(No Model.) 6 Sheets—Sheet 1.

J. A. WOODBURY, J. MERRILL, G. PATTEN, & E. F. WOODBURY.

HOT AIR ENGINE.

No. 325,640. Patented Sept. 1, 1885.

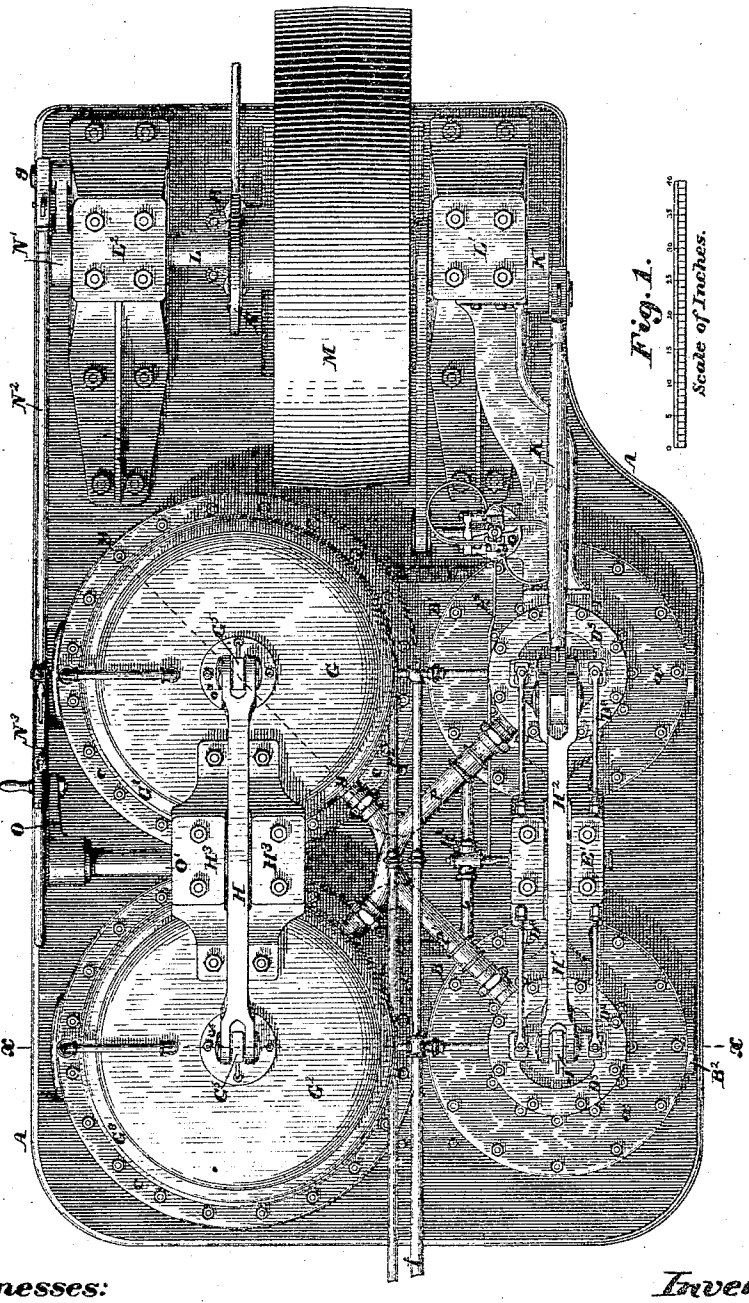

Fig. 1.

Scale of Inches.

Witnesses:

Walter E. Lombard.

E. A. Hemmenway.

Inventors:

James A. Woodbury,
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(No Model.) 6 Sheets—Sheet 2.

