5 Sheets—Sheet 1.

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

Air-Engine.

No. 228,712. **Patented June 8, 1880.**

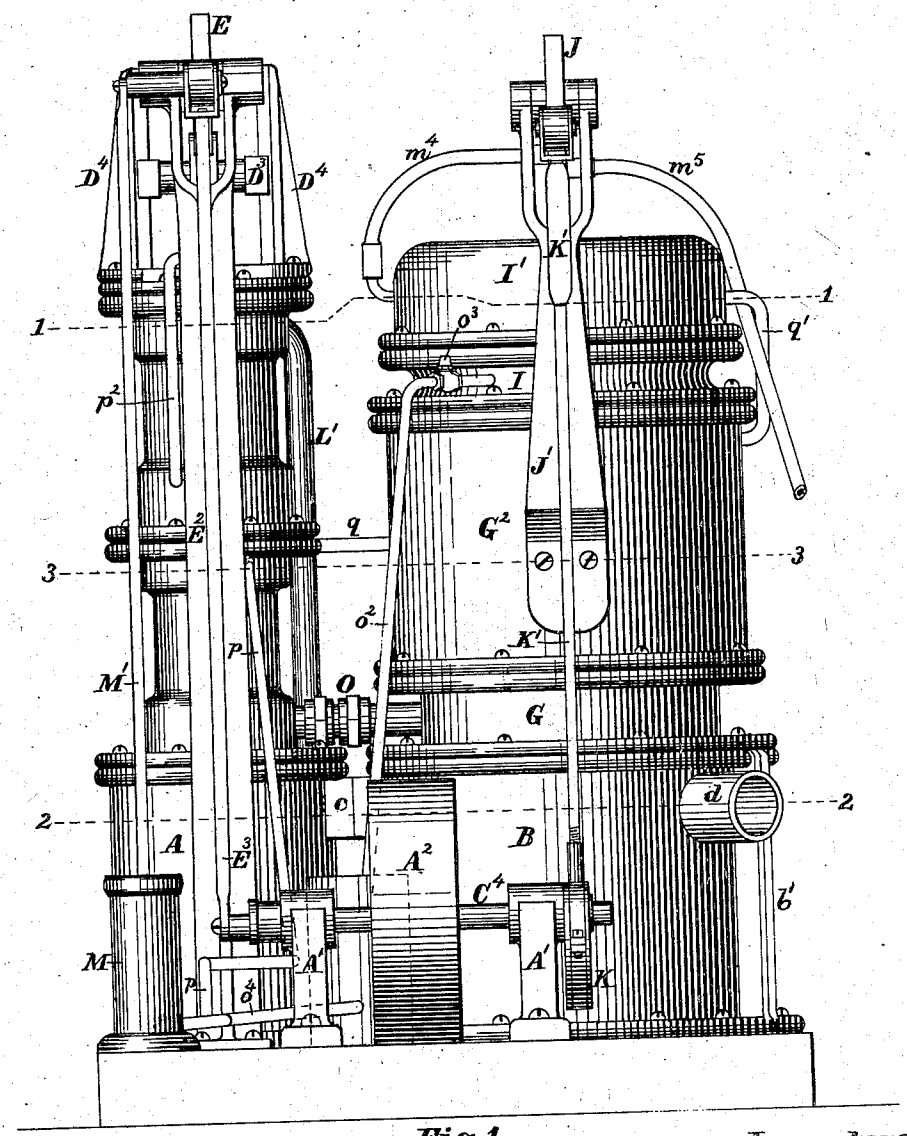

Fig. 1.

Witnesses:

E. A. Hemmenway.

Benj. Andrews Jr.

Inventors:

James A. Woodbury,

Joshua Merrill,

George Patten,

Edward Franklin Woodbury,

by N. C. Lombard *Attorney.*

5 Sheets—Sheet 2.

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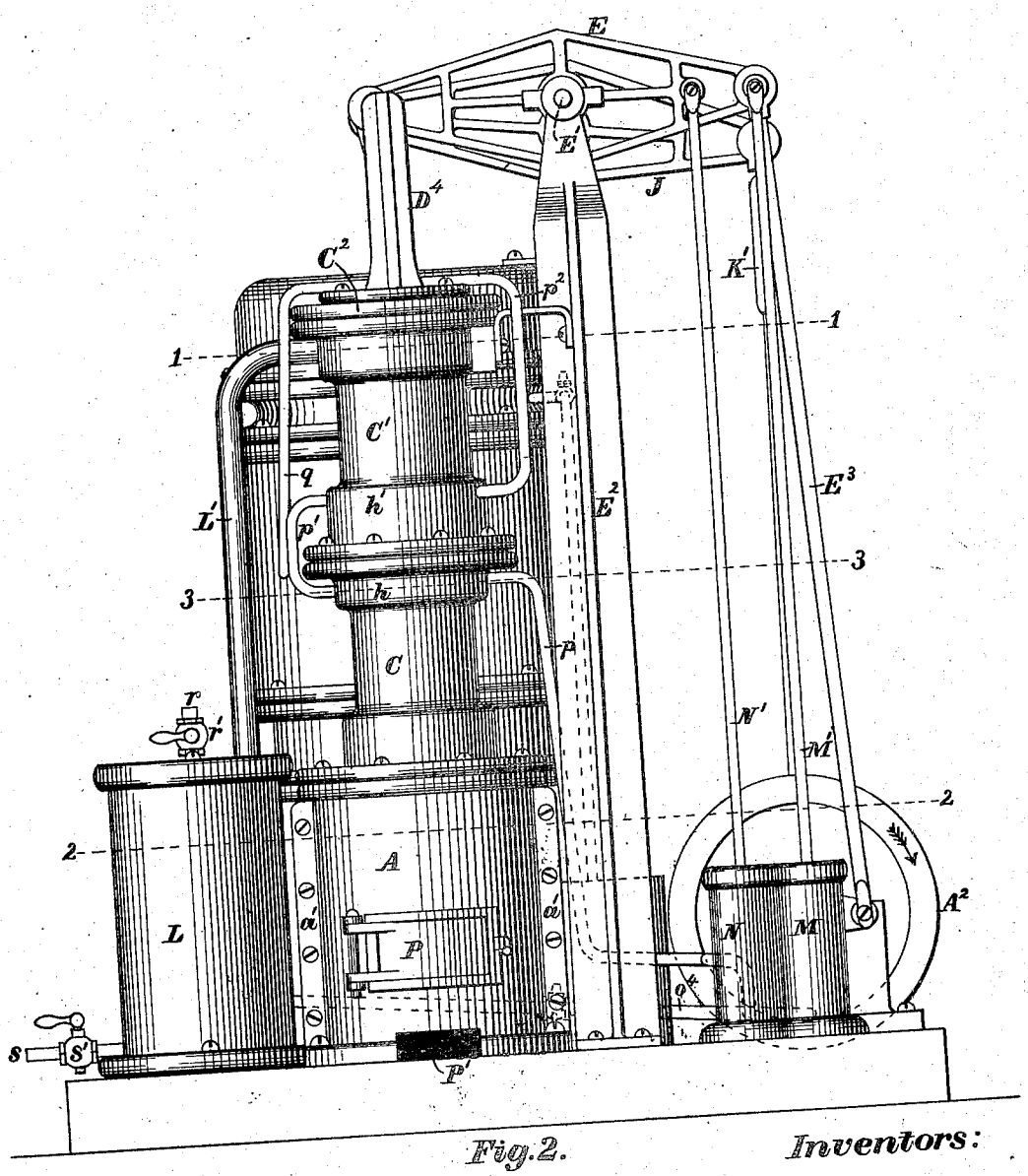

