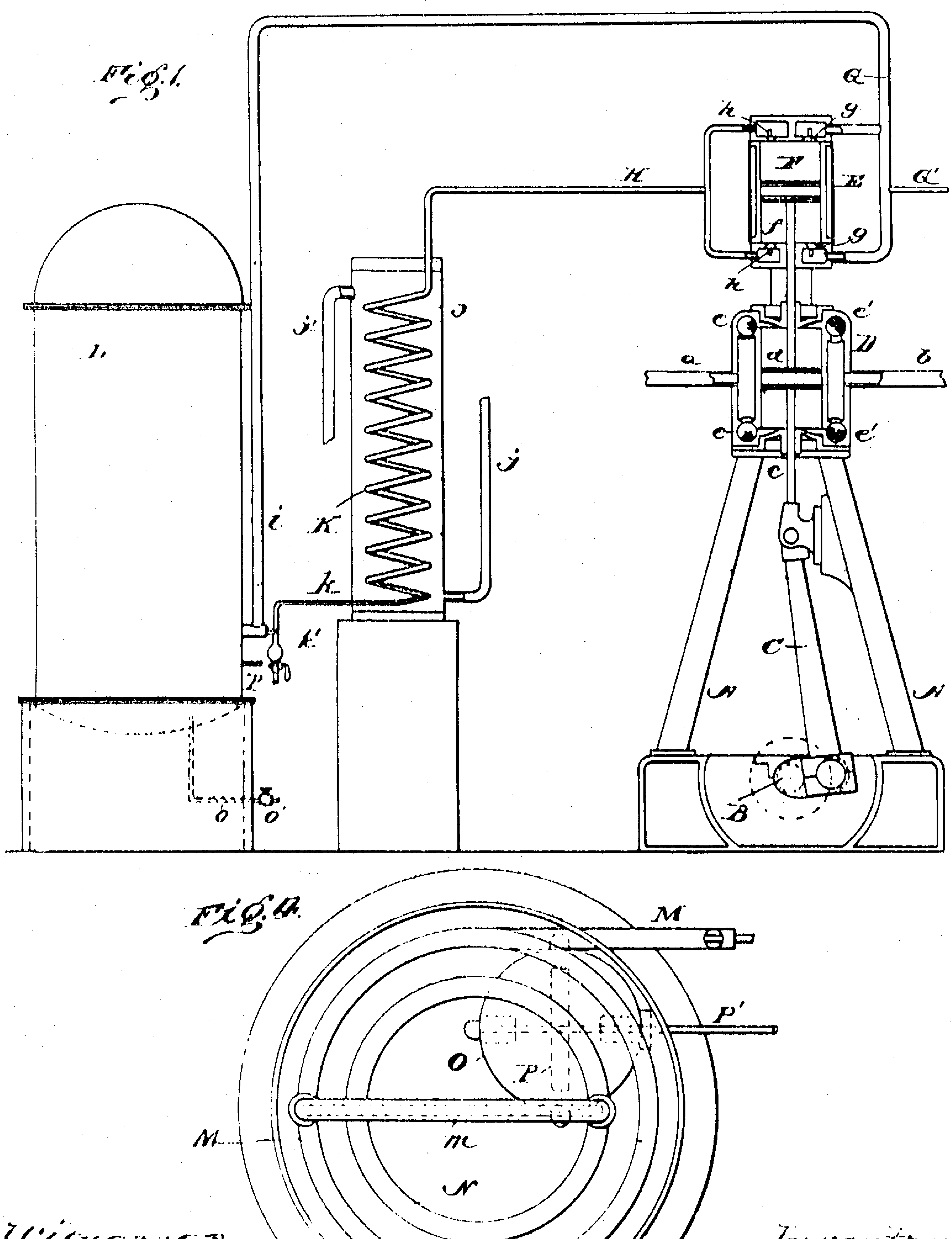
No. 627,696. Patented June 27, 1899.

J. E. JOHNSON, Jr.

APPARATUS FOR LIQUEFYING GASES.

(Application filed July 20, 1898.)

(No Model.) 3 Sheets—Sheet 1.



Witnesses:
J. M. Fowler Jr.
Walter B. Payne.

Inventor:
Joseph E. Johnson, jr:
by Henry H. Bates,
Attorney.

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(No Model.) 3 Sheets—Sheet 2.

Fig. 3.