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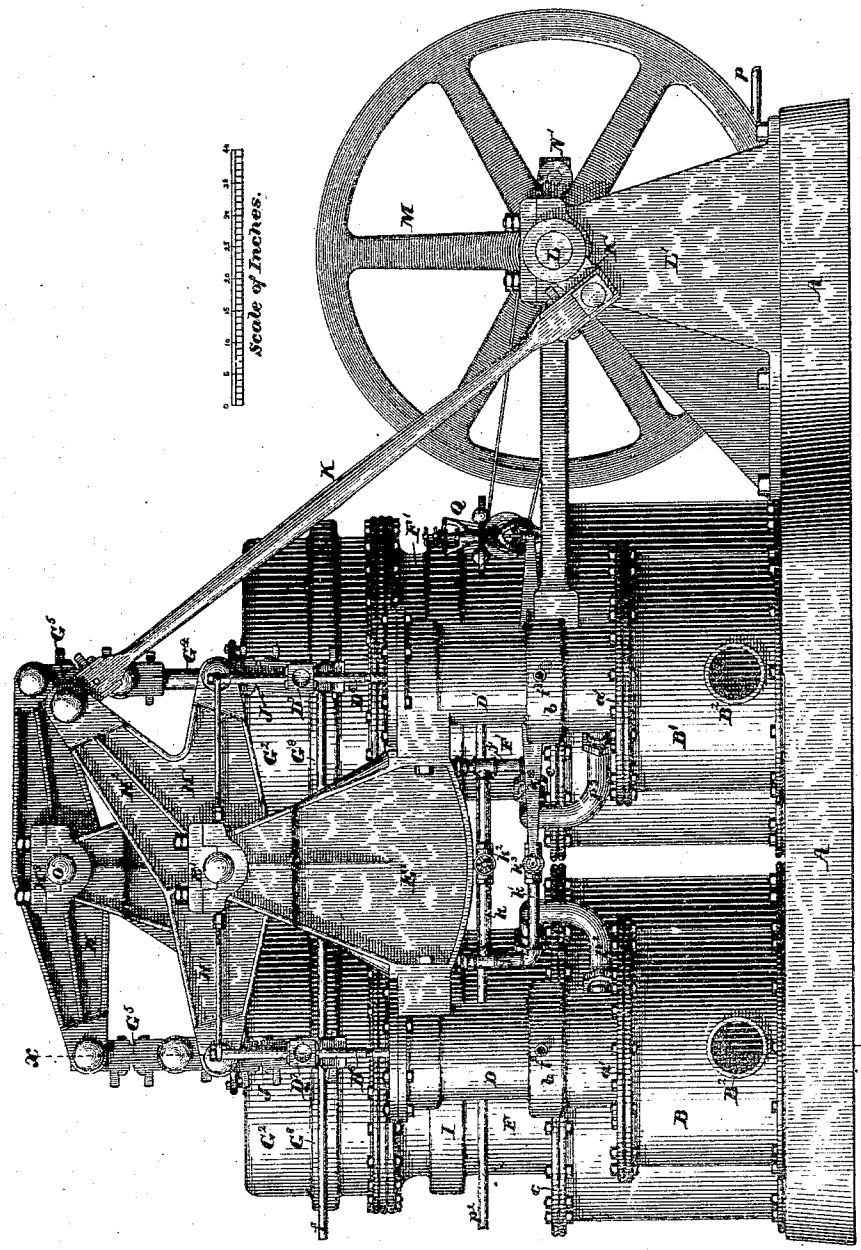

Fig. 2.

Witnesses:

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(No Model.) 6 Sheets—Sheet 3.

J. A. WOODBURY, J. MERRILL, G. PATTEN, & E. F. WOODBURY.

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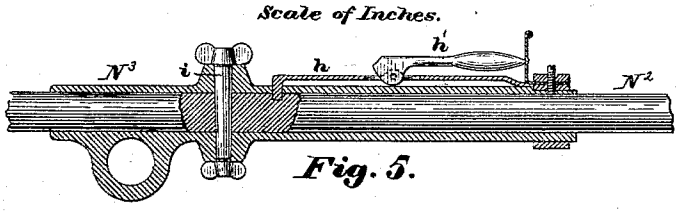

Fig. 5.

Fig. 4.

Scale of Inches.

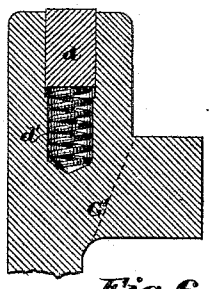

Fig. 6.

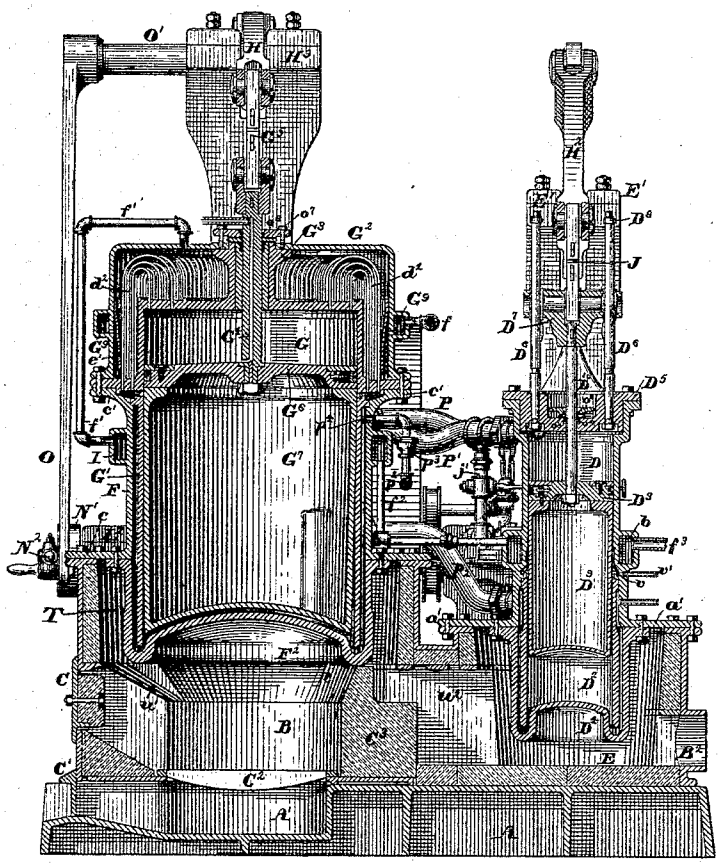

Fig. 3.