Fig. 2.

Witnesses:

E. A. Hemmenway

Benj. Andrews, Jr.

Inventors:

James A. Woodbury,

Joshua Merrill,

George Patten,

Edward Franklin Woodbury,

by N. C. Lombard **Attorney.**

5 Sheets—Sheet 3.

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

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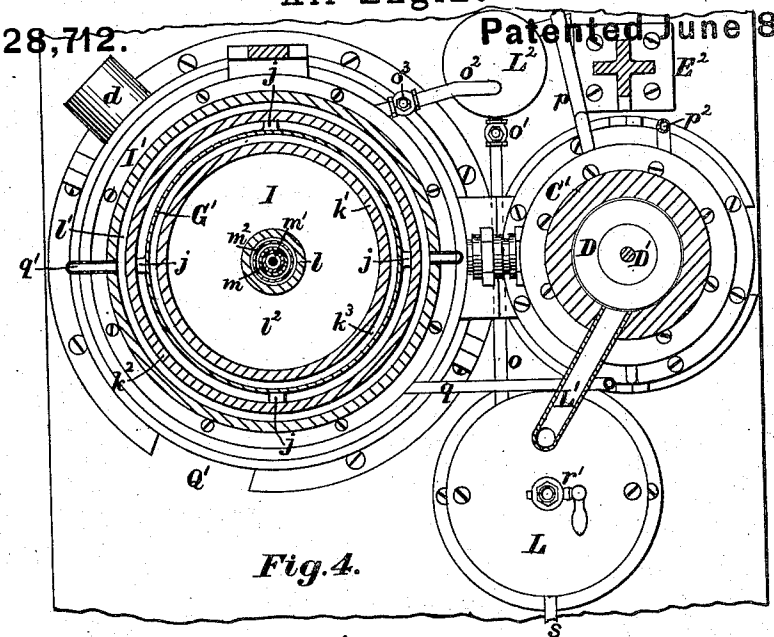

Fig. 4.

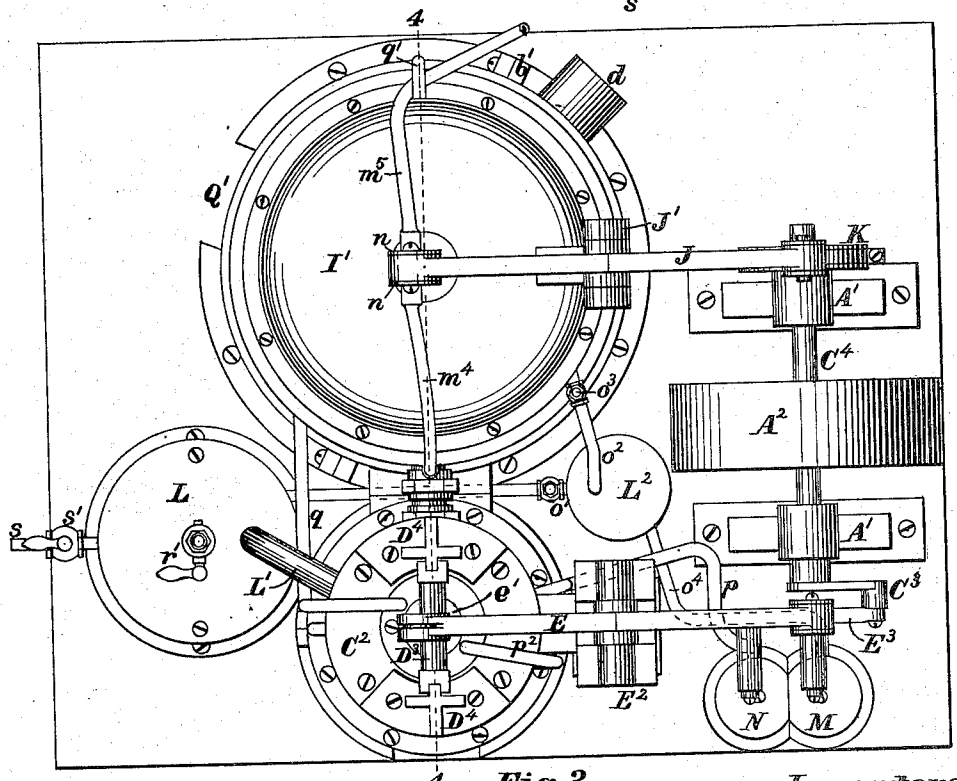

Fig. 3.

Witnesses:

E. A. Hemmenway.

Benj. Andrews, Jr.

Inventors:

James A. Woodbury,

Joshua Merrill,

George Patten,

Edward Franklin Woodbury,

by N. C. Lombard Attorney.