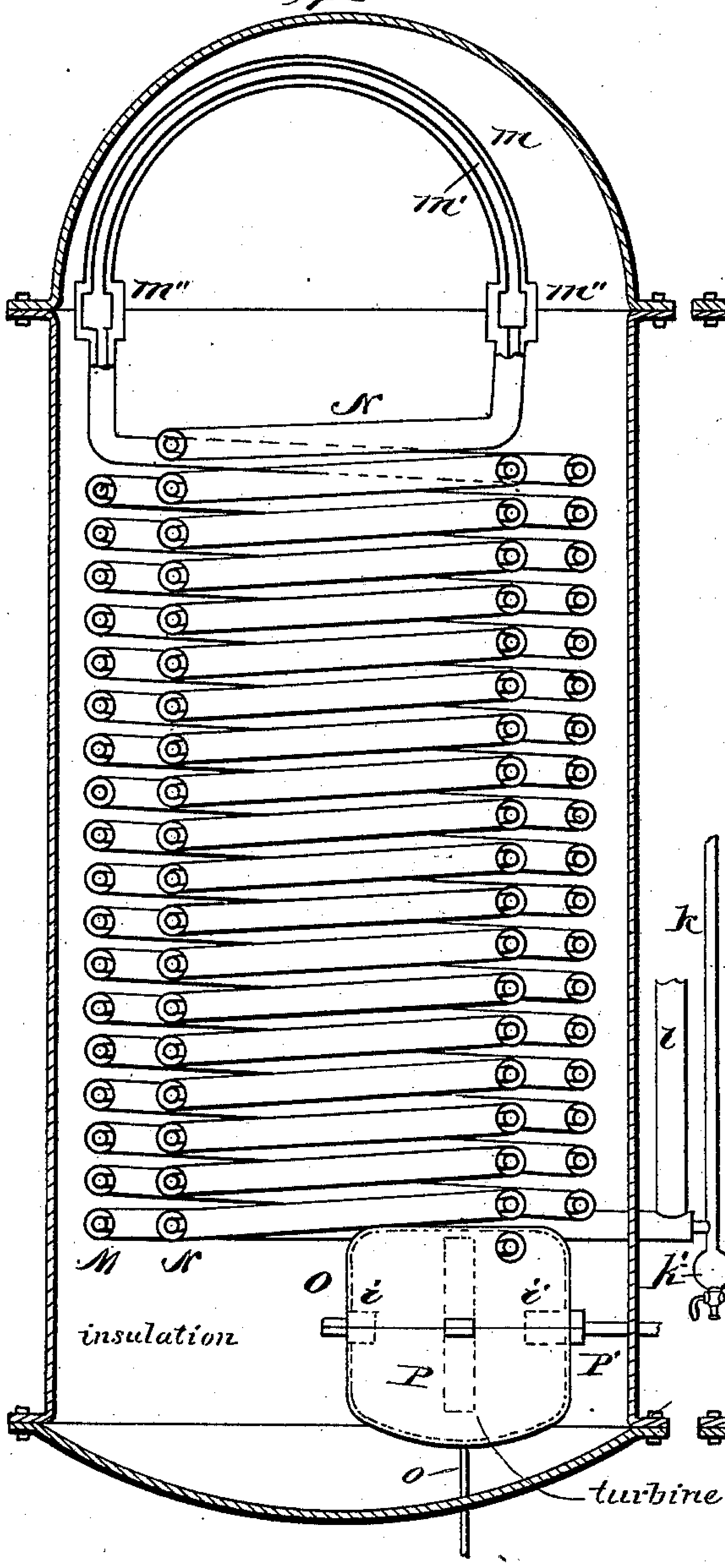

Fig. 2.