Scale of Inches.

Witnesses:

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(No Model.) 6 Sheets—Sheet 4.

J. A. WOODBURY, J. MERRILL, G. PATTEN, & E. F. WOODBURY.

HOT AIR ENGINE.

No. 325,640. Patented Sept. 1, 1885.

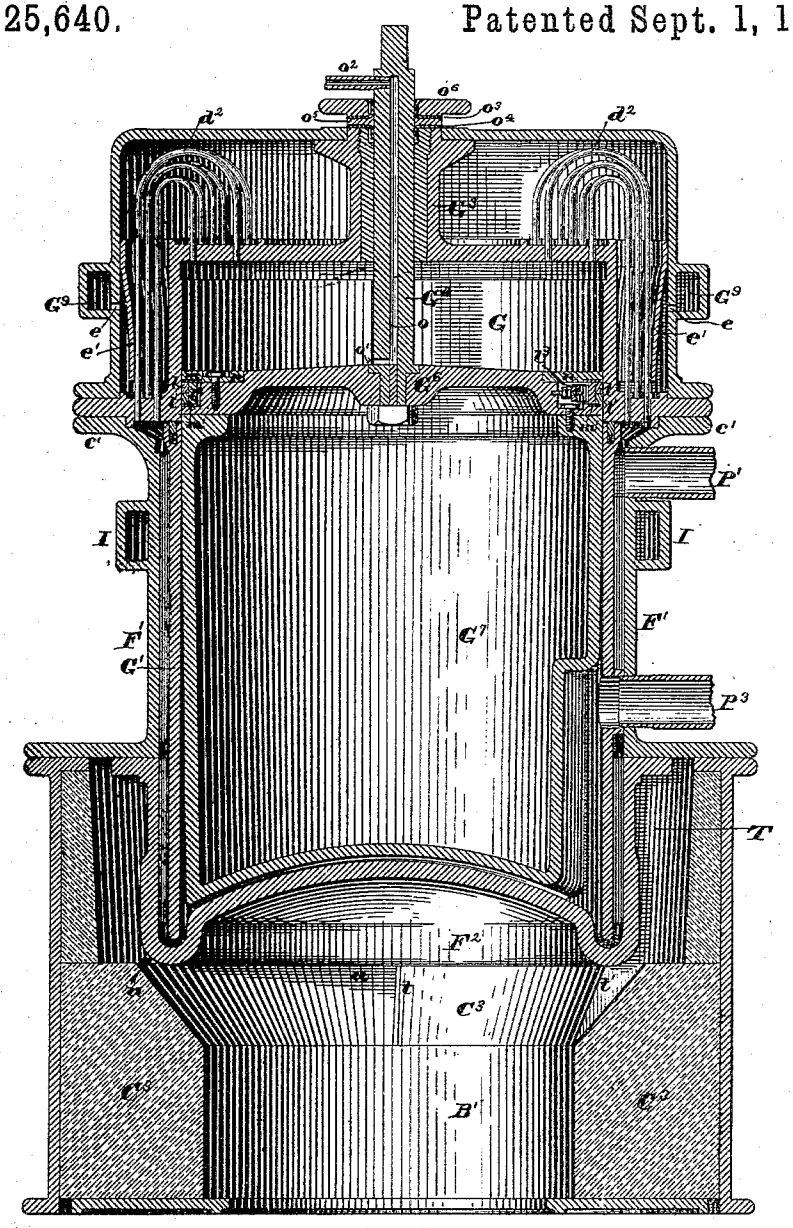
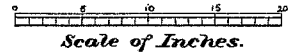


Fig. 7.



Scale of Inches.

Witnesses:

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(No Model.) 6 Sheets—Sheet 5.

J. A. WOODBURY, J. MERRILL, G. PATTEN, & E. F. WOODBURY.

HOT AIR ENGINE.

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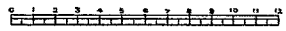

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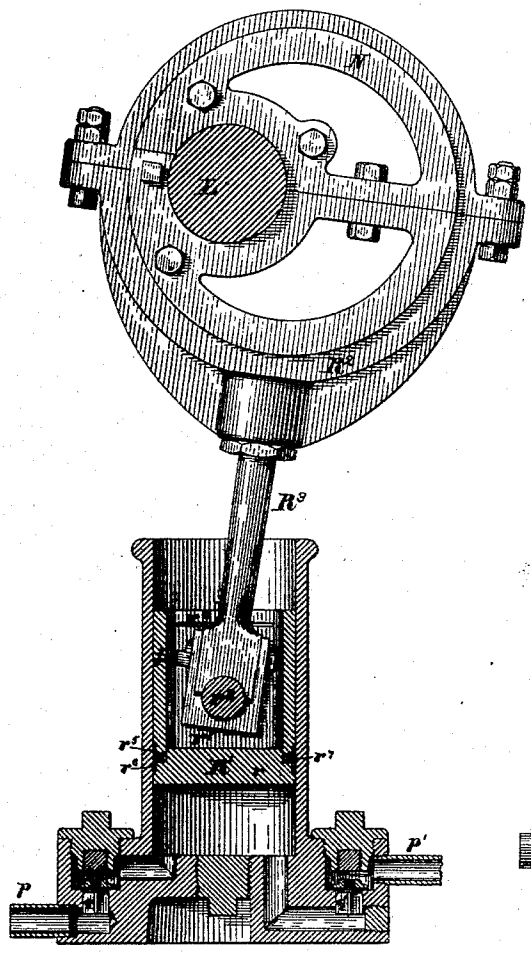

Fig. 8.