5 Sheets—Sheet 4.

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

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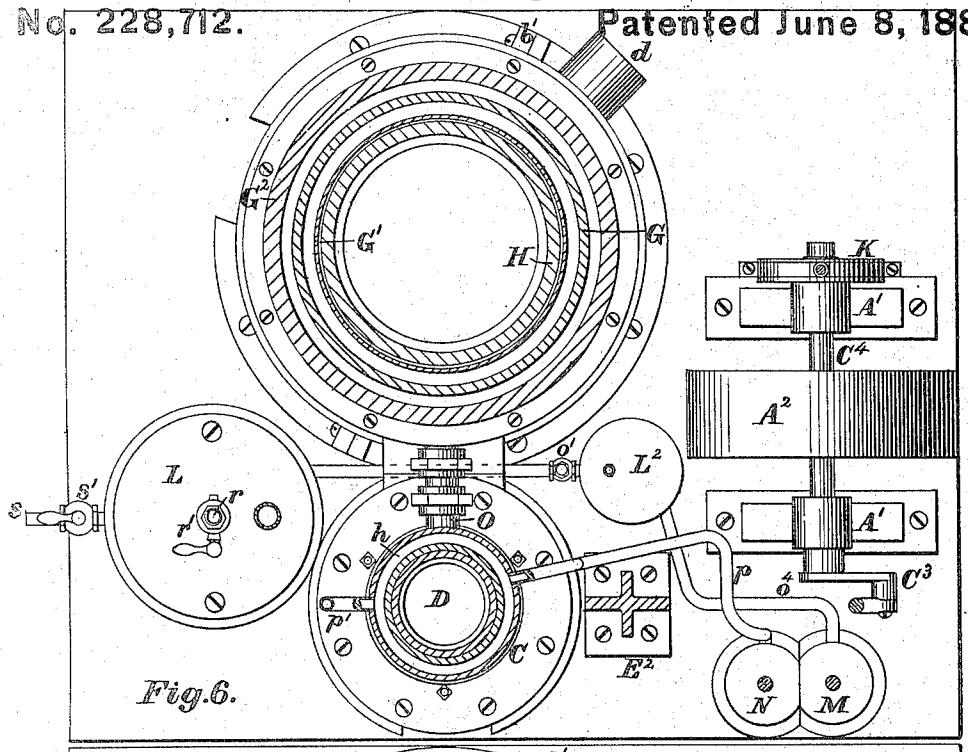

Fig. 6.

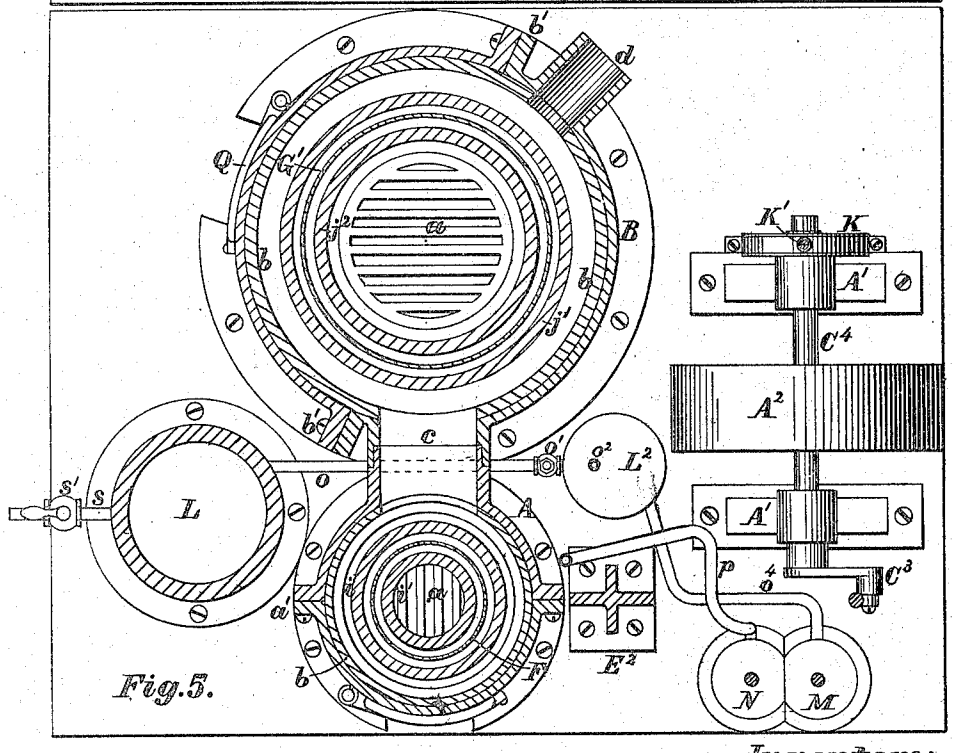

Fig. 5.

Witnesses:
E. A. Hemmenway
Benj. Andrews, Jr.

Inventors:
James A. Woodbury, Joshua Merrill,
George Patten, Edward Franklin Woodbury,
by N. C. Lombard Attorney.

5 Sheets—Sheet 5.

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

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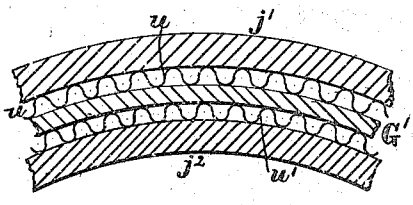

Fig. 8.

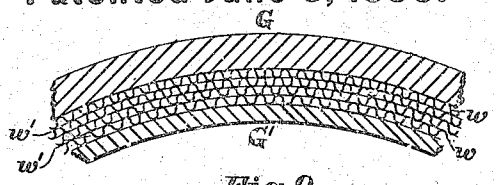

Fig. 9.