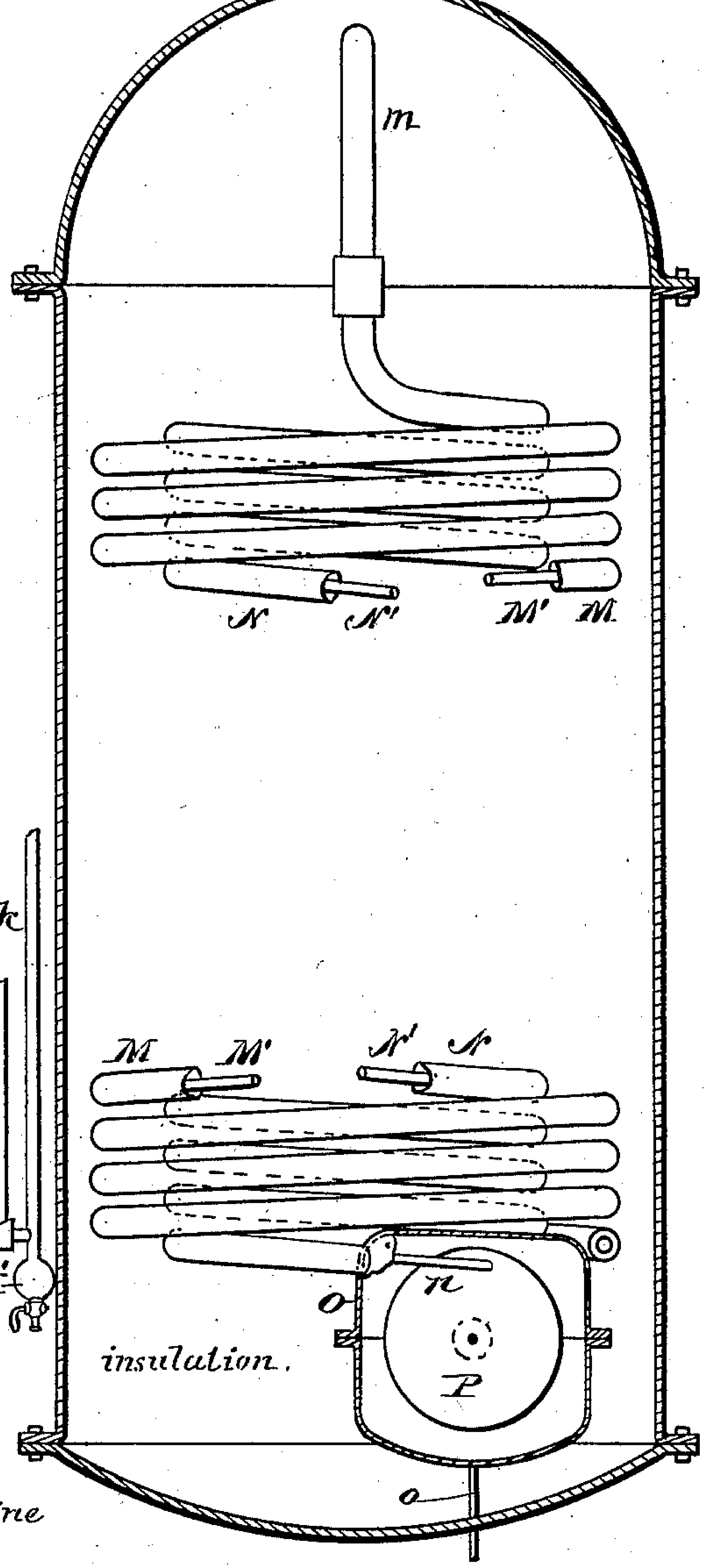

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Fig. 6.

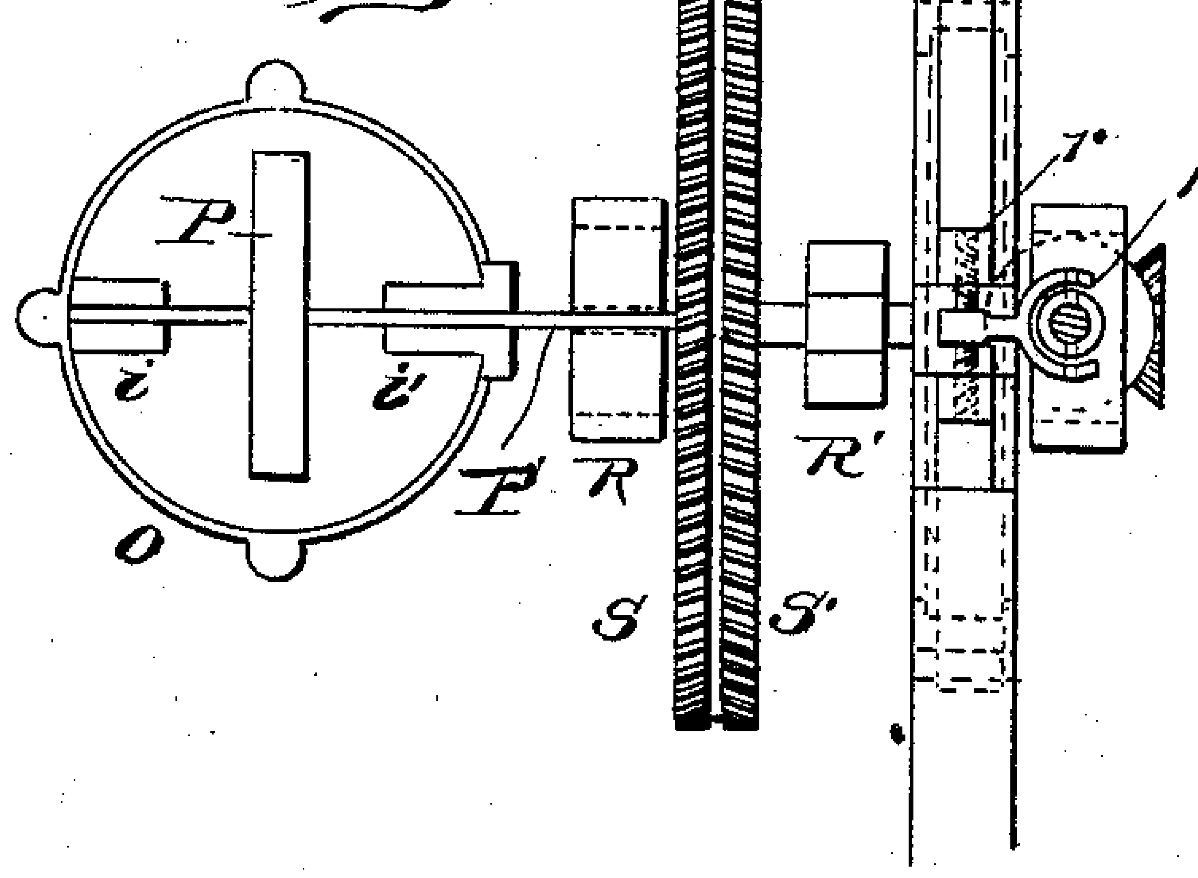


Fig. 7.

