March 1, 1966 F. WILSON 3,237,847

COMPRESSOR AND METHOD

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Fig. 1

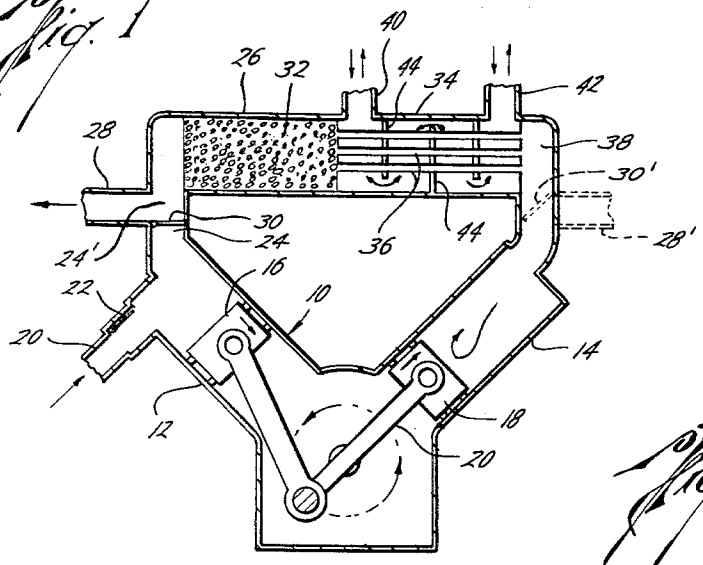


Fig. 2

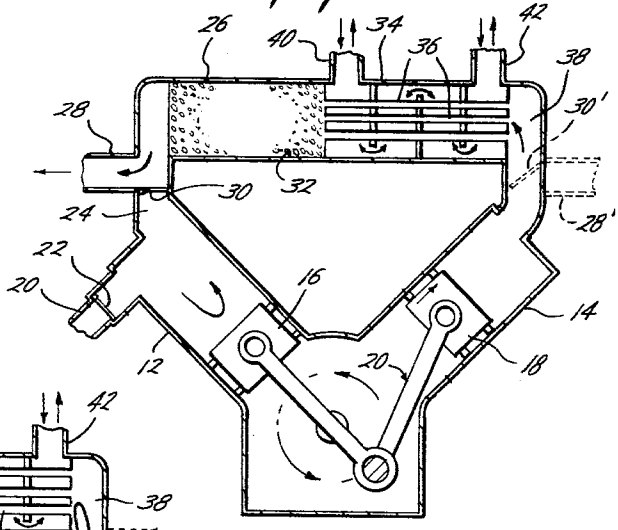
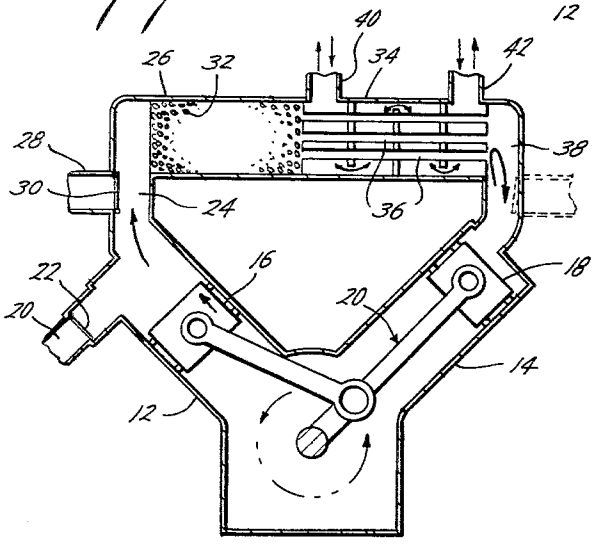


Fig. 3



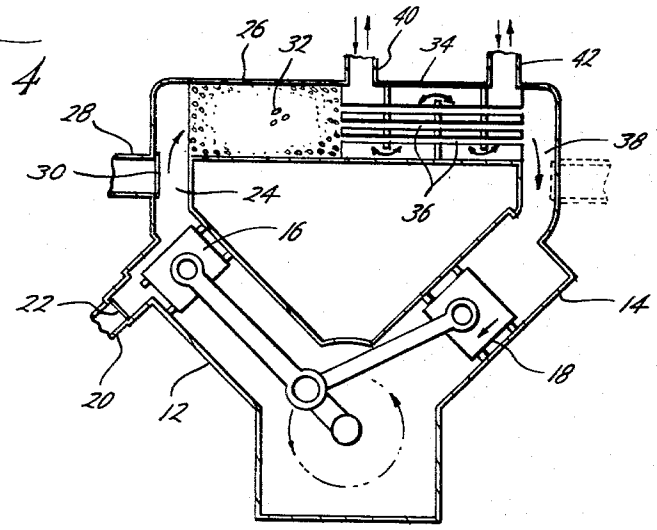
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COMPRESSOR AND METHOD