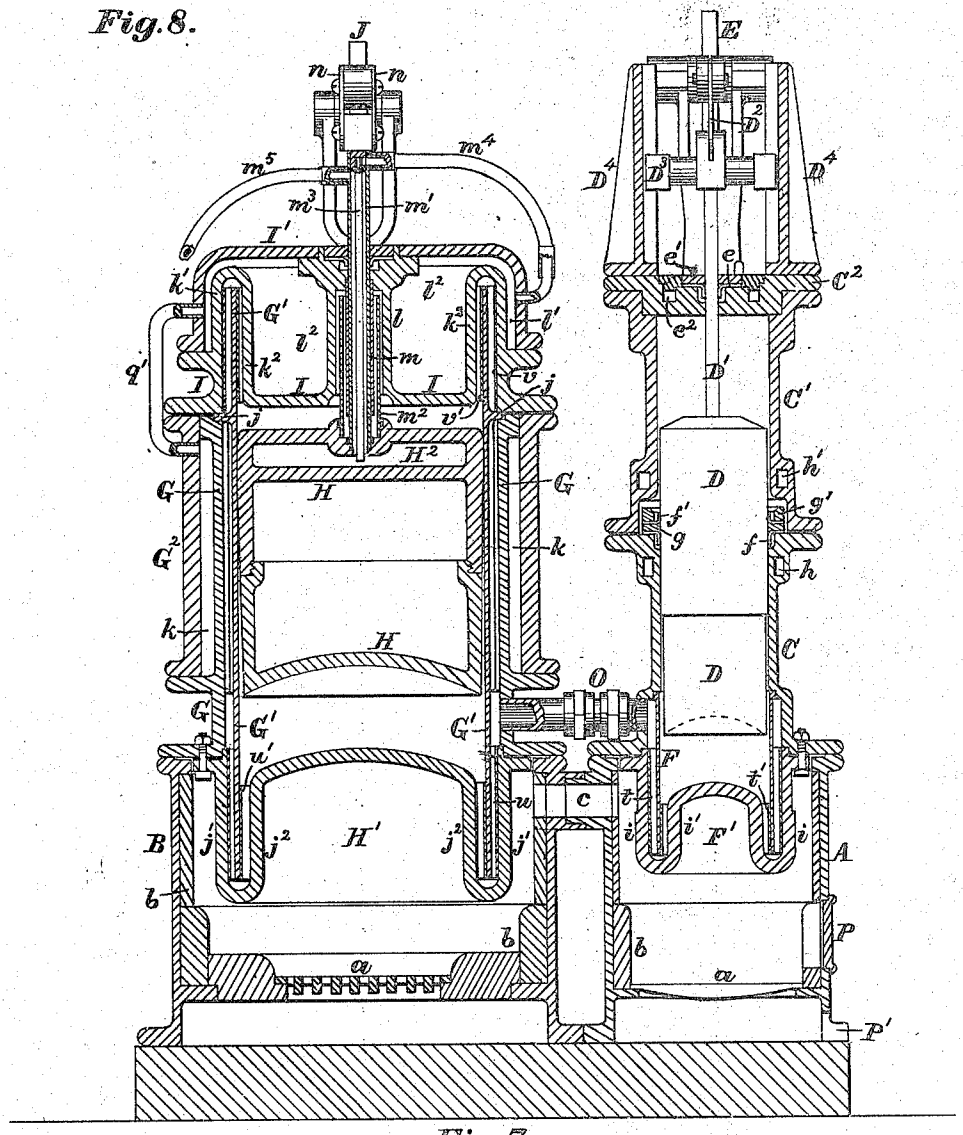

Fig. 7.

Witnesses:
E. A. Hemmenway.
Benj. Andrews, Jr.

Inventors:
James A. Woodbury,
Joshua Merrill,
George Patten,
Edward Franklin Woodbury,
by N. C. Lombard Attorney.

UNITED STATES PATENT OFFICE.

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

AIR-ENGINE.

SPECIFICATION forming part of Letters Patent No. 228,712, dated June 8, 1880.

Application filed May 1, 1879.

To all whom it may concern:

Be it known that we, JAMES A. WOODBURY, JOSHUA MERRILL, GEO. PATTEN, and EDWARD FRANKLIN WOODBURY, all of Boston, in the county of Suffolk and State of Massachusetts, have invented certain new and useful Improvements in Air-Engines, (Case A,) 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 has for its object the production of engines capable of being operated by air at very high pressures, and also capable of heating or cooling the air with very great rapidity.

It is a well-known fact that the application of about 480° of temperature to atmospheric air in a confined state doubles its pressure, and it has been proved by practical experiment that the same number of degrees of temperature applied to air compressed to a pressure equal to two, four, or more atmospheres doubles its pressure, as in the case of common atmospheric air. It is also well known that a given amount of fuel applied to heating air develops about four times the amount of mechanical force that the same amount of fuel develops when applied to the generation of steam from water.

After a long series of practical experiments made by us in working air under high pressures, we find that it takes no more units of heat to raise air compressed to a pressure equal to two, four, or more atmospheres to a given temperature than it does to raise common atmospheric air to the same temperature, and therefore it is obvious that there must be a great gain in operating air-engines with air at very high pressures.

We have shown our invention as applied to an engine having a single-acting working-cylinder and a single reverser-cylinder adapted to be worked by air compressed to a very high pressure; but many of the points of improvement are equally applicable to engines working under lower pressures as well as to engines in which one or more double-acting working-cylinders are used in combination with one or more reverser-cylinders.

Our invention consists, first, in the combination of a working-cylinder provided with a piston and containing air under pressure upon both sides of said piston, a reverser-cylinder, means of applying heat to the lower end of the reverser-cylinder, and means of conveying air from the heated end of the reverser to one end of the working-cylinder, while the air in the other end of said working-cylinder remains at its normal temperature, as will be described.

It further consists in the combination of a working-cylinder provided with a piston and adapted to contain air under pressure upon both sides of said piston, and to be worked by alternately heating and cooling the air upon one side of said piston while the air upon the other side of said piston remains at its normal temperature, and a reverser-cylinder, with a furnace attached to each of said cylinders.

It further consists in the combination of a working-cylinder and a reverser-cylinder, each having a furnace attached thereto, and a passage or flue connecting said furnaces together in such a manner that the products of combustion pass from one furnace through the other to reach the smoke-pipe or chimney.

It further consists in the combination of a single-acting working-cylinder, a reverser-cylinder having direct communication with the space beneath the piston of the working-cylinder, and an expansion-reservoir filled with air under pressure and connected by a suitable pipe or passage with the cold end of the working-cylinder.

It further consists in the combination, with a single-acting working-cylinder adapted to contain air under pressure upon both sides of its piston, of an expansion-reservoir adapted to contain air under pressure and connected by a suitable pipe or passage with the cold end of the working-cylinder, and means of varying its capacity for the purpose of regulating the pressure.