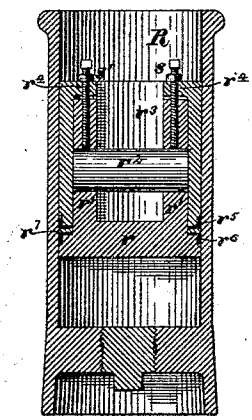

Fig. 10.

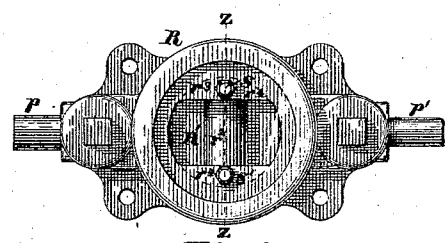

Fig. 9.

Witnesses:

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(No Model.) 6 Sheets—Sheet 6.

J. A. WOODBURY, J. MERRILL, G. PATTEN, & E. F. WOODBURY.

HOT AIR ENGINE.

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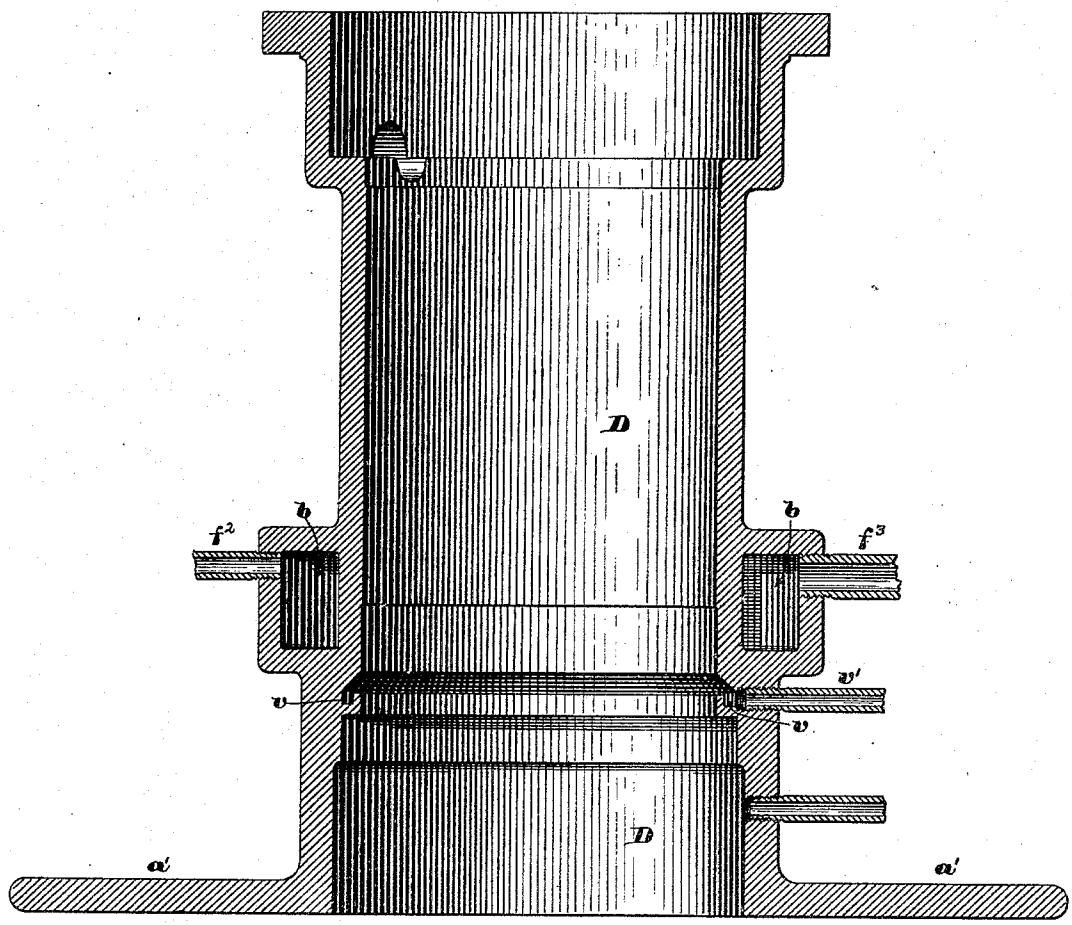

Fig. 11.

Witnesses:
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Inventors:
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George Patten, Edward F. Woodbury.
by N. A. Lombard,
Attorney.