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Fig. 4



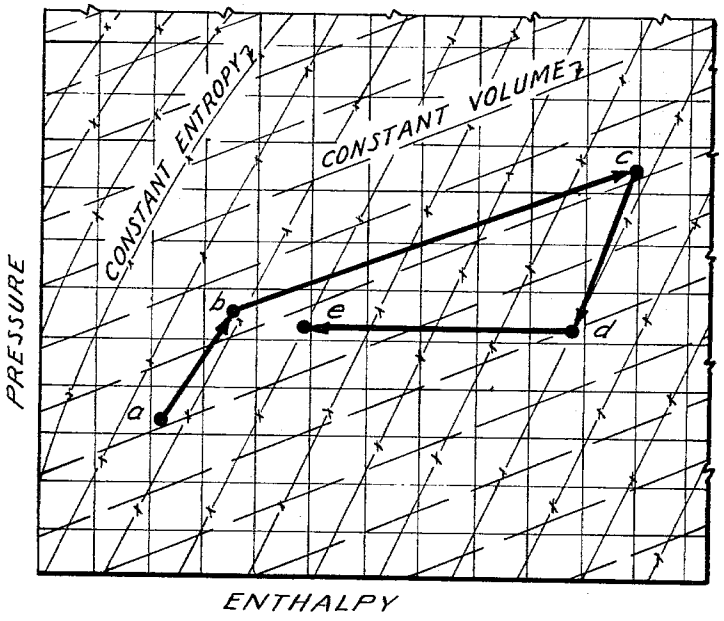


Fig. 5

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COMPRESSOR AND METHOD

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Fig. 6

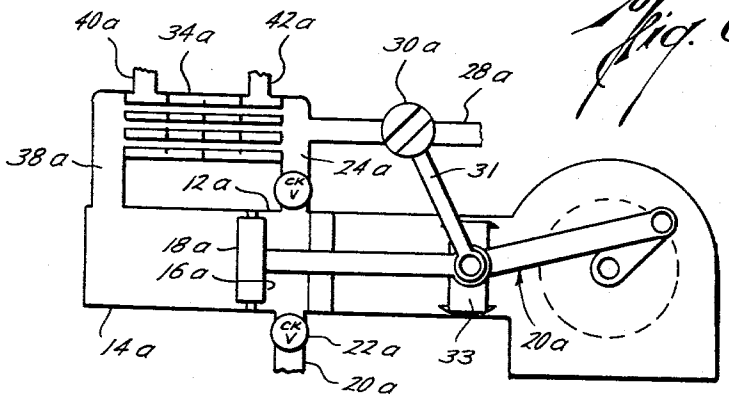


Fig. 7

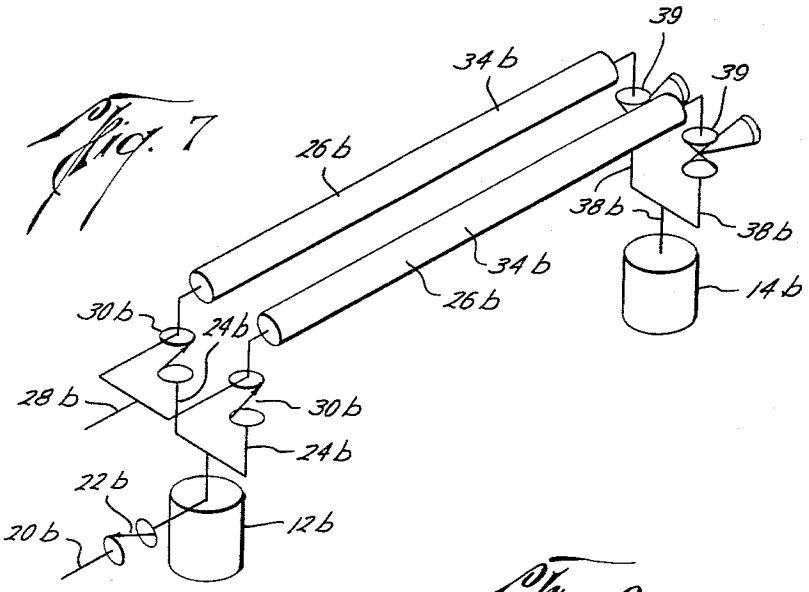
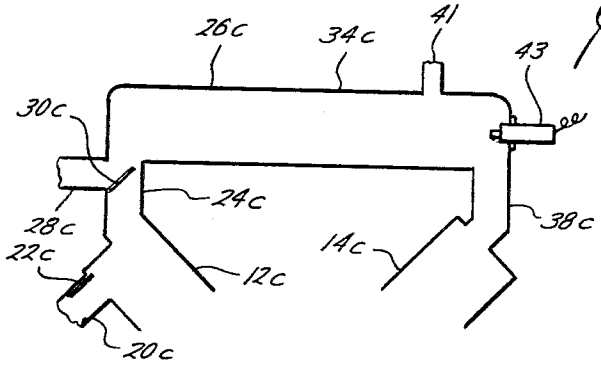