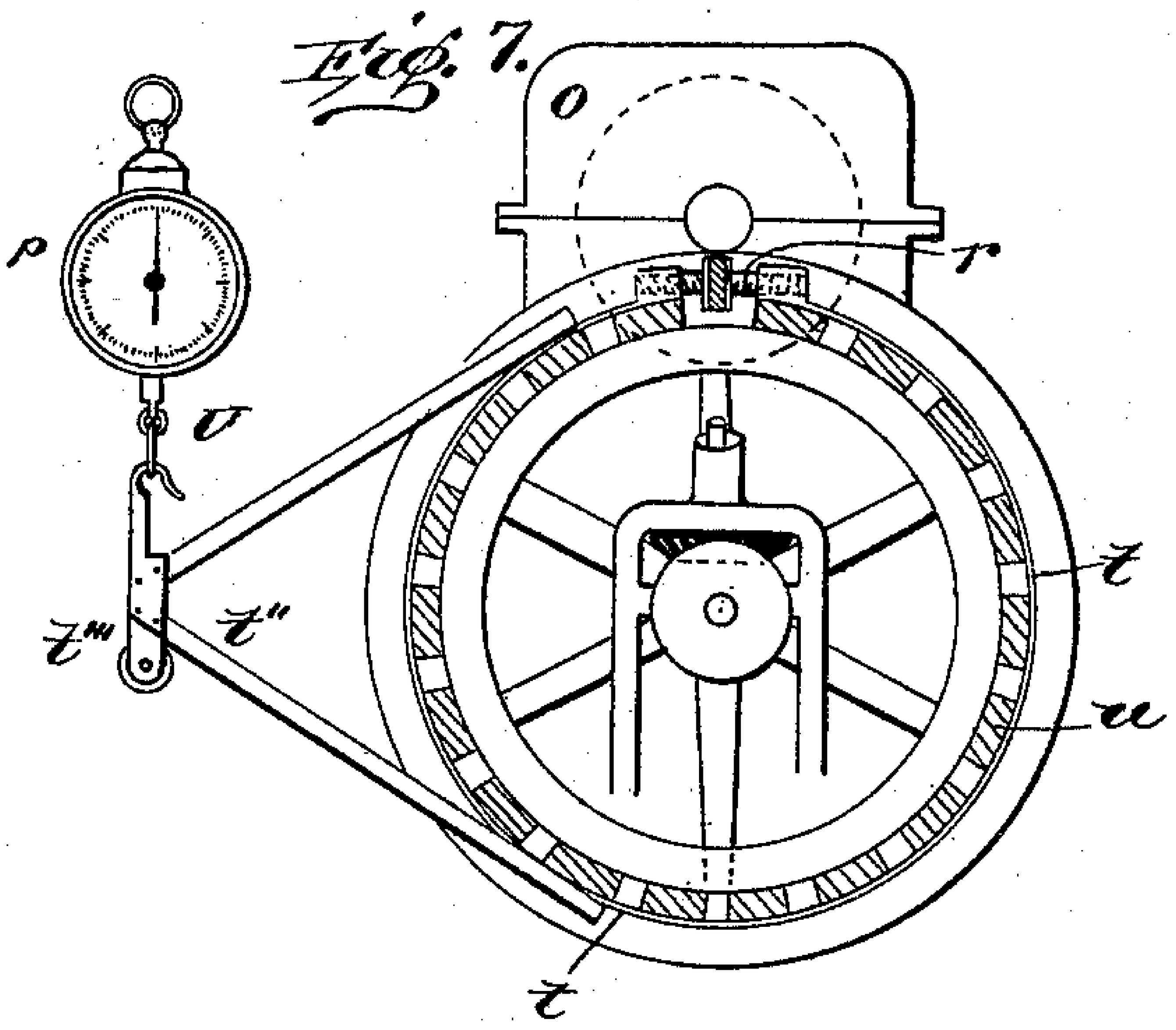


Fig. 8.

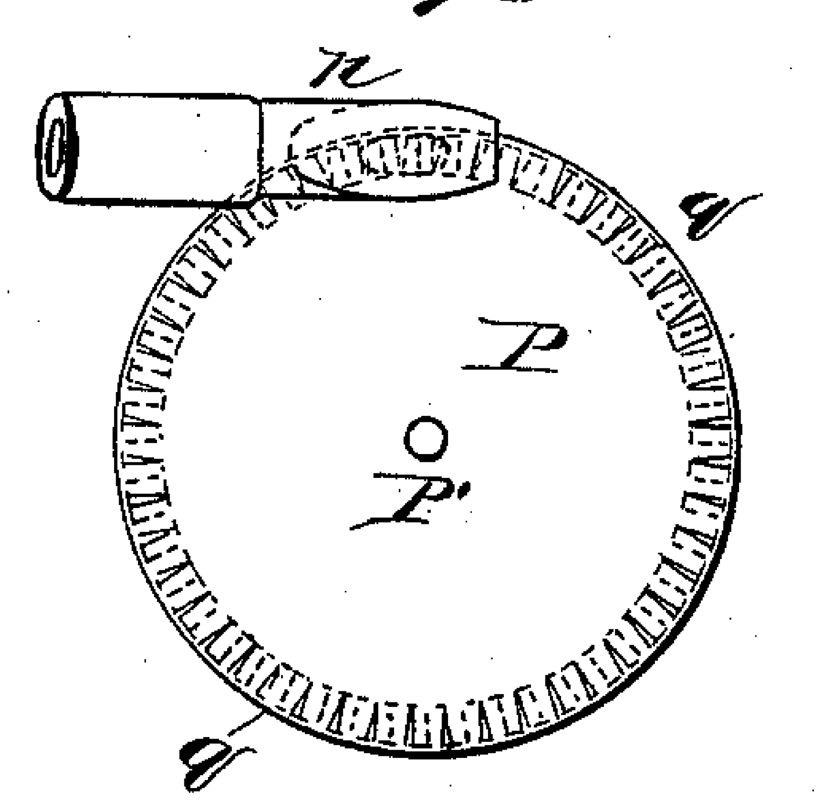


Fig. 5.