UNITED STATES PATENT OFFICE.

JAMES A. WOODBURY, JOSHUA MERRILL, GEORGE PATTEN, AND EDWARD F. WOODBURY, OF BOSTON, MASSACHUSETTS.

HOT-AIR ENGINE.

SPECIFICATION forming part of Letters Patent No. 325,640, dated September 1, 1885.

Application filed May 16, 1883. (No model.)

To all whom it may concern:

Be it known that we, JAMES A. WOODBURY, JOSHUA MERRILL, GEORGE PATTEN, and EDWARD F. WOODBURY, all of Boston, in the county of Suffolk and State of Massachusetts, have invented, jointly, certain new and useful Improvements in Hot-Air Engines, of which the following, taken in connection with the accompanying drawings, is a specification.

Our invention relates to that class of air-engines which are operated by alternately heating and cooling the same body of air over and over again, and to that particular class of such engines in which a working cylinder and piston are used in combination with a reverser; and it consists in certain novel constructions, arrangements, and combinations of the parts, which will be best understood by reference to the description of the drawings, and to the claims to be hereinafter given.

Figure 1 of the drawings is a plan of an engine embodying our invention. Fig. 2 is a side elevation. Fig. 3 is a vertical transverse section on line *x x* on Fig. 1. Figs. 4 and 5 are respectively a plan and a longitudinal section of the sleeve-support for the reverser operating-rod, drawn to an enlarged scale. Fig. 6 is a vertical section through packing-ring in top of displacer-cylinder, drawn to a still larger scale. Fig. 7 is a vertical section of the reverser on line *y y* on Fig. 1. Fig. 8 is a central vertical section of the air-pump for supplying the engine with air under pressure. Fig. 9 is a plan of the pump-cylinder and piston; and Fig. 10 is a vertical section of the same on line *z z* on Fig. 9. Fig. 11 is an enlarged central vertical section of the working-cylinder, and showing more clearly the annular oil-receiving channel for preventing waste of the oil used in lubricating the cylinder.

In the drawings, A is the bed-plate, having formed therein the ash-pit A′, and upon the upper surface of which are erected the furnaces B and B′, extending transversely across said bed, the rear portions of said furnaces being of somewhat less height than the front portions, and each provided with the discharge-orifice B^2, through which the products of combustion escape to the chimney. (Not shown.)

C is the fire-door; C^1, the ash-pit door; C^2, the grate, and C^3 the fire-brick lining of the furnace.

D and D′ are the two working-cylinders, each provided with the broad flange *a′*, by means of which said cylinder is supported on and secured to the upper side of the rearward extension of its furnace B or B′. A portion of the lower end of each of the cylinders D and D′ is bored out sufficiently large to receive the pendent cylindrical air-deflector D^2, the interior diameter of which corresponds with the interior diameter of that portion of the cylinder D or D′ in which the packing of the piston D^3 works.

To the lower end of the cylinder D or D′ is firmly bolted the heater D^4, which projects downward into the chamber E, and surrounds and incloses the lower portion of the deflector D^2.

The upper ends of the cylinders D and D′ are closed by the heads D^5, in which are set the guide rods D^6, upon which the cross-heads D^7 travel, the upper ends of said rods being stayed by the rods D^8 to the beam-stand E′, said stands connecting the upper ends of and being supported by said working-cylinders D and D′, as shown in Fig. 2.

Each of the cylinders D and D′ is surrounded by an annular chamber, *b*, at a point just below the lowest position to which the piston-packing descends, through which chamber water or air is made to circulate for the purpose of checking the transmission of heat to the upper portion of the cylinder, in which the packed portion of the piston works.

The piston D^3 has bolted to its under side the hollow cylinder D^9, made slightly smaller in diameter than the piston D^3, so that it shall not touch the interior of the cylinder D or D′, and having its lower end closed, the purpose of which cylindrical extension of the piston being to keep the large body of heated air at a considerable distance from the packing of said piston. The piston D^3 is firmly secured to the lower end of the piston-rod D^{10}, the upper end of which is set in and firmly keyed to the cross-head D^7 in a well known manner.

F and F′ are two regenerator-cylinders, provided at their lower ends with broad flanges *c c*, by which they are supported upon and secured to the furnace-casing B and B′.

F^2 is a heater firmly bolted to the lower end

of the regenerator-cylinder F or F′, and projecting downward into the furnace or combustion-chamber, as shown in Fig. 3, the inner diameter of said heater corresponding to the inner diameter of the regenerator-cylinder, as shown.

The upper ends of the regenerator-cylinders F and F′ are provided with the flanges c' c', to each of which is firmly bolted the short cooler-cylinder G, in which the displacer-piston proper works.

G′ is a displacer-cylinder open at both ends, the inside diameter of which corresponds with the inside diameter of the cooler-cylinder G, and the outside diameter of which is somewhat less than the inside diameter of the regenerator-cylinder F or F′, said cylinder G′ being supported centrally within the said regenerator-cylinder by means of radially-projecting lugs or ears cast thereon and resting in recesses formed in the upper end of the regenerator-cylinder, as shown and described in Letters Patent No. 228,716, granted to us June 8, 1880.

