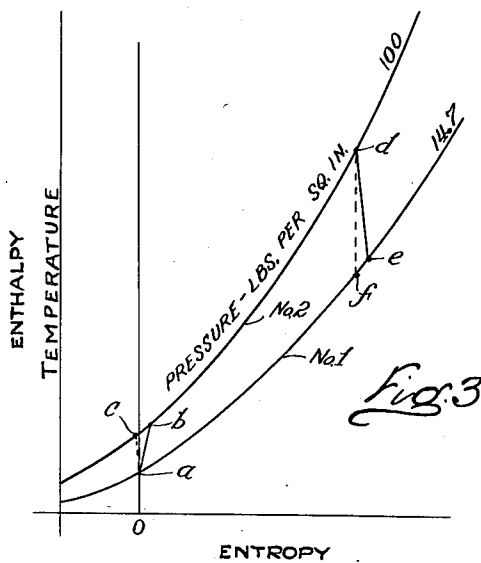
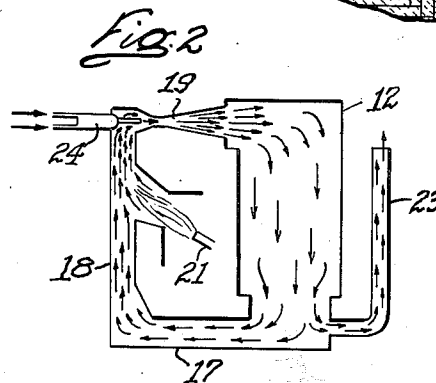
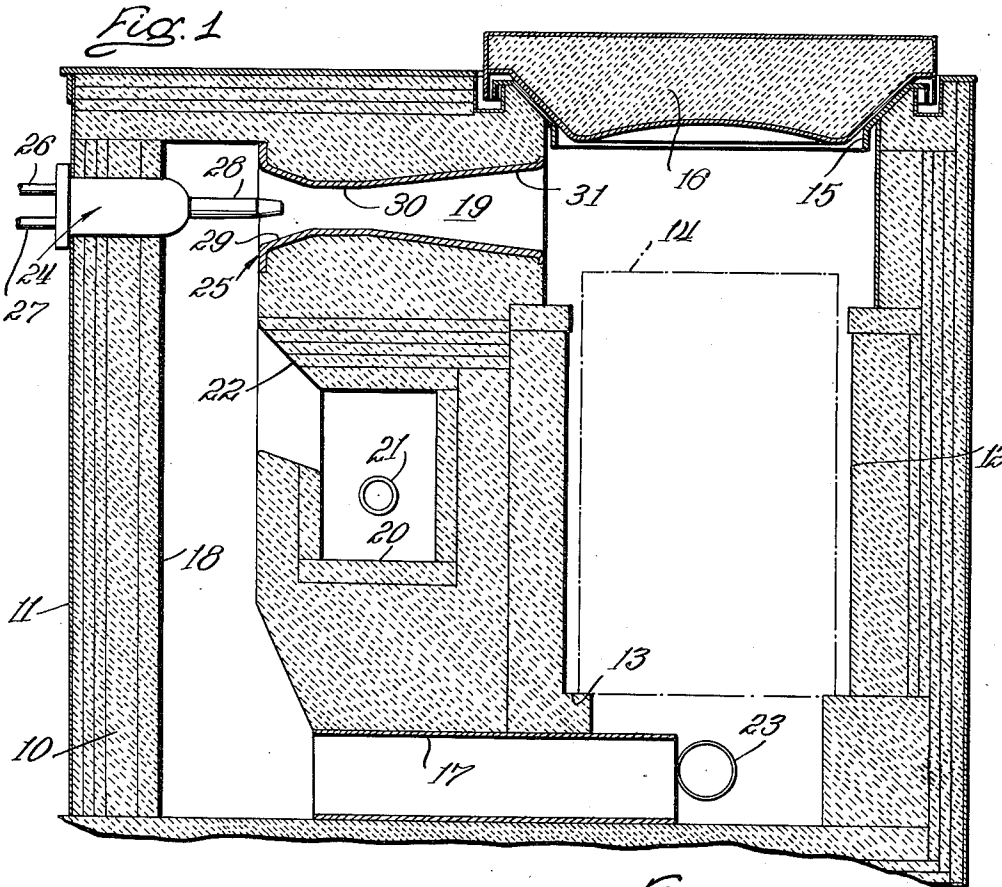