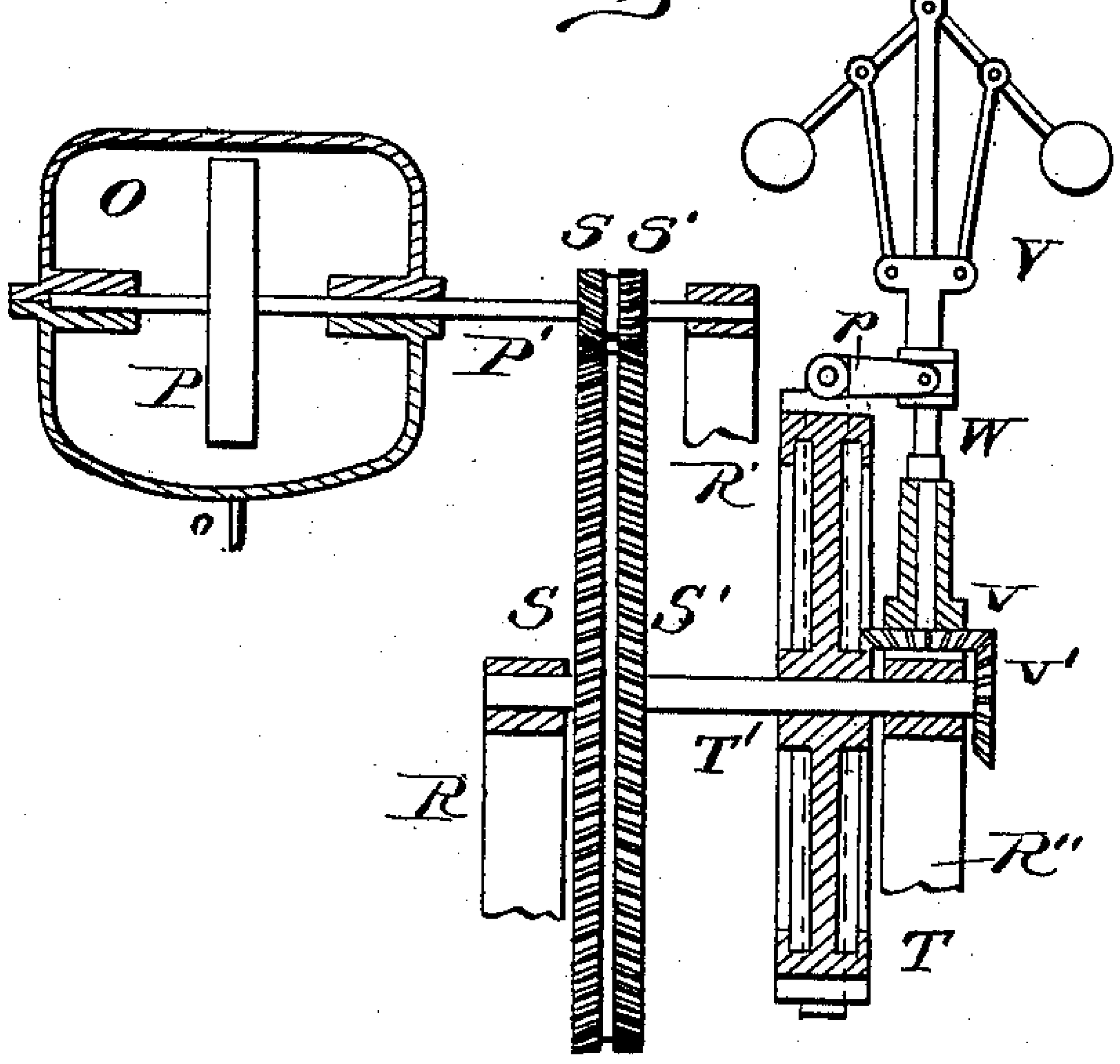
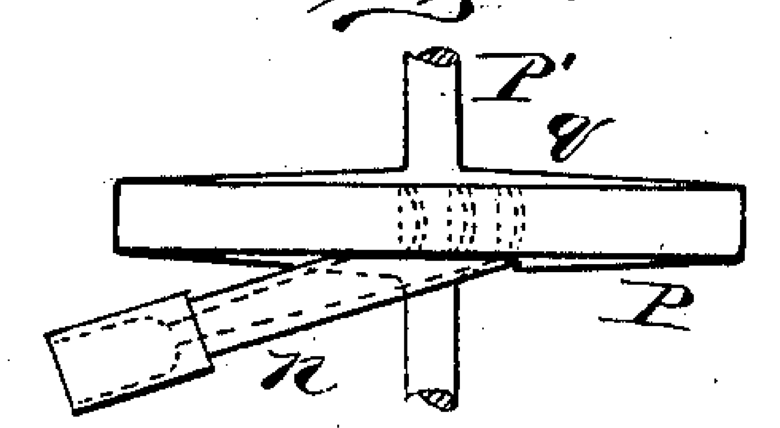


Fig. 9.



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Inventor:
Joseph E. Johnson, jr.
by Henry H. Bates,
Attorney.

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UNITED STATES PATENT OFFICE.

JOSEPH ESREY JOHNSON, JR., OF LONGDALE, VIRGINIA.

APPARATUS FOR LIQUEFYING GASES.

SPECIFICATION forming part of Letters Patent No. 627,696, dated June 27, 1899.

Application filed July 20, 1898. Serial No. 686,464. (No model.)