It further consists in the combination, with a single-acting working-cylinder containing air under pressure upon both sides of its piston, of an expansion-reservoir connected by a suitable pipe or passage with the cold end of the working-cylinder and adapted to contain air under pressure, and means of introducing

water or other liquid into and withdrawing it from said reservoir as a means of controlling the capacity of the chamber, and thereby the pressure.

It further consists in the combination of a heater, a refrigerator, the outer shell of the regenerator interposed between said heater and refrigerator, and a deflector or inner cylinder, made in separate pieces and firmly secured together to form a reverser-cylinder, as will be described.

It further consists in the use, in combination with a reverser-cylinder provided with a heater at one end and a refrigerator at the other end, of a stationary cylindrical deflector extending from near the lower part of the heater to near the top of the refrigerator, with space at each end thereof for the free passage of air around the same.

It further consists in the combination of a reverser-cylinder, a working-cylinder, a pump adapted to force air into said cylinders under pressure, and a furnace or other means of applying heat to one end or both of said cylinders while the air in the other end of the working-cylinder remains at or near its normal condition.

It further consists in the combination, with a reverser-cylinder provided with a heater and an inner cylinder adapted to serve as a deflector to compel the air to pass over the heated surface in the form of a thin film, of a pipe or passage leading from the heated portion of the reverser-cylinder to the working-cylinder.

It further consists in constructing the outer casing of the furnace of an air-engine in two parts divided in such a manner that one portion may be readily removed to give access to and permit the removal of the heater without disturbing the other parts of the engine.

It further consists in the combination, with the regenerator of an air-engine, of a water-space surrounding a portion or the whole of said regenerator.

It further consists in the combination, with the heater and the deflector of a reverser or working cylinder, of a corrugated plate of thin metal placed in the annular space or spaces between said heater and the deflector, for the purpose of increasing the area of heated metallic surface to which the air is exposed in passing to and from the chamber between the piston and the heater.

It further consists in the use, in combination with the deflector or inner cylinder of a reverser and the outer shell of the regenerator, of two or more corrugated plates of thin metal placed in the annular space between said deflector and outer casing, with or without a plain plate of thin metal interposed between each pair of said corrugated plates, whereby the air in passing from the heater to the refrigerator is brought in contact with a largely-increased area of metallic surface, which absorbs the heat from the air and gives it out again on the return of the air from the refrigerator to the heater.

It further consists in the use, in combination with the deflector or inner cylinder of a reverser and the outer shell of the regenerator, arranged relative to each other so as to form an annular chamber between them, of two or more rings of thin metal corrugated longitudinally and placed in said annular space, and one or more thin plain hoops or cylinders of metal alternating therewith, as will be described.

It further consists in the combination, with the refrigerator and the deflector or inner cylinder of the reverser, so arranged relatively to each other as to form one or more annular spaces between them, of a corrugated plate or cylinder of thin metal, placed in said annular space or spaces for the purpose of increasing the cooling-surface over which the air passes to reach the chamber between the reverser-piston and the refrigerator.

It further consists in the use of a refrigerator composed of a double-walled cylinder, the two walls of which are united at one end and open or disconnected at the other end, to form an annular space between said walls, open at one end, and a head or bottom connecting the detached edge of the inner wall, as will be more fully described.

It further consists in the combination, with a reverser-cylinder, of a refrigerator provided with an annular extension and with a water-chamber covering its top and the outer and inner walls of said annular extension, and means for causing a constant circulation of water through said chamber.

It further consists in the combination, with a reverser-cylinder provided with a refrigerator provided with an annular extension at its upper end, and a water-chamber covering its top and the outer and inner walls, of said annular extension, means of causing a constant circulation of water therein, and a furnace or other means of applying heat to the lower end of said reverser-cylinder, as will be described.

It further consists in the combination, with a reverser-cylinder provided with a heater and a deflector or inner cylinder, of a pipe or passage leading from the heated end of the reverser-cylinder to the working-cylinder, and a pump adapted to force air into said reverser-cylinder under pressure.

It further consists in the combination, with a reverser-cylinder provided with a heater at one end, a refrigerator at its other end, and a reciprocating piston, of a passage or passages leading from the heater to the refrigerator outside of the inner wall of the reverser-cylinder, through which the air must pass in the form of a thin film or films as it is displaced from one end of the reverser-cylinder by the reciprocation of the reverser-piston, whereby the heat is alternately extracted from and imparted to said air, as a means of facilitating the rapid cooling and heating of the air.

It further consists in the combination, with an air-engine operated by air under pressure upon both sides of its working-piston, of a

distributing-reservoir adapted to be filled with compressed air supplied thereto by an air force-pump, and suitable pipes and check-valves connecting said reservoir with the reverser-cylinder and with the chamber above the working-piston, all so constructed and arranged that air will escape from said distributing-reservoir to either the reverser-cylinder or the upper part of the working-cylinder whenever, from any cause, the pressure in said cylinders becomes less than it is in said reservoir. This is a very important arrangement of the mechanism, as it is all-important that the minimum pressure should be the same upon both sides of the working-piston, the power of the engine being dependent upon the difference between the maximum pressure beneath the working-piston and the minimum pressure above said piston.

Figure 1 of the drawings is a front elevation of an engine embodying our invention. Fig. 2 is a side elevation. Fig. 3 is a plan. Fig. 4 is a horizontal section on line 1 1 on Figs. 1 and 2. Fig. 5 is a horizontal section on line 2 2 on Figs. 1 and 2. Fig. 6 is a horizontal section on line 3 3 on Figs. 1 and 2. Fig. 7 is a vertical section on line 4 4 on Fig. 3. Fig. 8 is a partial section through heater and deflector on line 2 2, enlarged, and showing the corrugated plates; and Fig. 9 is a similar enlarged partial section on line 3 3, and showing the manner of applying the filling to the regenerator.

A is the furnace of the working-cylinder, and B the furnace of the reverser-cylinder, each provided with suitable gates *a*, and lined with fire-brick *b*, and connected together by the passage *c* in such a manner that the products of combustion pass from the furnace A through said passage *c*, and across the furnace B, to reach the smoke-pipe *d*, leading to the chimney. (Not shown.)