April 18, 1950

S. B. GAMBLE
METHOD OF AND APPARATUS FOR FORCED
CONVECTION HEATING
Filed Feb. 26, 1945

2,504,320



INVENTOR
Slade B. Gamble
By Carlson, Pitney, Hubbard & Wolfe
ATTORNEYS

UNITED STATES PATENT OFFICE

2,504,320

METHOD OF AND APPARATUS FOR FORCED
CONVECTION HEATINGSlade B. Gamble, Chicago, Ill., assignor to Lind-
berg Engineering Company, Chicago, Ill., a
corporation of Illinois

Application February 26, 1945, Serial No. 579,830

12 Claims. (Cl. 263—43)

1

The present invention relates generally to improvements in forced-convection heating, as commonly employed industrially for annealing, hardening and normalizing a wide variety of metal products, and has particular reference to a novel convection heating method and furnace in which a greatly improved forced circulation of the fluid heating medium is obtained.

One of the primary objects of the present invention is to provide a new and improved forced-convection heating method and furnace capable of operating at much higher temperatures than have been practicably obtainable heretofore, and without reduction in efficiency, increased maintenance costs, or impairment of the apparatus for effecting the forced convection.

Another object is to provide a novel forced-convection heating method and furnace in which the temperatures that can be attained and usefully employed are limited only by the capacity of the materials of construction, such as the refractory furnace lining, to withstand them, and in which all other temperature limiting conditions are substantially eliminated.

A further object is to provide a new and improved forced-convection furnace in which all moving machine parts are excluded from the heated enclosure, and in which, more particularly, the means for effecting forced circulation of the heating medium is entirely rigid in construction.

Another object is to provide a novel method and furnace of the foregoing character wherein, as an inherent characteristic, the weight of the heating medium that is circulated remains substantially constant as the temperature rises, and may actually increase due to improved efficiency at the higher temperatures.

Forced-convection heat transfer for high temperature work has come into popular use because of certain inherent advantages over heat transfer by conduction and radiation, among which may be enumerated substantially reduced floor space requirements, decreased labor demands and greatly increased production rates due to the velocity and turbulence of the convective medium. Of primary importance is the characteristic that shadows are avoided and only relatively small values of temperature differential are required. As a result, workpieces of varying section are not subject to unequal heating and attendant warpage or distortion. Nevertheless, the application of forced-convection heat transfer has been restricted by reason of certain operating limitations heretofore inherent in furnaces

2

of conventional design, and particularly in the centrifugal fan employed therein for effecting circulation of the heating medium. Thus, the centrifugal fan can be used satisfactorily only over a temperature range limited to a definite maximum, and if operated at a higher temperature will have a comparatively short life and require extensive maintenance. Also, as the furnace temperature is increased, the weight of the heating medium handled thereby and the horsepower requirements will decrease in direct proportion to the decrease in fluid density.

To overcome the foregoing disadvantages and thereby enlarge the field of usefulness of forced-convection heat transfer, the present invention utilizes a thermodynamic propulsion jet for inducing high velocity circulation of the fluid or gaseous heating medium in the furnace chamber. More particularly, the propulsion jet converts both pressure and heat energy into kinetic energy, and utilizes the latter to induce a convective flow of the heating medium in a recirculatory path through intimate and turbulent contact with all surface areas of the work undergoing treatment. Such propulsion jet includes no moving parts within the furnace chamber, is simple in construction and operation, and is highly efficient in use over a wide temperature range limited only to the maximum temperature which the materials of construction will withstand.

Other objects and advantages will become apparent as the description proceeds.

In the accompanying drawings:

Figure 1 is a fragmentary vertical sectional view of a convection heating furnace embodying the features of my invention.

Fig. 2 is a schematic view illustrating the flow of heated gaseous products of combustion through the furnace.

Fig. 3 is a representative enthalpy-entropy diagram illustrating the operation of the propulsion jet as a thermodynamic heat machine.

Referring more particularly to the drawings, the invention is specifically illustrated as applied to one type of forced-convection heating furnace, but it is to be understood that the invention is applicable to any such furnace in which a fluid or gaseous heating medium is adapted to be circulated through a heating chamber in heat exchange relation to the work, and, in its broad aspects, may be utilized for imparting momentum to various convected fluids.

The furnace, constituting the exemplary embodiment of the invention, is of the vertical type,

and comprises a suitable heat refractory structure 10 enclosed in a metal sheathing 11. Formed in one end portion of the structure 10 is a vertical work chamber 12 with a peripheral ledge 13 at the lower end adapted to support the work to be heat treated. It will be understood that the furnace is adapted for a large variety of workpieces, either of uniform or irregular section, and large or small in size. In many instances, large numbers of small workpieces are loaded in a basket 14 which is illustrated in dot and dash outline, and which substantially fills the work chamber 12 so that the circulating heating medium is forced to permeate the conglomerate mass. The top of the work chamber 12 is provided with an opening 15 through which the work charge may be inserted and removed, and which is normally closed by a cover 16.