To all whom it may concern:

Be it known that I, JOSEPH ESREY JOHNSON, Jr., a citizen of the United States, residing at Longdale, in the county of Alleghany and State of Virginia, have invented certain new and useful Improvements in Apparatus for Liquefying Gases; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

My invention relates to improvements in means and apparatus for the liquefaction of the so-called "permanent" gases, of which air is a type; and it consists of a combined group of appliances for, first, compressing the gas mechanically to bring it into a condition for subsequent expansion and cooling by convective means; second, means for the reduction of the gas so compressed to the lowest temperature possible for the attainment of the critical point of temperature at which it is possible for said gas to assume the liquid form, and, third, means for abstracting the remaining energy of said gas, which becomes apparent in molar form when the gas is relieved from pressure and allowed to escape and expand in the form of a jet, said latter means consisting of a rotary motor or similar mechanical appliance for doing work which will run without lubrication and can therefore be placed in proximity with the liquid air or other permanent gas in an intensely-cold chamber, where its presence is required to effect its function and where motors of the reciprocating type are practically inoperative. By these three conjoined means the inherent energy of the gas, which is the cause of its persistent gaseous form, is so far reduced and abstracted that a portion of the gas becomes liquid and inert at each successive passage through the cycle and is easily kept in that condition so long as its temperature is kept below the boiling-point of the gas at atmospheric pressure, which can be done by suitable means for heat insulation.

In the drawings forming a part of this specification, Figure 1 represents in a diagrammatic way the main elements of a motor, a compressor, a cooler, and an insulating vessel containing a counter-current apparatus for the reduction of temperature to or below the critical point, with other appliances not shown. Fig. 2 represents in enlarged view said insulating vessel in vertical section, showing counter-current coils and means for abstracting the final molar energy of the high-pressure jet—namely, a turbine wheel for doing mechanical work. Fig. 3 is a vertical sectional view of the same insulating vessel, taken at right angles to that of Fig. 2. Fig. 4 is a plan view of the same vessel and coils. Fig. 5 is a vertical sectional view of the liquid-air receptacle with contained turbine, a form of brake mechanism for doing work, intermediate gearing, and governor for regulating the speed of the mechanism to the point of maximum work. Fig. 6 is a plan view of same in part. Fig. 7 is a side elevation of same, partly in section. Fig. 8 is a detail view in elevation of one form of turbine wheel adapted for the purpose herein described. Fig. 9 is a plan view of same, showing expansion-nozzle for issuing the compressed jet.

Like letters of reference indicate like parts.

I will first describe the already-known elements of my apparatus in detail.

In Fig. 1 at the extreme right I have shown a diagram of a motor, which may be a steam-engine of any well-known type adapted to the purpose of operating a compressor. In the figure the engine is of the Corliss type, in which A A are the supporting-standards; B, the fly-wheel shaft; C, the connecting-rod; *c*, the piston-rod; D, the cylinder; *d*, the piston; *a*, the steam-inlet; *b*, the steam-exit, and *e e e' e'* the rotary valves. Above said engine is a diagram representing a compressor of ordinary type, which may be simple or compound, of which E is the cylinder; F, the piston; *f*, the piston-rod; *g g*, the inlet or induction valves; *h*, the exit or eduction valves. G is an induction-pipe conducting gas at low pressure to the induction side of the compressor. G' is an induction-inlet supplying fresh gas, which may be air at ordinary temperature and pressure to make good the deficit occasioned by liquefaction. H is the eduction-pipe conveying compressed gas at high pressure to the cooler. J is a cooler having means for carrying a current of cool water constantly through the same in pipes *j j'*, the former being the induction and the latter the eduction pipe, or vice versa.

K is a coil of pipe located in cooler J, being a continuation of pipe H, carrying the compressed air to be cooled. L is a vessel insulated as thoroughly as possible against the entrance of heat to the contained mechanism either by being packed with non-conducting material or by any other available means, such as a vacuum, which is one of the most efficient. It contains counter-current coils for reducing the temperature of the highly-compressed air to the lowest point possible, a liquid-gas receptacle, and a means for abstracting the remaining energy from the cooled and compressed gas. Said counter-current coils consist of the helically-wound pipe M, containing within itself the smaller helical pipe M′, the latter being a continuation of pipe *k*, which affords exit for the compressed air from the pipe K in cooler J. Said pipe *k* where it enters vessel L is provided with a drip-trap *k*′ and suitable cock. The two above-mentioned pipes M M′ continue their course in the bend *m m*′, coupled at *m*″ *m*″, and return downward in the double helical coil N N′ until they reach the liquid-gas receptacle O, where the outer pipe terminates, being secured thereto and opening into the same, while the inner pipe N′ enters the said receptacle and terminates therein in the form of an expansion-nozzle *n*. The pipe M where it enters the insulating vessel L is connected by a branch *l* to the pipe G, leading to the induction side of the compressor.

It should here be remarked that the counter-current coils above described are so arranged that the entering compressed gas flows upward continually through the first part of its course, so that as it gradually gets colder and any contained moisture is condensed out of it said moisture runs back down the coil and into the trap provided for that purpose. On the contrary when the gas is approaching liquefaction by continual loss of temperature and increasing density it is desirable that it should run downward, and this is accordingly provided for by its course in the inside coil N′.