To the upper side of the furnace A is firmly bolted the working-cylinder, composed of two sections, C and C′, firmly bolted together and having its upper end closed by the head C^2, through which the piston-rod D′ passes, and provided with the leather-cupped packing *e*, held in position by the disk or follower *e′*, and also provided with an annular water-chamber, e^2, in close proximity to said packing, through which chamber water is made to circulate as a means of keeping the packing cool.

D is the working-piston, made of a length considerably greater than its stroke, and connected by the piston-rod D′ and link D^2 to one end of the beam E, and guided in its movements by the cross-head D^3 and slides D^4.

The working-piston D is packed by means of two leather-cupped packing-rings, *f f′*, secured in position with their cylindrical portions turned in opposite directions by means of the two metal rings *g* and *g′*, firmly bolted to the upper end of the lower section, C, of the working-cylinder, the lower end of the upper section, C′, being chambered out to make room for said rings, as shown.

In the upper end of the lower section, C, and the lower end of the upper section, C′, of the working-cylinder are formed the annular chambers *h* and *h′*, respectively, through which water or other cooling-liquid is made to circulate to keep the packing-rings *f* and *f′* cool.

A portion of the lower end of the lower section, C, of the working-cylinder is enlarged in diameter, and said lower section has secured therein, above said enlargement, the cylindrical deflector F, which depends therefrom below the bottom of said section, and into the annular space formed between the outer and inner walls, *i* and *i′*, of the heater F′, as shown in Fig. 7.

The heater F′ is bolted to the lower end of the section C of the working-cylinder from below, and may be readily and easily removed by removing one portion of the furnace-casing A, which is made in two parts, secured together by bolts passing through the flanges *a′*, as shown.

The furnace B of the reverser-cylinder is also made in two parts, secured together in like manner by bolts passing through the flanges *b′ b′*, as shown in Fig. 5.

To the upper side of the furnace B is bolted the cylinder G, which forms one wall of the regenerator, and supports at its upper end, by means of lugs *j*, the inner cylinder, G′, so arranged relative to the cylinder G as to form a thin annular space between said two cylinders, which we term the "regenerator," said inner cylinder serving the double purpose of a guide for the reverser-piston H, which moves up and down therein, and a deflector to turn the air downward around its lower end, between it and the outer and inner walls, *j′* and j^2, of the heater H′, secured to and depending from the lower end of the cylinder G, as shown in Fig. 7.

An outer cylinder, G^2, is fitted and secured to the cylinder G in such a manner as to form an annular chamber, *k*, through which water may be made to circulate to cool the regenerator, if desirable.

To the upper ends of the cylinders G and G^2 is firmly secured the refrigerator I, composed of outer and inner cylindrical walls, *k′* and k^2, united at their upper edges, so as to form an annular space, k^3, open at the bottom, a head or bottom interposed between and connecting the lower edge of said inner wall, a central hub, *l*, through which the piston-rod passes, and an outer casing or bonnet, I′, inclosing the same in such a manner as to form the annular chamber *l′*, connected at its upper part with the larger annular chamber l^2, through which water is made to circulate.

The cylindrical deflector G′ projects upward into and nearly to the top of the annular space k^3, thereby compelling the air to pass around the end of said deflector and downward upon its inner side in passing from the heater to the space above the reverser-piston while spread out into a thin film and exposed to a large area of cooling-surface.

The hub l of the refrigerator is chambered out considerably larger than the diameter of the piston-rod from the bottom of the refrigerator to near its top, and has screwed into its upper part a pipe or sleeve, m, which just fits the periphery of the hollow piston-rod m', screwed into the upper end of the piston H, and opening into the chamber H^2, formed in the upper end thereof.

A thin tube or sleeve, m^2, is screwed into the upper end of the piston H, from which it projects upward into the annular chamber formed between the outer surface of the sleeve m and the inner surface of the hollow hub l, without touching either, forming an annular space to contain oil, for the purpose of lubricating the piston-rod and preventing the loss of air by leakage.

Within the hollow piston-rod m' is a pipe or tube, m^3, open at its lower end and connected at its upper end with the flexible pipe m^4, through which water is conveyed from the water-chamber l' to the chamber H^2, after which said water is discharged through the space in the hollow piston-rod m', surrounding the pipe m^3, and the flexible pipe m^5, the pipes m^4 and m^5 being made flexible to permit a free reciprocation of the piston-rod.

The upper end of the piston-rod m' is connected by the links $n\,n$ to one end of the beam J, mounted by suitable central journals or trunnions in the stand J', as shown.

The beam E is mounted by central journals or trunnions, E', in the column or stand E^2, and is connected by the rod E^3 to the crank C^3, formed upon or secured to the end of the shaft C^4, mounted in bearings A'A', and having secured thereon, between said bearings, the fly-wheel pulley A^2, and upon its end opposite to the crank C^3 the eccentric K, which, acting, through the weighted eccentric-rod K', the upper end of which is pivoted to the front end of the bearing J', imparts motion to said beam J, and through it and the piston-rod m', to the reversing-piston H.

L is an expansion-reservoir, made of sufficient strength to sustain a pressure of several atmospheres, and having direct communication by means of the pipe L' with the interior of the working-cylinder, above the working-piston, and connected by the pipe o, provided with the check-valve o', to the air-chamber L^2, from which the pipe o^4 leads to the air-pump M, the plunger M' of which is connected to and operated by the beam E. A branch pipe o^2, also provided with a check-valve o^3, leads from the chamber L^2 to the cooling end of the reverser-chamber, as shown.

N is a water-circulating pump, the plunger N' of which is connected to and operated by the beam E, said pump being connected by the pipe p to the annular chamber h, which in turn is connected by the pipe p' to the annular chamber h', both in the working-cylinder, and the chamber h' is in like manner connected by the pipe p^2 to the annular chamber e^2 in the head C^2 of the working-cylinder.

A pipe, q, connects the chamber e^2, in the head of the working-cylinder, with the annular chamber k, surrounding the regenerator of the reverser-cylinder, and the chamber k is in turn connected by the pipe q' to the annular chambers l' and l^2.