Fig. 8



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COMPRESSOR AND METHOD

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Fig. 9

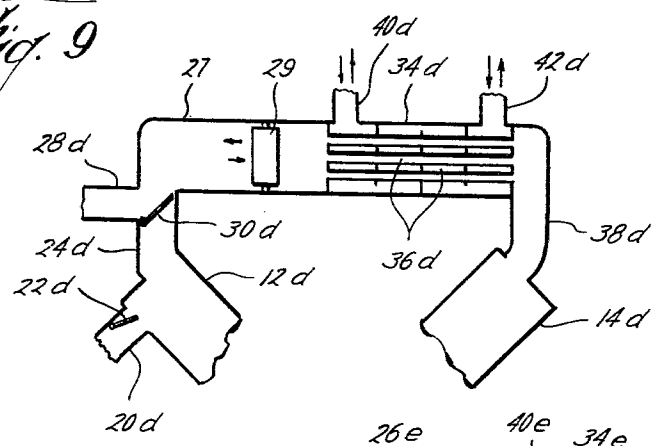


Fig. 10

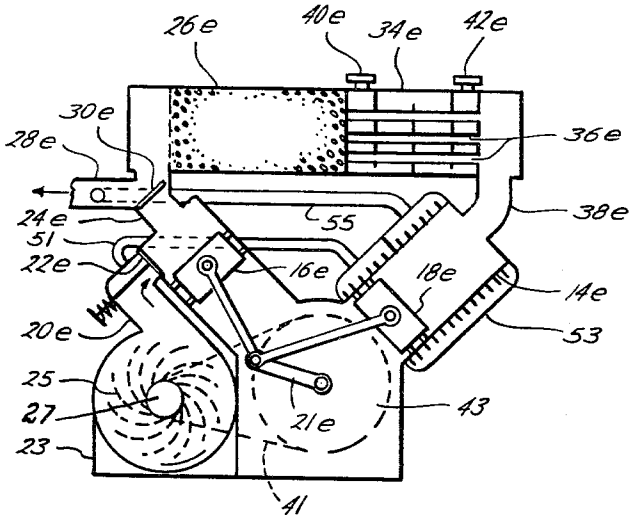
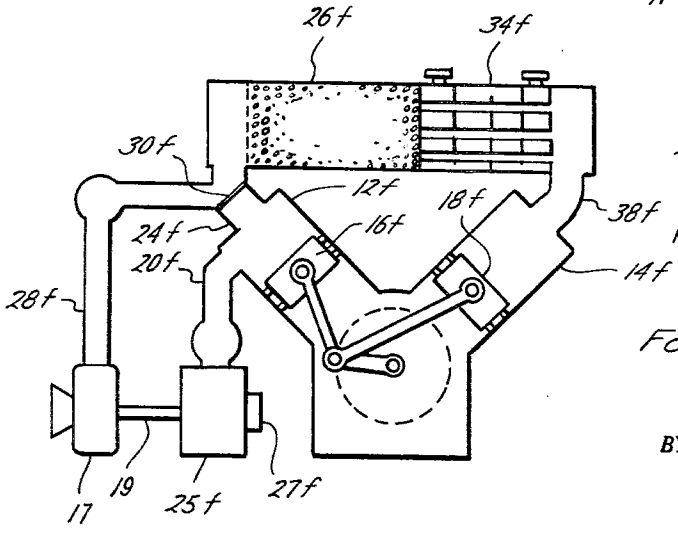


Fig. 11



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3,237,847

COMPRESSOR AND METHOD

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Filed July 3, 1961, Ser. No. 121,475
20 Claims. (Cl. 230—52)

The present invention relates to improvements in compressors for and methods of compressing gases.

It would be desirable to provide a compressor for gas and a method of compressing gas in which the energy source therefor is any convenient source of external heat directly applied or used thereby giving almost complete freedom of choice of fuels and allowing waste heat to be used in all or in part for further economy. By applying the external source of heat directly to the compressor or directly in the method without first converting this energy, the compressor and method can be operated from a convenient and nearby source of available heat without an outside additional drive being necessarily required. The present invention is directed to such a compressor and method.

It is therefore an object of the present invention to provide a compressor for and a method of compressing gas in which the direct application of heat from a convenient external source is utilized to drive the compressor and operate the method, at least in part.

Yet a further object of the present invention is the provision of such a compressor for and a method of compressing gas which is actuated by the direct application of heat from any convenient source of external heat and in which no outside engine or other driver is required.

Still a further object of the present invention is the provision of such a compressor and method in which the gas being compressed serves as its own working medium by the application thereto of heat from any convenient source of external heat.

Yet a further object of the present invention is the provision of a compressor for and a method of compressing gas in which the gas is first mechanically compressed, then heated at a substantially constant volume thereby increasing its pressure, the heated gas then being expanded and the energy derived from this last step being used to provide substantially toward the actuation for the mechanical compression. Preferably, this energy is utilized as the entire actuation of the mechanical compression, although more or less energy as required may be developed by the expansion phase.

Still a further object of the present invention is the provision of such an improved compressor for and a method of compressing gas in which blowers actuated thereby may be used to compress more gas, compression and heating of the gas may be accomplished alternately for balancing of heat and volume requirements when desired or necessary, and in which the heating and expansion can be accomplished in a variety of ways.

Other and further objects, features and advantages will be apparent from the following description of presently preferred embodiments of the invention, given for the purpose of disclosure, and taken in conjunction with the accompanying drawings, illustrating apparatus according to the invention and satisfactory for use in the method of the invention, where like character references designate like parts throughout the several views and where

FIGURE 1 is a diagrammatic sectional view, in elevation, illustrating a compressor according to the invention,

FIGURE 2 is a view of the compressor of FIGURE 1 with the parts in a position further along in the cycle,

FIGURE 3 is a view similar to that of FIGURES 1 and 2 with the parts in a still further position during the cycle,

FIGURE 4 is a view similar to that of FIGURES 1–3, inclusive, with the parts in a still different position during the cycle,

FIGURE 5 is a pressure-enthalpy diagram illustrating the general mode of operation of a compressor according to the invention,

FIGURE 6 is a diagrammatic elevational view, in section, illustrating a modification according to the invention,

FIGURE 7 is a diagrammatic view, in perspective, illustrating a still further modification,

FIGURE 8 is a diagrammatic elevational view illustrating a still further modification,

FIGURE 9 is a diagrammatic elevational view illustrating a still further modification,

FIGURE 10 is a diagrammatic elevational view illustrating a still further modification, and

FIGURE 11 is a diagrammatic view illustrating yet a further modification of the invention.