G^2 is the cooler cover, cast with its lower end open, and arranged to rest upon the flange of the cooler-cylinder G, and bolted therewith to the upper end of the regenerator-cylinder, and secured at the center of its upper end to the upper end of the hub G^3, which projects upward from the center of the upper end of the cooler-cylinder G, and forms the bearing and guide for the piston-rod G^4, said rod being connected at its upper end by the link or rod G^5 to one end of the beam H, and having secured to its lower end the piston G^6, all as shown in Figs. 3 and 7.

The upper end of the displacer-cylinder G′ has formed therein an annular groove, in which is fitted the metallic packing-ring *d*, supported upon and pressed upward by a series of spiral springs, *d′*, to a bearing against the lower end of the cooler-cylinder G, to compensate for unequal expansion, and to make a joint between the displacer-cylinder G′ and the cooler-cylinder G.

The piston G^6 has secured to its lower end the extension G^7, in the form of a hollow cylinder, with its lower end closed and adapted to work in the cylinder G′ without touching it, as shown in Figs. 3 and 7.

The upper ends of the regenerator-cylinders are chambered out, or made flaring, in order to increase the diameter of the upper portion of the space between said regenerator-cylinder and the displacer-cylinder G′.

A series of small thin metallic tubes, d^2, bent into the form of an inverted letter **J**, are secured with their long arms in openings through the base-flange of the cooler cylinder G, and their short arms in the upper head of said cylinder, as shown in Figs. 3 and 7, and as shown and described in another application of ours filed in the Patent Office June 7, 1881.

The cooler-cover G^2 has formed in its vertical wall an annular chamber, G^9, communicating by means of a series of small orifices, *e*, arranged at about equal distances from each other around the inner wall of said chamber, with the interior of the cooler-cover G^2 as a means of admitting water or air to the cooling-chamber between the cover G^2 and the cylinder G.

A ring deflector, *e′*, is secured to the inner periphery of the cooler-cover G^2, just above the annular chamber G^9, and serves to compel the water or air entering the chamber containing the tubes d^2 through the orifices *e* to descend to the bottom of said chamber before it can escape through the pipe *f′*, provided for the purpose.

The regenerator-cylinders are each surrounded by an annular chamber, I, with which the lower end of the pipe *f′* communicates upon one side of the cylinder, and connected upon the other side, through the pipe f^2, with the annular chamber *b*, surrounding the working-cylinder, the cold water or air, or both, for cooling being supplied to the annular chambers G^9 through the pipe *f*, and is finally discharged from the annular chambers *b* through the pipes f^3 f^3.

The spaces between the regenerator cylinders and the displacer-cylinders G^2 are filled with thin corrugated metal plates, which serve to extract heat from the heated air in its passage from the heater to the cooler, and give it back again as the air descends from the cooler to the heater, substantially as shown and described in Letters Patent No. 228,712, granted to us June 8, 1880. The spaces between the lower portions of the cylinders G′ and the vertical walls of the heaters F^2 are in like manner filled with thin corrugated plates, which serve to divide the air passing through said spaces into a number of thin films, and thus expose it to a much larger area of heating-surface, substantially as described in said last-cited Letters Patent.

The cross-heads D^7 are connected by the links or rods J to opposite ends of the beam H′, as shown in Fig. 2.

The beam H′ is provided with a third arm, H^2, to the movable end of which one end of the connecting-rod K is connected, the opposite end of said rod being connected to the crank K′ upon one end of the shaft L, mounted in bearings in the pillow-blocks L′ and L^2, and having mounted thereon the fly-wheel M, the eccentric N, and the crank N′.

The crank-pin *g* of the crank N′ has fitted thereto one end of the rod N^2, the opposite end of which has fitted thereto the sleeve N^3, which is connnected to the lower end of the pendent arm O, firmly secured at its upper end to one end of the shaft O′. The sleeve N^3 is secured to the rod N^2 by means of the spring-latch *h*, a projection upon the movable end of which enters a recess formed for the purpose in said rod, and from which it may be withdrawn by turning the handle of the cam-lever *h′* into an upright position. The sleeve N^3 is further secured in position by the taper bolt *i*, which

may be easily removed whenever it is desired to disconnect the sleeve from the rod to permit the rod to work through said sleeve. (See Figs. 4 and 5.)

The shaft O′ is mounted in the beam-stands H^3 H^3, and has secured thereon the beam H, as shown in Figs. 1 and 2.

P is a pipe communicating at one end with the upper portion of the regenerator-space within the regenerator-cylinder F, and at its other end with the upper end of the working-cylinder D′, and P′ is a similar pipe connecting the upper portion of the regenerator-space within the regenerator-cylinder F′ with the upper end of the working-cylinder D, as shown in Figs. 1, 3, and 7.