The liquid-gas receptacle O is hermetically tight except for the pipe connections N N′ and the liquid-gas-exit pipe *o*, supplied with a cock *o*′. Within this liquid-gas receptacle O is contained the provision before referred to for causing the jet of compressed gas as it issues from the expansion-nozzle to do mechanical work, and thereby exhaust its remaining inherent energy of condition. The means which I prefer to employ is an impulse-wheel or reaction-motor of proved efficiency, which may be either a tangential wheel of the Pelton type or a turbine of the De Laval type, such as is illustrated in the drawings, or a compound turbine, in which the gas is exhausted in steps or stages like those of a compound engine through a series of turbines on one shaft until the velocity of the gas is reduced to zero. The principle of the simple reaction or impulse wheel is to receive the impinging jet in buckets of such form and configuration as to practically reverse the direction of motion of the jet and move away from it at approximately one-half its initial velocity, whereby the final velocity of the impinging mass is reduced to zero, its energy of motion having been transferred against resistance to the revolving wheel.

The species of reaction-motor which I have chosen for illustration is of the De Laval type, this being one of the simplest and most efficient. It is suspended within the liquid-gas receptacle on a slender revoluble shaft having a bearing *i* at one end in the wall of the receptacle and passing through said wall at the other end by means of a long sleeve *i*′, fitting it only as close as may be necessary to prevent leakage without occasioning a perceptible amount of friction. If any lubricant should be employed, it would be of the kind unaffected by excessively low temperatures, as plumbago, while for the inner bearing ball-bearings may be employed. In this turbine the compressed gas is expanded through a narrow orifice and into an expansion-nozzle, the outer end of which is beveled off and lies close to the side of the disk in which the buckets are located, the gas being expanded at once down to the lowest pressure it is to have in the nozzle and its whole available energy being converted into velocity, which velocity is imparted to the wheel at such rate as to transfer the whole of it or as nearly so as practicable. I have illustrated such a device in Figs. 8 and 9, where P represents the wheel, P′ the shaft, and *n* the expansion-nozzle. The buckets *q q* are of the form shown in Fig. 9—open on the side opposite to the inclined expansion-nozzle, so that delivery is effected at an equal and opposite angle and the direction of motion reversed to the extent that its energy is absorbed as completely as possible by the receding buckets of the wheel, and the liquefied portion falls downward into the receptacle. The portion of gas still unliquefied renews its circuit in a way hereinafter explained.

I have pointed out that the motor is located in the liquid-air receptacle, which is the place of intensest cold. This is necessary, because it is here that expansion takes place and where the final energy of the escaping air is manifested. Expansion-chambers in which mechanical work is done have been employed in a similar relation where easily-liquefiable gases were concerned, but they are not adapted to the purpose when the liquefaction of the permanent gases is in question, because the reciprocating parts of such motors require lubrication, and no lubricant is operative in such engines in the presence of the excedingly low temperatures involved in the liquefaction of these gases. For this reason the rotary type of motor is essential.

If the jet simply played upon a wheel rotating without resistance, or if, on the other hand, it simply played upon an obstruction, no absorption of its molar energy would take place, but said molar energy would be reconverted into heat energy and the whole matter would simply change its condition to one of more volatile form when released from compression to such extent as the temperature would permit. The liquefying progress in such case is so slow as to make the operation tedious and expensive and with gases of extreme volatility, as hydrogen, commercially impracticable. It is therefore necessary to make the jet do work to conquer the last traces of its rebellious nature. The means for making the jet do its maximum work and record the same which I have conceived and applied are manifold and may be varied *ad infinitum;* but I have for purposes of illustration shown the means depicted in Figs. 5, 6, and 7 of the drawings, in which O is the liquid-gas receptacle; P, the turbine; P′, the turbine-shaft; R R′ R″, bearings; *s s′*, pinions on turbine-shaft; S S′, gears on brake-shaft; T, brake-wheel; T′, brake-wheel shaft; *t*, brake-strap; *t″*, brake-lever arm; *t‴*, roller on same; U, dynamometer, which in its simplest form is a platform-scale and scale-beam; *r*, right-and-left screw for adjusting friction of brake-strap; *p*, forked lever for controlling said adjustment; V, speed-governor for regulating tension of brake-strap; *v v′*, gears for conveying motion to governor; *w*, stem of governor. In order to prevent backlash or lost motion, the gears S S′ *s s′* have their teeth preferably cut askew or diagonally, so as to give a constant bearing.

The brake-wheel is made with an internally-recessed rim, as shown, so as to hold water supplied for cooling purposes. The water spreads out in a continuous ring all around the wheel by the action of the centrifugal force, and in this way the heat generated by friction is removed.

Around the brake-wheel a series of wooden blocks *u* are arranged to make the frictional contact. These are held in place by a brake-strap of iron passing completely around the wheel, except a small opening at the top. Here the strap is reinforced at the ends, the reinforcements being tapped with right-hand and left-hand screw-threads, respectively, of high pitch. With these engage a bolt *r*, whose ends are screw-threaded correspondingly with threads of similar pitch. To the center of said bolt is fastened the forked lever *p*, with pins through the ends of the forks carrying a collar. This collar is controlled in the customary way by the speed-governor V, to which it is attached, so that when the governor-arms fly out by increase of speed the strap is shortened, friction is increased, and the speed of the wheel is automatically reduced. Conversely, when the speed of the turbine-shaft decreases unduly the governor-arms drop, the brake-strap is lengthened, and the decreased friction permits an increase of speed in the turbine.