Referring first to FIGURE 5, the general principle and mode of operation of the various forms of the compressors are illustrated. In this figure enthalpy is plotted as the abscissa and pressure as the ordinate. The enthalpy volumes increase to the right and pressure values increase to the top, as the graph is viewed. Also plotted by the lines labeled as such are constant entropy and constant volume.

The lines plotted on the graph illustrate the principle and mode of operation as mentioned. Thus, gas under a suction condition enters the compressor at *a* and is mechanically compressed to an elevated pressure condition indicated by the reference letter *b*. The energy required for compression is represented by the difference in enthalpy between conditions *a* and *b*. At this point the gas is heated at a substantially constant volume where it attains the pressure indicated by the letter *c*. The gas is then expanded thereby reducing its pressure until it reaches point *d* thereby providing mechanical energy for the compressor system. The energy derived from expansion of the gas is represented by the difference in enthalpy between conditions *c* and *d*. Preferably, the gas is then cooled to condition *e* and then discharged from the compressor, the cycle starting over again. Preferably, the heat obtained from the cooling advantageously is used in the heating phase.

When the gas is expanded to a pressure below the elevated pressure *b* and above the incoming pressure *a* a check valve may be used rather than some other valve. When the work output of the expansion phase, represented by the enthalpy difference *c–d*, is equal to or greater than the work input initially required in initially mechanically compressing the gas, represented by the enthalpy difference *b–a*, the compression is self actuating. If the converse occurs, external work is required to assist in the drive.

Thus, the general mode of operation of the compressor comprises mechanically compressing the gas to elevate its pressure, further increasing its pressure by heating by the direct application of heat from an external source of heat while maintaining the gas at a substantially constant volume, expanding the heated gas sufficiently to provide the desired or available mechanical energy for the system, then preferably cooling the gas and then discharging it from the compressor at its increased pressure. The heat removed in cooling the gas preferably is used in providing part of the heat for heating the gas at a constant volume, the remainder of the heat required being provided from an external source, as previously mentioned.

By direct application of heat is meant application of heat without first converting it to some other type of energy and includes all types of heating, such as direct, indirect or generating heat in situ.

Referring now to FIGURE 1, a presently-preferred form of a compressor generally designated by the reference numeral **10** is illustrated. The compressor **10** includes the compression chamber cylinder **12** and expansion chamber cylinder **14** provided with the compression piston **16** and expansion piston **18**, respectively, which are linked together by the crank arrangement **20**. As illustrated, the compression cylinder **12** and expansion cylinder **14** are oriented approximately 90° apart, although other orientations may be utilized, and through the crank linkage **20** the pistons **16** and **18** move so that a constant volume of gas is maintained during the heating step as hereinafter described.

For the purpose of illustration, only a single compression cylinder **12** and compression piston **16** are shown connected through the crank system **20** to a single expansion piston **18** in the single expansion cylinder **14**. It will be understood, of course, that any number of these members may be utilized as desired.

A gas inlet **20** is provided into the upper portion of the compression cylinder **12** and a check valve **22** is provided which permits gas to enter the inlet **20** but prevents it from escaping therethrough.

The upper end of the compression chamber **12** is connected by the passage **24** to a regenerator **26**. Connected to the passage **24** is the discharge outlet **28** through which gas which has been compressed is discharged from the compressor **10**. A double acting check valve **30** is provided adjacent the discharge outlet **28** and the passage **24** so that it serves to alternately close and open the passage **24** and the discharge outlet **28** automatically during a cycle of the compressor **10** as more fully described later.

Confined within the regenerator **26** may be a plurality of particles, segments or passageways **32** for the purpose of retaining or exchanging heat and assisting in heating gas compressed in the compression cylinder **12**.

A heater **34**, here shown of the indirect type, is connected to a regenerator **26** by means of the heater tubes **36** which provide a passage for the gas from the regenerator **26** to the passage **38** into the expansion cylinder **14**. The heater **34** is provided with the heat inlets and outlets **40** and **42** and preferably with the baffles **44** so that heat from any convenient external source may be brought into indirect heat exchange relationship with the gas passing through the heater tubes **36**. The passage **24**, heater tubes **36** and passage **38** thus form a passage connecting the compression cylinder or chamber **12** with the expansion cylinder or chamber **14** through the heater **34**.

While not described in detail, obviously, suitable frame, body members, fly wheels and the like may be utilized and provided to make a completetly operable compressor.

In the operation of the compressor illustrated in FIGURES 1–4, inclusive, in FIGURE 1 the compressor piston **16** is moving in the direction of the arrows and is part way through its suction stroke causing gas to be compressed to enter the compression cylinder **12** through the open check valve **22** and inlet **20**. The two-way check valve **30** has closed the passage **24** from the compression cylinder **12**, being actuatetd by the lower pressure in the passage **24** below it.

At the same time, the expansion piston **18** has just completed its expansion stroke and is beginning its displacement stroke causing heated and expanded gas in expansion cylinder **14** to begin moving back through passage **38**, heater tubes **36** and regenerator **26** out the discharge outlet **28**. During this time, the heated gas heats the particles or segments **32** in the regenerator **26** to provide some heat for initially heating the incoming gas to the compression cylinder **12** through the inlet **20**.