The work chamber 12 is interposed in and forms part of a closed circulatory path for the heating medium and comprising the heated enclosure of the furnace. In the present instance, the lower end of the work chamber 12 is connected through a horizontal passage 17 to a vertical leg 18 in turn connected through a passage 19 to the upper end of the chamber to complete the flow path.

The heated enclosure of the furnace may be supplied with any suitable fluid or gaseous heating medium from any suitable source, and the heating medium may be introduced at any desired point in the circulatory path. Preferably, the furnace is integrally constructed with a heating unit. If gas or oil is used as fuel, the heating unit may comprise a primary combustion chamber 20 provided with a suitable burner 21 and having an outlet flue 22 for discharging the highly heated gaseous products of combustion continuously to the leg 18.

Excess products of combustion are exhausted from the circulatory system through a vent pipe or stack 23, the output and input of the heating medium being coordinated. Preferably, the stack 23 opens from the lower end of the work chamber 12.

High velocity circulation of the heating medium is continuously induced in the furnace chamber by a thermodynamic propulsion jet to bring a constant and generous amount of heat to each part of the active work charge. The propulsion jet may be located at any suitable point in the closed circulatory system, for example either to one side or the other of the flue 22 from the firebox 20. Preferably, however, the jet is located in advance of the flue 22 since it will operate at maximum efficiency when the density of the circulating medium most nearly approaches that of the propulsive component.

The propulsion jet, within the broad aspects of the invention, may consist of any suitable device adapted to convert potential energy into kinetic energy, and to utilize the latter for aspirating the fluid heating medium. In the preferred form of the invention, the propulsion jet comprises a thermodynamic machine 24 for making available a substantial amount of enthalpy of a propulsion gas for conversion into kinetic energy to perform work, and a Venturi aspirator 25 for employing said energy to impart momentum to the heating medium. More particularly, the machine 24 comprises a relatively small secondary combustion chamber mounted in the furnace structure 10, and adapted to be supercharged with a propulsion gas, such as air, through a supply line 26, and fuel, such as oil or

combustible gas, through a supply line 27. The air and fuel constitute a combustible mixture which is burned continuously to increase the enthalpy of the resulting products of combustion by the addition of heat energy to the initial pressure energy. The available enthalpy is subject to control by varying the amount of excess air supplied to the chamber 24. Opening from the chamber 24 into the heated enclosure of the furnace is a restricted injection nozzle 28 which serves to expand the products of combustion and cause same to issue in the form of a high velocity jet.

The Venturi aspirator comprises a tube defining the cross passage 19 from the leg 18 to the work chamber 12, and having an entrance cone 29, a short intermediate throat 30 of minimum uniform cross-section, and a discharge cone 31. The tube is so disposed that the nozzle 28 extends axially into the entrance cone 29 and the latter is in open communication with the passage 18. It will be understood that the high velocity jet issuing from the nozzle 28 constitutes the propulsive component, and, as it enters the entrance cone 29, induces the heating medium in the passage 18 to flow into the cone as the circulating component. The heating medium consists of products of combustion from the work chamber 12 to be recirculated therethrough, and newly added products of combustion from the firebox 20. The two fluid components passing through the tube 25 are combined and their velocity energy is partially converted back into pressure energy in the discharge cone 31. The aspiration of the heating medium through the Venturi tube serves to effect circulation and recirculation of the medium, unidirectionally as illustrated in Fig. 2, and at a high rate of speed, through the work chamber 12, thereby obtaining a rapid and uniform transfer of heat to the work.

In carrying out the present method of forced-convection heating, it is to be noted that the air and fuel constituents of the combustible mixture in the chamber 24 are supplied continuously at an elevated pressure. Referring to the diagram illustrated in Fig. 3, if precompression of the gaseous constituent is effected from normal atmospheric pressure of 14.7 pounds per square inch, for example to a predetermined pressure of 100 pounds per square inch, it experiences a polytropic compression along line *a-b* from curve No. 1 to curve No. 2, departing but slightly from a theoretical isentropic compression along line *a-c*, thereby resulting in a rise in temperature and an increase in enthalpy. It will be understood, of course, that precompression may be effected to any other suitable pressure. The input and output of the combustion chamber 24 are coordinated so that the pressure therein is maintained substantially constant. If the air or other gaseous medium now were merely expanded, the available kinetic energy derived from the prior compression would not be substantial in amount. However, isobaric combustion of the entering fuel serves to add heat to the resulting products of combustion, and thereby results in a substantial rise in temperature and increase in both enthalpy and entropy along line *b-d*. This is the condition of the propulsive medium before issuing as a jet through the nozzle 28.