P^2 is a pipe communicating at one end, through the lower portion of the regenerator-cylinder F, with the chamber within the displacer-cylinder G′ and at its other end with the space between the lower end of the working-cylinder D and the deflector-cylinder D^2, and P^3 is a similar pipe in like manner connecting the lower part of the regenerator-cylinder F′ with the lower end of the working-cylinder D′, as shown in Figs. 1, 3, and 7.

With this arrangement of the pipes P, P′, P^2, and P^3 one reverser supplies air to the upper end of the working-cylinder D and to the lower end of the working-cylinder D′, and the other reverser supplies air to the upper end of the working cylinder D′ and to the lower end of the working-cylinder D, the air for operating the working-pistons being supplied alternately from one reverser and then from the other.

The pipes P and P′ are connected by means of the two vertical pipes *j* and *j′* and the two horizontal pipes *k* and *k′*, the pipe *k* being provided with a valve or cock, k^2, to be operated by hand for stopping the engine, and the pipe *k′* being provided with a valve or cock, k^3, which is connected by the lever k^4 to the governor Q in such a manner that if the engine runs too fast the action of the governor will open the valve k^3 more or less, and thus allow air to pass from one reverser to the other to partially equalize the pressures therein and thus reduce the speed.

The pistons of the reversers and working-cylinders are somewhat novel in construction, and except in one particular are of similar construction, and therefore a description of one of the reverser-pistons will answer for all.

The reverser-piston proper, G^6, is of ordinary construction, except, as will be hereinafter described, in the respect that it differs from the working-piston, and is provided with three metal packing-rings, *l*, *l′*, and l^2, which are pressed outward by a series of leaf-springs, l^3, in a well-known manner, as shown in Fig. 7.

In order that the packing-rings may be kept as cool as possible, so that the piston may be properly lubricated, it is necessary that the piston be extended in the direction of the length of the cylinder, for the purpose of keeping the great body of the heated air at a distance from the piston-packing and that portion of the cylinder in which the packing works. To obtain this result we secure to the under side of said piston G^6 the hollow cylinder G^7, by means of bolts passing through the main body of the piston proper, G^6, and screwing into an inwardly-projecting flange on the upper end of the cylinder G^7, without passing through, the joint between the cylinder G^7 and the piston G^6 being packed so as to form a perfectly tight joint, so that the compressed air used to work the engine cannot find its way into the chamber in the piston G^6 G^7. By this construction we are enabled to use a comparatively light piston and still maintain that portion of the cylinder in which the piston packing works comparatively cool.

We have found by experiment that in a reverser provided with a cooler in which copper tubes, or tubes containing copper, are used in connection with iron cylinders and pistons, when water containing saline or other corrosive impurities is used, a galvanic action takes place, which very soon causes such a corrosion of the surfaces of the piston contiguous to the packing-rings that said rings stick and become inoperative. To obviate this difficulty we secure thin rings of brass or composition, *m* and *m′*, to the surfaces of the piston G^6 and its follower *n*, respectively, that are next to the packing-rings *l*, *l′*, and l^2, and between which said rings move as they expand or contract, and we make said packing-rings of composition, and we then have no trouble from galvanic action.

It is obvious that if the entire piston were made of brass or composition the same effect would be produced.

The piston-rod G^4 is hollow for the greater part of its length, or is provided with the central passage, *o*, which communicates at its lower end, by means of the orifice *o′*, with the chamber above the piston G^6, and at its upper end, through the pipe o^2, with some suitable oil-cup or oil-reservoir, (not shown,) for the purpose of introducing oil or other lubricant to the interior of the cooler-cylinder G.

The piston-rods D^{10} and G^4 are each surrounded by two cupped leather packing-rings, o^3 and o^4, separated by the metal ring o^5, and secured firmly in place by the follower-ring o^6 and bolts o^7, as shown in Figs. 3 and 7.

R is an air-pump located beneath the shaft L, the piston R′ of which is operated by the eccentric N, eccentric-strap R^2, and rod R^3, as shown in Fig. 8, air being taken in through the pipe *p*, and discharged through the pipes *p′* and p^2, the check-valves p^3, and delivered into the regenerator-space of each of the reversers at p^4, Fig. 3.

The air-pump R is provided with the induction-valve *q* and the eduction-valve *q′*, constructed, arranged, and operating in a well-known manner.

The piston R′ is composed of the head *r*, provided with the upwardly-projecting and segmentally-shaped ears *r′* *r′*, in which is set the

wrist-pin r^2. The diameter or distance across from the curved surface of one ear to the curved surface of the other ear is considerably less than the interior diameter of the pump-cylinder, so that they will just fit into the interior of the cylinder r^3, which is provided at its upper end with two inwardly-projecting segmentally-shaped flanges, r^4 r^4, which project over the ears r' r', as shown in Fig. 10. Between the lower end of the cylinder r^3 and the head r is placed two cupped leather packing-rings, r^5 and r^6, and the metallic ring r^7, the whole being secured together by the bolts s, which pass freely through the flanges r^4 and are screwed into the ears r' r', and press upon the wrist-pin r^2 and the nuts s', which are threaded upon said bolts and screw down upon the flanges r^4 r^4, all as shown in Figs. 9 and 10.