Referring now to FIGURE 2, the continuation of the cycle is illustrated in which the compression piston **16** is now in position to begin its compression stroke, thus closing the check valve **22**, the expansion piston **18** continuing its movement from FIGURE 1 and continuing to force the hot expanded gas through the heater tubes **36**, the regenerator **26** and out the outlet **28**, as previously described.

FIGURE 3 illustrates the parts in a next phase of the cycle with the compression cylinder **16** near the completion of the compression stroke and the expansion cylinder **18** having completed its displacement stroke. Since the incoming gas has been compressed to a pressure slightly greater than the outlet pressure in the discharge outlet **28**, the double acting check valve **30** closes the discharge outlet **28** and the incoming gas is directed through the regenerator **26** and heater **34** and into the expansion cylinder. As the gas passes through the regenerator **26** it is initially heated by the particles or segments **32** previously heated by the hot gas just discharged and is further heated in passing through the heater **34**. As previously explained, since the incoming gas has been mechanically compressed by the compressor **16** to elevate its pressure, it is then heated at a nearly constant volume which causes its pressure to be increased considerably, as previously described in connection with the graph of FIGURE 5.

Referring now to FIGURE 4, a further phase of the compression cycle is illustrated in that the compression cylinder **16** has completed its compression stroke causing the incoming gas to flow through the regenerator **26** and heater **34**, as previously described, into the expansion cylinder **14**. In this connection, a comparison of the position of the parts in FIGURES 3 and 4 illustrates that the volume above the compressor piston **16** and above the expanded piston **18** remains nearly constant in the time interval between the movement of the parts from the positions illustrated in FIGURE 3 to those illustrated in FIGURE 4. The initially compressed gas is thus further compressed by heating while confined at a substantially constant volume while confined by the passages **24** and **38**, the heater tubes **36** and the communicating portions of the compression and expansion cylinders **12** and **14**, respectively.

The super compressed gas therefore expands forcing the expansion piston **18** downwardly in the direction of the arrow thereby providing a power stroke and providing mechanical energy to actuate the piston **16** through the leverage of the crank linkage **20**. At this point, as illustrated in FIGURE 4, the compression piston **16** is approximately at top dead center and does not exert any appreciable leverage to resist this motion.

A next phase of the cycle is illustrated in FIGURE 1 in which the expansion piston **18** has completed its power stroke and is staritng to move upwardly and thereby force the heated and compressed gas from the compressor **10**, the compression piston **16** having begun its suction stroke, as previously described.

Thus, as previously mentioned in connection with the graph of FIGURE 5, incoming gas at point *a* is mechanically compressed by the compression cylinder **16** (FIGURES 2, 3 and 4), heated at a substantially constant volume by the regenerator **26** and heater **34** (FIGURES 3 and 4) to further increase its pressure between the points *b* and *c* shown in the graph of FIGURE 5, expanded in expansion cylinder **14** (FIGURES 4 and 1) from the point *c* to point *d* on the graph of FIGURE 5 to provide the mechanical energy or power for the compressor piston **16** and then is expelled from the compressor at a pressure slightly less than the pressure at point *b* of the graph during the return stroke of the expander cylinder **18** and the suction stroke of the compression piston **16** (FIGURES 1 and 2).

If desired, of course, the regenerator **26** may be eliminated and the incoming gas after being mechanically compressed introduced directly into the heater **34** and if desired, the gas discharged from the cylinder **14** without passing back through the heater **34**. Such an arrangement is illustrated in the dotted lines of FIGURES 1–4. Thus, discharge passage **28** is eliminated and the portion **24'** completes the passage **24**. The discharge outlet **28'** is placed between the expansion cylinder **14** and the

heater 34 in the passage 38. The check valve 30' is added to close the discharge outlet 28' and open the passage 38 during the expansion stroke of expansion piston 18 (FIGURES 3 and 4) and to close the passage 38 and open the discharge outlet 28' during its displacement stroke (FIGURES 1 and 2).

If desired, mechanical valving can be utilized. Such embodiments are illustrated in FIGURE 6, to which reference is now made, and in which the letter "*a*" has been added to the corresponding reference numbers of FIGURES 1–4, inclusive, for convenience of reference.

It is noted that the compression and expansion cylinders have been combined. Accordingly, the reference characters 12*a* and 16*a* designate the compression chamber side of the cylinder piston, respectively, and the reference numerals 14*a* and 18*a* designate the expansion chamber side of the cylinder and piston, respectively. As previously mentioned, in this embodiment mechanical opening and closing of the discharge valve 30*a* is provided by connecting the link arm 31 to the crank system 20*a* at a crosshead guide 33 so as the crank system 20*a* is actuated back and forth the discharge valve 30*a* is opened and closed.

The other parts and mode of operation, except for the mechanical opening and closing of the discharge valve 30*a* is the same as that previously described in connection with FIGURES 1–4, the mechanical valving permitting adjustment of the system over that of utilizing an automatic discharge valve as in the other embodiments. If desired, of course, a regenerator, such as illustrated in FIGURES 1–4, inclusive, may be added to this embodiment or the automatic valving can be substituted for the mechanical valving.