The operation is as follows: The gas to be treated is compressed in the compressor to the necessary extent, practically from one hundred to two hundred atmospheres, thereby increasing the temperature to an enormous degree. Said compressed gas flows through exit-pipe H to the cooling-coil, where its heat is abstracted down to ordinary temperatures—say 5° to 15° centigrade. The gas still under high compression then flows into the inner pipe M′ of the outside coil within the insulated vessel, passing up to the top, over the bend *m m′*, and down through the inner pipe N′ of the inside coil until it reaches the expansion-nozzle *n* within the liquid-gas receptacle, where it expands down to a low pressure, acquiring in so doing a high velocity. This velocity is taken up by doing work against resistance in the wheel or other appliance employed for the purpose, and the expanded gas is thus brought as nearly as may be to a state of quiescence or non-elasticity. This, however, would not be the case at the temperatures at which the gas left the cooler.

The means for reducing the temperature to the low point necessary for practical results will now be explained. The gas when relieved from compression in the expansion-nozzle enters the annular space in the outer pipe M of the outside coil with its temperature greatly reduced. It traverses this pipe on the return-track, taking up heat as it travels with great avidity from the only source available—namely, the compressed air in the inner pipe M′ of the coil—which thereby becomes greatly reduced in temperature by the time it reaches the expansion-nozzle. The return-current of gas meantime arrives at branch pipe *l* with continually-rising temperature, and thence is conveyed to the induction side of the compressor to be again compressed and renew its journey. By this means a portion of the gas becomes liquefied at each circulation after a sufficiently low temperature has been reached and falls to the bottom of the liquid-gas receptacle, whence it may be drawn off and utilized. It should be understood that every portion of the apparatus within the insulated vessel is as thoroughly insulated as possible from any accession of heat by vacuum or otherwise. It should also be stated that if the low-pressure return-current is at or below that of the atmosphere fresh gas or air will be drawn into the compressor automatically; but if it is above atmospheric pressure the air is supplied by mechanical means.

I will now explain the operation of the means shown for causing the expansion-jet to do work. The wheel and nozzle have already been described. The motion imparted to the turbine by the impingement of the jet against its buckets is transferred through shaft P′ and gears S S′ *s s′* to brake-wheel shaft T′. As heretofore explained, the degree of frictional contact of the brake-strap with the brake-wheel is automatically regulated by the right-and-left screw-bolt r and forked lever p, the latter being controlled by the speed-governor V, which derives its motion from shaft P′ through gears v v'. This governor is so adjusted as to maintain that amount of friction on the brake-strap that shall keep the speed of the turbine at that predetermined velocity which shall enable it to get the maximum of work out of the expansion-jet. The dynamometer indicates the frictional pressure, from which the work done may be computed.

In place of the frictional brake herein described, which simply wastes the power, it is obvious that the power may be utilized in the work of compression, if desired, by suitable well-known mechanical connections.

The process when once started goes on continuously, with constantly-lowering temperature, until the temperature of liquefaction is reached on emergence from the high-pressure pipe and a portion of the gas becomes liquefied. When mixtures of gases are operated upon, as in the case of air, the liquefied gas becomes richer in that one of the constituents which has the higher boiling-point, which in the case of air is oxygen, the nitrogen constantly vaporizing and passing off through the low-pressure system, while the oxygen remains liquefied at the same temperature and pressure.

The employment of a cooler is not absolutely necessary and may be dispensed with, as the whole work of refrigeration may be put upon the counter-current apparatus; but in practice I prefer to use the cooler, as specified.

It is not absolutely necessary that the orifice of the discharge-nozzle n should be formed on conical lines, as shown, since there is a powerful forward and lateral expansion of the jet upon the buckets, owing to the diagonal incline of the outlet, even when the aperture is made cylindrical.

By the term "counter-current coils" where used in this specification I mean the apparatus herein described, (illustrated in Figs. 2 and 3,) consisting of a coil within a coil, wherein the gas travels in opposite directions in the two coils.

I claim and desire to secure by Letters Patent—

1. In an air-liquefying apparatus, in combination, a compressor, a cooler, an insulating vessel, a counter-current apparatus in said vessel, a separate liquid-air receiver in said vessel with which the counter-current apparatus is connected, and a means in said receiver for causing the compressed air to do mechanical work against resistance when released, substantially as specified.

2. In an air-liquefying apparatus, in combination, a compressor, a cooler, an insulating vessel, a counter-current apparatus in said vessel, a liquid-air receiver in said vessel, an expansion-nozzle for the counter-current apparatus opening into said receiver, and a rotary motor in said receiver, receiving its impulse from the air flowing from said expansion-nozzle, whereby said air is caused to do mechanical work through the medium of said motor, substantially as specified.

3. In an air-liquefying apparatus, in combination, a compressor, a cooler, an insulating vessel, a counter-current apparatus in said vessel, a liquid-air receiver in said vessel, a discharge-nozzle delivering compressed air from said counter-current apparatus into said receiver, an impulse-wheel or turbine impelled by the discharge of air from said nozzle, and means connecting said wheel or turbine with a mechanical resistance, substantially as specified.

In testimony whereof I affix my signature in presence of two witnesses.

JOSEPH ESREY JOHNSON, Jr.

Witnesses:

H. C. Baughman,

J. L. Wood.