The pump-piston described in the last two paragraphs forms the subject-matter of another application, filed January 15, 1885, and numbered 152,985, as a division of this case.

The fire-bricks C^3, which form the walls of the furnace beneath the reversers, are so constructed as to substantially close the passage between said brick and the bottoms of the heaters F^2 for about one-quarter of the circumference of said heater directly opposite to the fire-door C, as from t to t', Fig. 7, and at each side of said points t and t' the brick is beveled, so as to form a space between it and the heater, as shown at u u, Fig. 7, through which the products of combustion pass to the annular chamber T, surrounding the heater F^2, and at the front, on each side of the fire-door C, the brick is cut away still more, so as to give a more free passage of the products of combustion to said annular chamber, as shown at u' in Fig. 3. This construction of the fire-brick furnace compels the products of combustion to completely envelop the heater F^2 before they can escape through the passage u^2 to the chamber E, where they envelop the heater D^4 before escaping to the chimney through the pipe B^2.

The pipes P^2 and P^3 are bent horizontally, so that their axes at their two ends are at right angles, or nearly so, to each other, and they are coupled to short nozzles or pipes set in the working and regenerator cylinders at corresponding angles to each other. This is a great advantage in setting up the engine; or in case of its becoming necessary to remove said pipes after they have once been put in place, they can be easily removed and replaced without disturbing any of the other parts or breaking other joints.

Each of the working-cylinders D and D' has formed in its inner periphery the annular channel or pocket-like groove v, as a means of catching the oil after it has done duty in lubricating the piston, and from which said oil may be drawn through the pipe v'.

We have found by practical experiment that in an air-engine in which two reversers and two double-acting working-cylinders are used the best results are obtained by making the capacity of each working-cylinder about equal to three-tenths of the capacity of one of the reverser-cylinders.

We have also found that a great advantage is obtained by constructing the heater in the form shown and described—that is, in a cylindrical form with a dome-shaped bottom that rises only a small portion of the height of said cylinder, in order that the lower end of the displacer-piston in its motion shall not rise above the upper portion or flange of the heater, thereby forming a hot chamber the bottom and vertical walls of which are entirely surrounded by the products of combustion, which maintains the air at a very high temperature.

What we claim as new, and desire to secure by Letters Patent of the United States, is—

1. The combination and arrangement of a reverser, a pipe leading from the upper part of the regenerator-space to and communicating with the upper end of the interior of one working-cylinder, and another pipe leading from the chamber below the piston of the same reverser to and communicating with the space beneath the piston of another working-cylinder.

2. The combination of the regenerator-cylinder F or F', the cooler-cylinder G, the displacer-cylinder G', and the yielding metallic ring d, all arranged and adapted to operate substantially as and for the purposes described.

3. The pipes P^2 and P^3, curved, as set forth, so that their axes at their two ends shall be at an angle to each other, substantially as and for the purposes described.

4. The combination of the by-pass pipe j j' k and the valve or cock k^2, to be operated by hand, the valve or cock k^3, the lever k^4, and the governor Q, all arranged and adapted to operate substantially as and for the purposes described.

5. The combination of the pendent arm O, the sleeve N^3, connected thereto, the crank N', the rod N^2, and the spring-actuated latch h, all arranged and adapted to operate substantially as described.

6. The combination of the arm O, the sleeve N^3, the rod N^2, and the taper bolt i, all arranged and adapted to operate substantially as described.

7. In combination with the working-cylinder of an air-engine, provided with a piston having a packing arranged to work air-tight in said cylinder, the annular channel or pocket-like groove v, formed in the inner periphery of said cylinder, just below the lowest point to which said packing descends, substantially as and for the purposes described.

8. The annular deflector e', secured to the interior of the cooler-cover, substantially as and for the purposes described.

9. The combination of the cooler-cover G^2, provided with the annular chamber G^9, connected with the interior of said cover by a series of orifices, e, and the deflector e', secured

thereto above said orifices and adapted to deflect the cooling medium to the bottom of the cooling-chamber, substantially as described.

10. In an air-engine, the combination of a cooling-chamber through which water is circulated, and provided with air-circulating pipes containing copper, and a reverser-piston provided with composition packing-rings, and having brass or composition surfaces contiguous to said packing-rings for intercepting or preventing galvanic action, substantially as described.

11. In combination with the pendent heater of an air-engine, the fire-brick fire-pot C^8, constructed and arranged as set forth, to substantially close the passage between said brick and the heater for about one-quarter (more or less) of the circumference of said heater opposite to the fire-door, and thus compel the products of combustion to pass upward around said heater at the front and sides, and then pass to the rear around said heater, substantially as and for the purposes described.

In testimony whereof we have signed our names to this specification, in the presence of two subscribing witnesses, on this 14th day of May, A. D. 1883.

JAMES A. WOODBURY.
JOSHUA MERRILL.
GEORGE PATTEN.
EDWARD F. WOODBURY.

Witnesses:
E. A. HEMMENWAY,
WALTER E. LOMBARD