In some instances there may be some difficulty in matching up the volume of the heat exchanger alone or combined with a regenerator with the volume required by the reciprocating device. In such circumstances it may be desirable to provide two or more heaters either alone or combined with a regenerator, in which the compressed gas is alternately or sequentially introduced so that the other corresponding heater or heaters, with or without their regenerators, may have a longer period of time for heating per compression cycle. Such an arrangement is illustrated in FIGURE 7, to which the reference is now made, and in which the reference character "*b*" has been added to parts corresponding to those of the embodiments previously described. Thus, in this arrangement a pair of heaters 34*b* and a pair of regenerators 26*b* are illustrated which include a pair of double acting check valves 30*b* in the branch passages 24*b* leading into the regenerators 26*b*. Similarly, a pair of valves 39 are provided on the branch lines 38*b* into the expansion cylinder 14*b*. The valves 39 are actuated by suitable controls, not shown, the check valves 30*b* acting as slave valves so that the alternate or sequential operation is obtained. No detailed description of the controls is given or deemed necessary since numerous suitable controls are readily available on the open market.

The operation of this embodiment is the same as that of FIGURES 1–4, the main difference being that the incoming gas is compressed and is directed into one set of regenerators 26*b* and heaters 34*b* while the other set is being heated. By actuating the valves 24*b* and the valves 39, the next incoming compressed gas is directed into the other set of the regenerators 26*b* and the heaters 34*b* while the first mentioned pair is being heated.

If desired the heat for the compressor may be formed in situ, such as provided by combustion within the system. If desired, a hot compressed gas may be introduced into the mechanically compressed gas directly to obtain the heating. Both of these may be done with or without a regenerator. Such an arrangement is illustrated in FIGURE 8 to which reference is now made and where the reference letter "*c*" has been added to numerals designating parts corresponding to those previously described.

As illustrated, the inlet 41 is provided directly into the heater 34*c* which may introduce either hot compressed gas from a suitable external source, not shown, to provide heat for the system or a combustible mixture may be introduced in the passage 41 and the combustor 43, such as a spark plug and suitable sparking system, not shown, provided to periodically ignite or combust the incoming combustible mixture. In the event the gas to be compressed is combustible, it would only be necessary to introduce a source of gas containing oxygen. While not shown, of course, suitable valves and the like are provided for this particular system. The remaining parts and remaining mode of operation will be the same as that described in connection with the preceding embodiments.

In some instances it may be desirable to heat and expand a fluid separate from the gas being compressed. Such an arrangement is illustrated in FIGURE 9, to which reference is now made and where the reference letter "*d*" has been added to numbers designating corresponding parts in the previous figures.

In this arrangement, the heater 34*d* is extended as indicated by the reference number 27 to provide in effect a cylinder provided with a free floating piston 29. Thus, the gas which is compressed in the compression cylinder 12*d* never reaches the heater 34*d*, but instead, a captive fluid is provided behind the free floating piston 29 and in the heater 34*d*, passage 38*d* and expansion cylinder 14*d*. Any desired captive gas may be used. If desired, a liquid may be used which will vaporize to a gaseous state to drive the expansion piston, not shown in this view, in the expansion cylinder 14*d*. The vapors may or may not be condensed, as desired. The remaining parts and mode of operation is the same as previously described, the piston 29 reciprocating with the flow of gas in the compressor 10*d*.

In some uses it may be desirable to provide a super charger for super charging the gas incoming to the compressor. Such an arrangement is illustrated in FIGURE 10, to which reference is now made and in which the reference letter "*e*" has been added to reference numbers designating corresponding parts of the previous figures. Thus, in this arrangement, the super charger 23 has been added which includes the mechanically driven blower 25 and air inlet 27, the blower 25 here illustrated as being driven by the belt 41 from the flywheel 43. If desired, the super charger 23 may be driven from an outside source of energy. The remaining parts and the mode of operation are the same as previously described in connection with FIGURES 1–4, inclusive. This arrangement is particularly useful where there is available an excess of heat or energy, the blower 25 introducing more gas into the compressor 10*e*. Thus, this particular arrangement compresses a larger unit volume of gas.

If desired, some of the incoming gas to the compressor may be utilized to cool the expansion cylinder and then be directed back and intermingled with the compressed gas. Such an arrangement is also illustrated in FIGURE 10 which includes the line 51 from the inlet passage 20*e* which communicates with the finned heat exchanger 53 disposed about the expansion cylinder 14*e* and the return line 55 which returns this gas to the discharge outlet 28*e* downstream from the valve 30*e*.

Instead of driving the blower 23 mechanically it may be desirable to utilize a turbo-type charger. Such an arrangement is illustrated in FIGURE 11, to which reference is now made and to which the reference letter "*f*" has been added to numerals designated corresponding parts of previous views.

In this embodiment the compressed gas passing out the discharge 28*f* passes through the turbine 17 and partially expands thereby rotating it which rotation is transmitted by the shaft 19 to the blower 25*f*. The remaining parts

and mode of operation are the same as that illustrated in connection with FIGURE 10 except that the gas discharged from the compressor is expanded slightly when passing through and driving the turbine **17**.

It will be understood, of course, that one or more features of the various embodiments of the invention may be utilized with any one or more of the other embodiments, the arrangements illustrated in the figures being for convenience of disclosure and to shorten this specification and to eliminate any further figures. It will be further understood that the compressors according to the present invention may be combined with and form a part of other types of compressors.

While the method of the invention has been touched on previously, the method comprises the steps of first mechanically compressing gas, heating the compressed gas at a substantially constant volume thereby further compressing it, expanding the gas to obtain energy which is applied to driving the first-mentioned compression step. Preferably, sufficient energy is obtained to completely drive the mechanical compressor, in which event the enthalpy decrease derived in the expansion step must be equal to or greater than the enthalpy required in the compression step first mentioned. The energy derived not used for driving the system may be used for any desired purpose.