The expansion-reservoir L is provided with an inlet-pipe, r, and cock r', through which water or other liquid may be introduced as a means of reducing the capacity of the air-space thereof, and also with a discharge-pipe, s, and cock s', by means of which the water or other liquid contained in the receiver may be withdrawn, or any portion of it, when it is desired to reduce the pressure by increasing the capacity of the air-space within said reservoir.

Corrugated plates of thin metal t and t', preferably of sheet-copper, are placed in the annular spaces between the cylindrical deflector F and the outer and inner walls, i, and i', respectively, of the heater F' of the working-cylinder, with their corrugations so arranged as to divide said annular spaces into a great number of small tubes or passages, arranged preferably in a vertical position or parallel to the axis of the cylinder as a means of very greatly increasing the area of heated metallic surface to which the air is exposed in passing from the reverser to the space below the working-piston through the pipe O, and vice versa. The annular spaces between the lower portion of the cylindrical deflector G' and the outer and inner walls, j' and j^2, respectively, of the heater H', is, in like manner, supplied with corrugated plates u and u', as shown in Fig. 8. In like manner the annular spaces between the upper portion of the cylindrical deflector G' and the outer and inner walls, k' and k^2, of the refrigerator I have placed therein similar corrugated plates v and v', as a means of increasing the area of cooling metallic surface to which the air is exposed in passing from the heated end of the reverser to the space between the reverser-piston and the refrigerator. The annular space between the central portion of the inner cylinder or deflector, G', and the regenerator-casing G has placed therein a series of finely-corrugated plates or rings of thin metal, w, alternating with plain plates or rings of thin metal w', as shown in Fig. 9, said plates being preferably made of sheet-copper, and dividing said annular space into a very great number of small tubes or passages, arranged preferably parallel, or nearly so, to the axis of the reverser-cylinder, through which the air is compelled to pass to reach the space above the reversing-piston.

P is the fire-door of the working-cylinder furnace, and P' the ash-pit door of the same; Q, the fire-door of the reverser-cylinder furnace, and Q' the ash-pit door of the same.

In order to make the cylinders capable of holding air compressed to a pressure equal to several atmospheres, we make the flanges at all the joints extra wide and pack them with

holding air compressed to a pressure equal to several atmospheres, we make the flanges at all the joints extra wide and pack them with asbestus packing; or in some instances—as the joints between the lower end of the cylinders and the furnaces—we use a gasket of fine copper-wire gauze embedded in red lead.

It being understood that the working-cylinder is single-acting, or, in other words, that the engine is operated by alternately heating and cooling the air upon one side of the working-piston, while the space upon the other side of said piston is filled with air at its normal temperature, and also that the eccentric which operates the reverser-cylinder leads the crank through which motion is imparted to the fly-wheel shaft by the reciprocation of the working-piston from seventy-five to ninety degrees, or the crank and eccentric must be so set relative to each other that from the time when the reverser-piston completes its stroke to the time when the working-piston completes its stroke the shaft must revolve from seventy-five to ninety degrees, the following description of the operation will be more readily understood.

The working-piston D being in the position due to the crank C^3, having just passed its upper dead-center in the direction indicated by the arrow, or, in other words, said piston having just commenced its upstroke, the reverser-piston H is moved by hand to the extreme of its upward stroke, displacing the air from the space above said piston, forcing it through the series of small passages by the corrugated plates *v* and *v'*, between the upper portion of the cylindrical deflector G' and the outer and inner walls, *k'* and k^2, of the refrigerator, thence through the still smaller passages in the regenerator, and then through the passages formed by the corrugated plates *u* and *u'*, placed between the lower portion of the cylindrical deflector and the outer and inner walls, *j'* and j^2, of the heater H' of the reverser-cylinder into the chamber between said heater and the piston H, and through the pipe O and the passages formed by the corrugated plates *t* and *t'*, placed between the cylindrical deflector F and the outer and inner walls, *i* and *i'*, of the heater F' of the working-cylinder to the space between said heater and the working-piston D, where it is heated and thereby expanded, and acting upon the working-piston, causes it to move upward with the full force of the increased pressure due to the expansion of the air contained in the spaces beneath the working and reverser pistons and the connecting-passages. When the working-piston has arrived at about the center of its upward stroke the reverser-piston H begins to move downward, moving quite slowly, while the working-piston is moving fast, and as the speed of the latter decreases as it approaches the limit of its upward movement the speed of the reverser-piston increases, and as it moves downward it displaces the air below it and forces it around the lower end of the cylindrical deflector G', up through the regenerator, where a large part of the heat is given off and absorbed by the large area of metallic surface over which it passes, and thence around the upper end of said cylindrical deflector, where the air is still further cooled, and into the chamber above said piston.

The sudden cooling of the air so reduces its volume that the pressure beneath the working-piston becomes less than the pressure in the chamber above said piston, occasioned by the compression of said air by the upward movement of said piston, and as a consequence the pressure above the piston, acting in conjunction with the momentum of the fly-wheel, causes the working-piston to descend or make its downstroke, at about the middle of which the reverser-piston starts on its upstroke, forcing the cold air contained in the chamber above said piston therefrom and through the passages before described, taking up a large part of the heat given out in its upward passage through the regenerator to the chambers beneath the working and reverser cylinders, where it is again heated, as before described, and the operation is repeated indefinitely.

At each double vibration of the beam E the pistons of the air and water pumps each make a reciprocation or double stroke, the air-pump at each downward stroke of its piston forcing air through the pipe o^4 into the air-chamber L^2, to maintain therein a given pressure, from which chamber the air escapes, through the pipe o^2 and check-valve o^3, to the reverser-cylinder, or through the check-valve *o'* and pipe *o*, into the reservoir L, whenever for any cause the minimum pressure in the reverser-cylinder and in the reservoir is below the pressure in the air-chamber L^2.

The pump M is so arranged that when the desired pressure is maintained in the air-chamber the air drafted by the pump is discharged into the open air.

The movements of the piston of the water-pump maintain a constant circulation of water or other cooling-liquid through all the water or cooling chambers of both cylinders, as hereinbefore described.

Water or other liquid is introduced into the reservoir L to reduce its capacity, for the purpose of increasing the maximum pressure on the upper side of the working-piston through the pipe *r* and cock *r'*, and when it is desired to reduce the maximum pressure above said piston a portion of said water may be withdrawn through the pipe *s* and cock *s'*.

