil film.

Incorrect oils, especially in the presence of dirty air, cause the formation of a carbonaceous or pasty deposit on the discharge valves, which interferes with their automatic operation. Foul valves ultimately fail to close properly, permitting the leakage of compressed air back into the compressor. The carbonaceous deposit may pass on into the pipe lines and receivers and, due to the very high temperatures of compression, may become heated sufficiently to ignite the mixture of vaporized oil and air.

Soap and water, which is sometimes used as a substitute for oil, is a poor lubricant and its use does not make the compressor explosion proof. Considerable deposit, that will ignite at a temperature of about 400 degrees F., is frequently formed as a result of using soap and water. Soap-water is good for cleaning the interior of an air compressor but the parts so cleaned must be thoroughly flushed with oil immediately afterward to avoid rusting.

EXPLOSIONS

E*XPLOSIONS in air compressors* and receivers are undoubtedly due to high temperature, as a result of bad operating conditions, which first causes the lubricating oil to vaporize and combine with the compressed air and form an explosive mixture and ultimately ignites the gas. If the cylinder temperature rises sufficiently high any lubricating oil will vaporize and decompose but an incorrect oil will greatly aggravate this trouble. It is sometimes difficult to determine the cause of an unusual increase in temperature which may bring about the decomposition of the lubricating oil.

The water jacket abstracts but little of the heat of compression from the air because air is a poor conductor of heat and only a small per cent of the volume of the compressed air can come in actual contact with the water jacketed surface of the cylinder during the limited compression period. The main function of the jacket is to keep the temperature of the cylinder wall down and make the lubricating and the operating conditions as easy and safe as possible.

High temperature: The most common cause of high temperature is air leakage past the piston or delivery valves, allowing hot compressed air to pass back into the air cylinder where it is re-compressed. At the beginning of the stroke, the air in the cylinder consists of that which was not discharged but remained in the clearance space at the end of the compression stroke. The air remaining in the clearance space re-expands and causes but a slight additional rise in temperature, but if there is considerable leakage back past an improperly seated discharge valve, the temperature will ultimately rise so high that the lubricating oil will gasify or decompose and burn.

The heat effect of air leakage back into the compressor cylinder past the discharge valves is cumulative, because the air so entering the cylinder has a high temperature resulting from the previous compression and its temperature is further increased by each successive compression. High initial temperature is reflected in a correspondingly higher discharge temperature. It is obvious, therefore, that a few strokes of a compressor under these conditions will sometimes develop a temperature sufficiently high to vaporize and decompose even the best grade of air compressor oil and possibly cause a serious explosion.

Failure of discharge valves to operate properly may, as a rule, be traced to one or more of the following causes: The use of an incorrect oil that carbonizes rapidly and causes the valves to stick; the overfeeding of oil, and impurities in the air that collect on the valve seats and in the air passages and bake into a hard carbonaceous deposit.

High pressure which is local and not shown by the pressure gage, may be the cause of an explosion. Such increase in pressure may be caused by the choking of the discharge passages with a carbonaceous deposit. Improperly designed air passages or too many bends or elbows in the pipes also cause high temperature.

Slow combustion may result in so much heat that the parts affected may become distorted and weakened to such an extent that they are incapable of resisting the normal working pressure and fail—a subnormal condition of strength of the container—or

Rapid combustion, generally termed explosion, may increase the pressure to such an extent that some part of the container gives way—an abnormal condition of pressure.

Similarity of Results

The result, in either case, may be the same, or indistinguishable, yet the causes or conditions leading up to the failure are entirely different. In the first instance it is cumulative, i.e., a carbonaceous deposit is formed gradually and finally takes fire. The extent of the accumulation largely determines the length of time combustion will continue and the intensity of the heat. In the second case, the compressor may or may not be free from a carbonaceous deposit but working (momentarily or continuously) at a sufficiently high temperature to ignite an oil vapor that may be present.

An oil that vaporizes at the normal working temperature of the compressor is a continual source of danger requiring only slightly abnormal conditions to bring about ignition and an explosion.

An oil that carbonizes or collects carbonaceous material will surely cause trouble in time if the compressor is not frequently cleared of such deposit.

Ignition and combustion may occur without an actual explosion and may cause a foul or poisonous gas which, passing out of the exhaust of machines and tools in poorly ventilated rooms or in mines, may cause discomfort and even death to those near by. Consequently, every precaution should be taken to maintain the compressor in proper running condition to prevent combustion.

Precautions Against Explosions

(1) *Clean inlet air*, as cool and clean as possible, should always be used. This is conducive to economy in operation and helps to keep down the final temperature and prevent the formation of deposits.

(2) *Water cooled cylinders* should be completely water jacketed, including the cylinder heads, and liberally supplied with cold water. The cooling water should always be turned on before the compressor is started. It is good practice to circulate the cooling water for some time after the compressor is shut down, to carry away the heat in the metal of the cylinder. Scale is likely to form within the water jacket if the circulating water is allowed to get too hot.

(3) *Stage compression*, with efficient intercoolers and an aftercooler, will eliminate the danger of high cylinder or receiver temperature because the air is moderately compressed in each stage and is partly cooled between stages so that the highest temperature developed is less than in single-stage machines. The leakage of air from one side of the piston to the other and the leakage back past the discharge valves is less as the difference in pressure is less.

(4) *Inspection and cleaning:* The valves, discharge pipes, coolers and the receiver should be regularly and frequently inspected, cleaned and drained of oil and water. In

multiple stage air compressors, the discharge valves should be examined every week, the low pressure valves every month and the receiver and coolers should receive regular attention every month to six months depending upon the severity of operating conditions.

(5) *Temperature observations* should be regularly taken of the intake and discharge air and the cooling water. An abnormal rise in temperature is a sure indication of trouble and the air compressor should be immediately slowed down or stopped until the trouble is corrected.

(6) *Lubrication:* A sparing and uniform supply of high grade compressor oil should be applied by a lubricator capable of positive delivery and regulation. An excessive supply of oil will cause trouble. Only about 10 per cent. of the amount of oil that would be fed to a steam engine cylinder should be fed to an air compressor cylinder of the same size.

(7) *Gages should be tested* periodically and corrected by comparison with a standard gage.

(8) *Kerosene oil should never be used* for cleaning the compressor, valves or pipes internally. The flash point of kerosene is 120 to 150 degrees F. and, if any of this oil is allowed to come in contact with the hot compressed air, an explosion is almost sure to occur. Soap and water should be used for cleaning after which the surface should be thoroughly coated with compressor oil to prevent rusting.