The method includes heating the gas either by direct or indirect heat exchange or relationship, by generating heat in situ, such as by combustion, including heating a confined or captive gas or fluid separate from the mechanically-compressed gas, rather than the mechanically compressed gas, to provide the energy for the system and include the use of a regenerator for initially heating the compressed gas by the previous outgoing gas.

The method also encompasses the use of the supercharger or turbocharger for introducing a larger volume of gas into the compression system, includes alternate heating, sequential valving and the like. The apparatus of the invention previously described are suitable for use in the method of the invention although other apparatus may be used if desired.

If desired, both the method and apparatus may be utilized as boosters for other compressors. Also, the energy obtained by the expansion phase or step may be utilized for any purpose, as desired.

The present invention, therefore, is well suited and adapted to attain the objects and ends and has the advantages mentioned as well as others inherent therein.

While several presently-preferred embodiments of the apparatus and the method of the invention have been given for the purpose of disclosure, changes in details and arrangement of parts and in the various steps may be made which are within the spirit of the invention as defined by the scope of the appended claims.

What is claimed is:

1. A method of compressing gas comprising,
initially compressing the gas to an elevated pressure,
further compressing the initially-compressed gas by heating the initially compressed gas while maintaining it at a substantially constant volume,
partially expanding the gas from the last-mentioned step,
then utilizing the energy derived from partially expanding the gas in initially compressing the gas, and
discharging the partially expanded gas.

2. A method of compressing gas comprising,
initially compressing the gas to an elevated pressure,
further compressing the initially-compressed gas by heating it while maintaining it at a substantially constant volume,
expanding the gas from the last mentioned step to a pressure below the elevated pressure and above the initial pressure of the gas,
utilizing the energy derived from expanding the gas for initially compressing the gas, and
discharging the partially expanded gas at a pressure above the initial pressure of the gas.

3. The method of claim **2** where the gas is heated by indirect heat exchange.

4. The method of claim **2** where the gas is heated by direct heat exchange.

5. The method of claim **2** where the gas is heated by combustion.

6. The method of claim **2** where the gas is heated by alternately flowing it through a plurality of heaters.

7. A method of compressing gas comprising, initially compressing the gas to an elevated pressure, heating a second gas separated from the initially-compressed gas, expanding the second gas sufficiently to obtain energy at least equal to the energy required in initially compressing the gas, utilizing the energy derived from the last-mentioned step in initially compressing the initially-compressed gas, and discharging the last-mentioned gas.

8. A gas compressor comprising,
a first stage compression chamber,
a first piston head in the compression chamber,
a heater,
an expansion chamber,
a second piston head in the expansion chamber,
passage means connecting the first stage compression chamber to the expansion chamber through at least a portion of the heater,
the heater, the passage means and the communicating portions of the first stage compression chamber and the expansion chamber comprising a second stage compressor which further compresses by heating compressed gas from the first stage compression chamber,
means interconnecting the first piston head and the second piston head for movement thereof as a unit, movement of the first and second piston heads maintaining between them a substantially constant volume in the heater, the passage means and communicating portions of the first stage compression chamber and the expansion chamber during the further compression of the gas by heating in the second stage compressor,
an inlet in the compressor in fluid communication with the first stage compression chamber introducing gas to be compressed into the compression chamber,
an outlet in the compressor in fluid communication with the second stage compressor discharging compressed gas from the second stage compressor, and
valve means permitting inflow and preventing outflow of the gas through the inlet and controlling the flow of gas out of the outlet, said valve means operable to close the gas outlet during compression of the gas in the first stage compression chamber and in the second stage compressor and operable to open the gas outlet upon substantial completion of partial expansion of the gas in the expansion chamber,
whereby, the gas entering the first stage compression chamber is compressed above its initial pressure, the compressed gas from the first stage compression chamber is then further compressed by heating at substantially constant volume in the second stage compressor, after which the partial expansion of the compressed gas from the second stage compressor in the expansion chamber provides energy for the compressor and moves the second piston head in the expansion chamber and thereby drives the first piston head in the first stage compression chamber, then the displacement portion of the movement of the second piston head in the expansion chamber discharges compressed gas out the outlet.

9. The compressor of claim **8** where the valve means operable to open the gas outlet is disposed in the passage means between the compression chamber and the heater.

10. The compressor of claim **8** including linkage connecting the valve means in the outlet to one of the piston

heads and the means interconnecting them so that said valve means is actuated in response to movement of said piston heads.

11. The compressor of claim 8 including means for flowing heat in the heater in indirect heat exchange relationship with said passage means.

12. The compressor of claim 8 including means for introducing heat directly into the heater.

13. The compressor of claim 8 including a combustion system provided with means in communication with the passage means igniting gas therein.

14. The compressor of claim 8 including a piston freely reciprocal in the passage means between the compression chamber and the heater preventing flow of gas from the compression chamber into the heater and the expansion chamber, a second gas confined in the heater, expansion chamber and passage means between the freely reciprocal piston and the expansion chamber, said outlet disposed between the piston freely reciprocal of the passage means and compression chamber.

15. The compressor of claim 8 including a blower in the inlet blowing the gas into the compression chamber and drive means operatively connecting the blower with at least one of said piston heads for driving the blower.

16. The compressor of claim 8 including a blower in the inlet blowing gas into the compression chamber, a turbine, and drive means connecting the turbine to the blower driving the latter, said outlet connected through and being in fluid communication with the turbine whereby discharged compressed gas actuates the turbine.