The amount of enthalpy that is attained may be controlled by varying the amount of excess air supplied, and this in turn is influenced by the temperature requirements of the heating operation.

In issuing from the outlet nozzle 28, the products of combustion are expanded to form a powerful high velocity jet which in coaction with the Venturi tube 25, as previously described, imparts momentum to the primary gaseous heating medium. The propulsion products are expanded polytropically at the nozzle 28 and in the discharge cone 31 along line *d-e* from the elevated pressure to the furnace pressure, i. e., approximating normal atmospheric pressure. The polytropic expansion closely approaches theoretical isentropic expansion along line *d-f*, and results in a substantial reduction in enthalpy, with an attendant decrease in temperature and slight increase in entropy. The drop in enthalpy, as measured along the line *d-e*, represents the available enthalpy converted into the kinetic energy of the propulsion jet, and it will be noted that this conversion of pressure and heat energy is much greater than that of pressure energy alone. As a result, the propulsion jet is highly effective as a means for circulating large volumes of the primary heating medium at a fast rate of speed.

Obviously, all parts of the thermodynamic propulsion jet, including the combustion chamber 24, nozzle 28 and Venturi tube 25, are all static, rather than movable, and impose no temperature limitations on the device by reason of any operating characteristics. Since the jet will circulate a substantially constant weight of the heating medium regardless of the temperature, its efficiency will not drop when operating at high furnace temperatures, but may actually improve due to the decreased density of the aspirated gases.

I claim as my invention:

1. A convection heating furnace comprising, in combination, a heating structure having a work chamber adapted to receive the material to be heated and a flow passage connecting opposite extremities of said chamber in a circulatory path, a combustion chamber in said structure opening to said flow passage for supplying heated gaseous products of combustion, a burner in said combustion chamber, a vent stack opening from one extremity of said work chamber for exhausting excess products of combustion, and a propulsion jet mounted in said flow passage at the downstream side of said combustion chamber, said jet comprising a Venturi tube having an entrance cone, an intermediate restricted throat and a discharge cone opening to the other extremity of said work chamber, a second combustion chamber in said structure, a burner in said second chamber, and a restricted nozzle opening from said second chamber into said entrance cone for discharging heated gaseous products of combustion from said second chamber in a high velocity jet into said tube to effect a rapid circulation of said products of combustion through said path to pass repeatedly through said work chamber.

2. A convection heating furnace comprising, in combination, a heating structure having a work chamber adapted to receive the material to be heated and a flow passage connecting opposite extremities of said chamber in a circulatory path, a combustion chamber in said structure opening to said path for supplying heated gaseous products of combustion, a burner in said combustion chamber, a vent stack opening from one extremity of said work chamber for exhausting excess products of combustion, and a propulsion jet mounted in said flow passage, said jet comprising a Venturi tube having an entrance cone, an intermediate restricted throat and a discharge

cone opening to the other extremity of said work chamber, a second combustion chamber in said structure, a burner in said second chamber, and a restricted nozzle opening from said second chamber into said entrance cone for discharging heated gaseous products of combustion from said second chamber in a high velocity jet into said tube to effect a rapid circulation of said products of combustion through said path to pass repeatedly through said work chamber.

3. A convection heating furnace comprising, in combination, a heating structure having a work chamber adapted to receive the material to be heated and a flow passage connecting opposite extremities of said chamber in a circulatory path, means for supplying heated gaseous products of combustion to said path, a vent stack for exhausting excess products of combustion from said path, and a propulsion jet mounted in said flow passage, said jet comprising a Venturi tube opening to said work chamber, a combustion chamber in said structure, a burner in said combustion chamber, and a restricted nozzle opening from said combustion chamber into said tube for discharging heated gaseous products of combustion from said combustion chamber in a high velocity jet into said tube to effect a rapid circulation of said products of combustion through said path to pass repeatedly through said work chamber.

4. A convection heating furnace comprising, in combination, a heating structure having a work chamber adapted to receive the material to be heated and a flow passage connecting opposite extremities of said chamber in a circulatory path, means for supplying heated gaseous products of combustion to said path, a vent stack for exhausting excess products of combustion from said path, and a propulsion jet separate of said means and mounted in said structure, said jet comprising a fluid induction passage opening to said work chamber, a restricted nozzle opening into one end of said induction passage, and means for supplying a propulsion fluid to said nozzle, said nozzle serving to discharge said fluid in a high velocity jet into said induction passage to effect a rapid circulation of said products of combustion through said path.