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

1. The combination of a single-acting working-cylinder provided with a long piston, a reverser-cylinder with air of equal pressure on each side of its piston, means of applying heat to the lower end of the reverser, and means of conveying air from the heated end of the reverser to one end of the working-cylinder, substantially as and for the purposes described.

2. The combination of a single-action work-

ing-cylinder, provided with a piston and containing air under pressure upon both sides of said piston, a reverser-cylinder, means of applying heat to the lower end of the reverser, and means for conveying air from the heated end of the reverser to one end of the working-cylinder while the air in the other end of the working-cylinder remains at its normal temperature, substantially as and for the purposes described.

3. The combination of a working-cylinder provided with a piston and adapted to contain air under pressure upon both sides of said piston, and to be worked by alternately heating and cooling the air upon one side of said piston, while the air upon the other side of said piston remains at its normal temperature, a reverser-cylinder, and a furnace or other means of applying heat to both the working-cylinder and reverser, substantially as described.

4. The combination of a working-cylinder provided with a long piston adapted to be worked by alternately heating and cooling the air upon one side of said piston, while the air upon the other side of said piston remains at its normal temperature, a reverser-cylinder, and a furnace or other means of applying heat to the working-cylinder and reverser, substantially as decribed.

5. The combination of a working-cylinder provided with a furnace, a reverser-cylinder, also provided with a furnace, and a communicating passage between the two furnaces, substantially as described.

6. The combination of a single-acting working-cylinder, a reverser-cylinder having direct communication with the space at one end of the piston of the working-cylinder, and an expansion-reservoir filled with air under pressure, and connected by a suitable pipe with the space at the other end of said piston, substantially as and for the purposes described.

7. In combination with a single-acting working-cylinder adapted to contain air under pressure upon both sides of its piston, an expansion-reservoir adapted to contain air under pressure, and communicating with the cold end of the working-cylinder, and means for varying its capacity for the purpose of regulating the pressure, substantially as described.

8. In combination with a single-acting working-cylinder containing air under pressure upon both sides of its piston, an expansion-reservoir connected by a suitable pipe or passage with the cold end of the working-cylinder and adapted to contain air under pressure, and means of introducing water or other liquid into and withdrawing it from said reservoir as a means of varying the pressure, substantially as described.

9. The combination of a heater, a refrigerator, the outer shell of the regenerator interposed between said heater and refrigerator, and a cylindrical deflector, each made separate from the other and firmly secured together to form a reverser-cylinder, substantially as shown and described.

10. In combination with a reverser-cylinder provided with a heater at one end and a refrigerator at the other end, a stationary cylindrical deflector extending from near the lower part of the heater to near the upper part of the refrigerator, substantially as and for the purposes described.

11. The combination of a reverser-cylinder, a working-cylinder, a pump for forcing air into said cylinders under pressure, and a furnace or other means of applying heat to one end of both of said cylinders, while the air in the other end of the working-cylinder remains at or near its normal temperature, substantially as described.

12. In combination with a reverser-cylinder provided with a heater, and a deflector, a pipe or passage leading from the heated portion of the reverser-cylinder to the working-cylinder, substantially as described.

13. The outer casing of the reverser or working-cylinder furnace, made in two parts, divided in such a manner that one portion may be removed to give access to the heater and allow it to be removed without disturbing the other parts of the engine, substantially as described.

14. In combination with a regenerator of an air-engine, a water-space surrounding a portion or the whole of said regenerator, substantially as and for the purposes described.

15. In combination with the heater and deflector of a reversing or working cylinder, a corrugated plate of metal placed in the annular space or spaces between said deflector and heater, substantially as and for the purposes described.

16. In combination with the deflector of a reverser and the outer shell of a regenerator arranged relative to each other so as to form an annular chamber between them, one or more corrugated plates of metal placed in said annular chamber, substantially as and for the purposes described.

17. In combination with the deflector of a reverser and the outer shell of the regenerator, two or more corrugated plates alternating with one or more plain plates placed within the annular space between said shell and deflector, substantially as and for the purposes described.

18. In combination with the refrigerator provided with an annular space between its two cylindrical walls and the deflector of the reverser projecting into said space, as set forth, a corrugated plate of thin metal placed in one or both of the annular spaces between said deflector and the refrigerator-walls, substantially as and for the purposes described.

19. The refrigerator, composed of a double-walled cylinder, the two walls of which are united at their upper edges and disconnected at their lower edges, thus forming an annular space open at the bottom, and a head or bottom connecting the lower edge of the inner wall, substantially as shown and described.
and the outer and inner walls of said annular extension, and means for causing a constant

circulation of water through said chamber, substantially as described.

21. In combination with a reverser-cylinder provided with a refrigerator at its upper end and having an annular extension, and a water-chamber covering its top and the outer and inner walls of said annular extension, and means of causing a circulation of the water therein, a furnace or other means of applying heat to the lower end of said cylinder, substantially as described.

22. In combination with a reverser-cylinder provided with a heater, and a deflector, a pipe or passage leading from the heated end of said cylinder to the working-cylinder, and a pump adapted to force air into said reverser-cylinder under pressure, substantially as described.

23. In combination with a reverser-cylinder provided with a heated chamber at one end, a refrigerated chamber at its other end, and a

20. In combination with a reverser-cylinder, a refrigerator provided with an annular extension, and a water-chamber covering its top reciprocating piston, a passage or passages leading from the heated chamber to the r frigerated chamber, adapted to spread the a into a thin film or films on its passage throu the heater or refrigerator to the heated or r frigerated chamber when the air, in its pa sage from the heater to the refrigerator, passed outside of the inner reverser-cylinde substantially as described.

24. In combination with an air-engine ope ated by air under pressure upon both sides o its working-piston, a distributing-reservo adapted to be filled with compressed air an to distribute it to the several cylinders, sub stantially as and for the purposes described.

Executed at Boston, Massachusetts, this 28th day of April, A. D. 1879.

JAMES A. WOODBURY.
JOSHUA MERRILL.
GEO. PATTEN.
EDWARD FRANKLIN WOODBURY.

Witnesses:
N. C. LOMBARD,
E. A. HEMMENWAY.