17. A gas compressor comprising,
a first stage compression chamber,
a first piston head in the compression chamber,
a heater,
a regenerator,
an expansion chamber,
a second piston head in the expansion chamber,
passage means connecting the first stage compression chamber to the expansion chamber through the regenerator and then the heater,
the heater, the passage means and the communicating portions of the first stage compression chamber and the expansion chamber comprising a second stage compressor which further compresses by heating compressed gas from the first stage compression chamber,
means interconnecting the first piston head and the second piston head for movement thereof as a unit, movement of the first and second piston heads maintaining between them a substantially constant volume in the regenerator, the heater, the passage means and communicating portions of the first stage compression chamber and the expansion chamber during the further compression of the gas by heating in the second stage compressor,
an inlet in the compressor in fluid communication with the first stage compression chamber introducing gas to be compressed into the compression chamber,
an outlet in the compressor in fluid communication with the second stage compressor discharging compressed gas from the regenerator, and
valve means permitting inflow and preventing outflow of the gas through the inlet and controlling the flow of gas out of the outlet, said valve means operable to close the gas outlet during compression of the gas in the first stage compression chamber and in the second stage compressor and operable to open the gas outlet upon substantial completion of partial expansion of the gas in the expansion chamber,
whereby, the gas entering the first stage compression chamber is compressed above its initial pressure, the compressed gas from the first stage compression chamber moves through the regenerator and is then further compressed by heating at substantially constant volume in the second stage compressor, after which the partial expansion of the compressed gas from the second stage compressor in the expansion chamber provides energy for the compressor and moves the second piston head in the expansion chamber and thereby drives the first piston head in the first stage compression chamber, then the displacement portion of the movement of the second piston head in the expansion chamber moves the partially expanded compressed gas back through the heater, then the regenerator and then out the outlet.

18. A gas compressor comprising,
a first stage compression chamber,
a first piston head in the compression chamber,
a heater,
an expansion chamber,
a second piston head in the expansion chamber,
passage means connecting the first stage compression chamber to the expansion chamber through at least a portion of the heater,
the heater, the passage means and the communicating portions of the first stage compression chamber and the expansion chamber comprising a second stage compressor which further compresses by heating compressed gas from the first stage compression chamber,
means interconnecting the first piston head and the second piston head for movement thereof as a unit, movement of the first and second piston heads maintaining between them a substantially constant volume in the heater, the passage means and communicating portions of the first stage compression chamber and the expansion during the further compression of the gas by heating in the second stage compressor,
an inlet in the compressor in fluid communication with the first stage compression chamber introducing gas to be compressed into the compression chamber,
an outlet in the passage means between the first stage compression chamber and the heater discharging compressed gas from the second stage compressor passing back through the heater, and
valve means permitting inflow and preventing outflow of the gas through the inlet and controlling the flow of gas out of the outlet, said valve means operable to close the gas outlet during compression of the gas in the first stage compression chamber and in the second stage compressor and operable to open the gas outlet upon substantial completion of partial expansion of the gas in the expansion chamber,
whereby, the gas entering the first stage compression chamber is compressed above its initial pressure, the compressed gas from the first stage compression chamber is then further compressed by heating at substantially constant volume in the second stage compressor, after which the compressed gas from the second stage compressor is partially expanded in the expansion chamber thereby moving the second piston head in the expansion chamber, then the displacement portion of the movement of the second piston head in the expansion chamber moves the partially expanded gas back through the heater and then out the outlet.

19. A gas compressor comprising,
a first stage compression chamber,
a first piston head in the compression chamber,
a plurality of heaters,
an expansion chamber,
a second piston head in the expansion chamber,
passage means connecting the first stage compression chamber to the expansion chamber through the heaters,
the heaters, the passage means and the communicating portions of the first stage compression chamber and the expansion chamber comprising a second stage

compressor which further compresses by heating compressed gas from the first stage compression,

means interconnecting the first piston head and the second piston head for movement thereof as a unit, movement of the first and second piston heads maintaining between them a substantially constant volume in the heaters, the passage means and communicating portions of the first stage compression chamber and the expansion chamber during the further compression of the gas by heating in the second stage compressor,

an inlet in the compressor in fluid communication with the first stage compression chamber introducing gas to be compressed into the compression chamber,

an outlet in the compressor in fluid communication with the second stage compressor discharging compressed gas from the second stage compressor,

valve means permitting inflow and preventing outflow of the gas through the inlet and controlling the flow of gas out the outlet, said valve means operable to close the gas outlet during compression of the gas in the first stage compression chamber and in the second stage compressor and operable to open the gas outlet upon substantial completion of partial expansion of the gas in the expansion chamber, and

additional valve means operable to sequentially open and close the passage means through each of the heaters,

whereby, the gas entering the first compression chamber is compressed above its initial pressure, the compressed gas from the first stage compression chamber is then alternately compressed by one of the heaters by heating at substantally constant volume in the second stage compressor, after which the partial expansion of the compressed gas from the second stage compressor in the expansion chamber provides energy for the compressor and moves the second piston head in the expansion chamber and thereby drives the first piston head in the first stage compression chamber, then the displacement portion of the movement of the second piston head in the expansion chamber discharges compressed gas out the outlet.

20. The compressor of claim **19** including,

a plurality of regenerators,

the passage means connecting the compression chamber through one each of the regenerators to one each of the heaters, and

the outlet discharging compressed gas from each regenerator.

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