5. A convection heating furnace comprising, in combination, a heating structure having a heating chamber with an inlet and an outlet for a gaseous heating medium and adapted to receive the material to be heated and to support it in heat exchange relation to said medium, a propulsion jet operatively associated with said inlet, said jet comprising a Venturi tube disposed in said inlet and having an entrance cone, an intermediate restricted throat and a discharge cone opening to said chamber, a combustion chamber, a burner in said combustion chamber and having fuel and air inlets, and a restricted nozzle opening from said combustion chamber into said entrance cone for discharging heated gaseous products of combustion in a high velocity stream into said tube, and means for supplying a gaseous heating medium to said entrance cone, said stream of products of combustion serving to induce the flow of said medium through said tube and to effect rapid circulation of said medium through said heating chamber.

6. The method of forced-convection heating which comprises positioning the work for direct contact with a fluid heating medium, continuously supplying said heating medium simultaneously producing highly heated gaseous products of

7

combustion containing a predetermined amount of excess air under a relatively high pressure, converting the pressure energy of said products to kinetic energy to obtain a high velocity jet, and utilizing said jet to induce a continuous unidirectional circulation of said heating medium in a closed path through direct contact with the work.

7. The method of forced-convection heating which comprises positioning the work in a chamber forming part of a closed circulatory system, constantly supplying heated products to said system for direct contact with the work, simultaneously supplying a highly heated gaseous medium under a relatively high pressure, converting the potential energy of said medium to kinetic energy to obtain a high velocity jet, and utilizing said jet to induce a continuous unidirectional circulation of said products in said system through direct contact with the work.

8. The method of forced-convection heating which comprises positioning the work to be heated in a work chamber for direct contact with heated gaseous products of combustion, supplying heated gaseous products of combustion at a predetermined temperature continuously to said chamber, simultaneously supplying other heated gaseous products of combustion with excess air at a high temperature and pressure, injecting said other products in the form of a high velocity jet into said chamber, utilizing said jet to aspirate said first mentioned products whereby to circulate all products continuously and unidirectionally through said chamber to heat the work, and venting excess products of combustion continuously from said chamber as new products are supplied.

9. The method of forced-convection heating which comprises positioning the work to be heated in a work chamber connected in series in a closed circulatory flow path, supplying heated gaseous products of combustion at a predetermined temperature continuously to said path, simultaneously providing a supercharged gaseous propulsion medium, increasing the enthalpy of said medium isobarically, expanding said medium polytropically to the pressure in said path to convert the available enthalpy into kinetic energy, and utilizing said kinetic energy to impart momentum to said products of combustion, whereby to effect circulation of said products through said path in direct heat transfer contact with the work.

10. The method of producing forced-convection of a fluid in a circulatory flow path which

8

comprises providing a supercharged gaseous propulsion medium, increasing the available enthalpy of said medium isobarically, expanding said medium polytropically to substantially the pressure in said path whereby to convert a portion of the enthalpy of said medium into kinetic energy, and utilizing said kinetic energy to impart momentum to said convected fluid, whereby to effect circulation of said fluid through said path.

11. The method of forced-convection heating which comprises positioning the work in the path of a heating fluid, providing a supercharged gaseous propulsion medium, increasing the available enthalpy of said medium, expanding said medium to substantially the pressure in said path whereby to convert a portion of the enthalpy of said medium into kinetic energy, and utilizing said kinetic energy to impart momentum to said fluid whereby to cause said fluid to flow through said path.

12. The method of producing a gaseous propulsion medium for a convection fluid comprising supplying air under supercharged pressure continuously to a confined combustion space, supplying fuel to said space continuously in an amount less than required for combining proportions of the air and fuel, burning the fuel as supplied in contact with the air in said space substantially at said pressure, and causing the resulting products of combustion to issue from said space at the rate at which they are produced and in a high velocity jet to a second space maintained at a lower pressure than that in said confined space.

SLADE B. GAMBLE.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,617,609	Smith	Feb. 15, 1927
1,717,115	McCann	June 11, 1929
1,729,763	De Florenz	Oct. 1, 1929

FOREIGN PATENTS

Number	Country	Date
111,381	Great Britain	Nov. 29, 1917
796,047	France	Jan. 17, 1936

OTHER REFERENCES

"Improvements in Production and Shop Equipment," pages 48 and 49 of "The Iron Age," September 3, 1936.