May 30, 1933. R. H. ANDREWS 1,912,243

PROCESS AND APPARATUS FOR FIRING FURNACES

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Fig. 1.

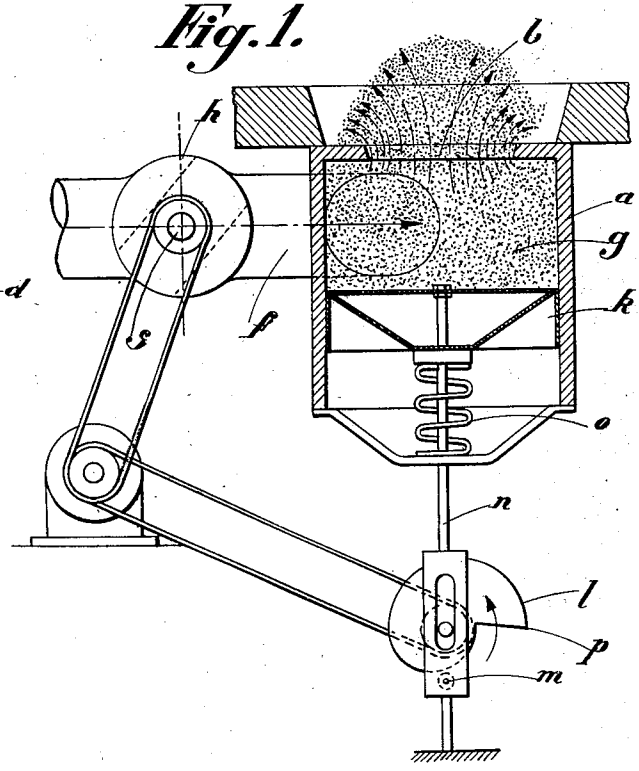
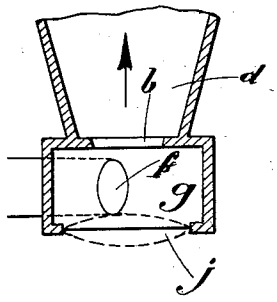


Fig. 8.



Richard Henry Andrews,

by James L. Norris

Attorney

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Fig. 1a.

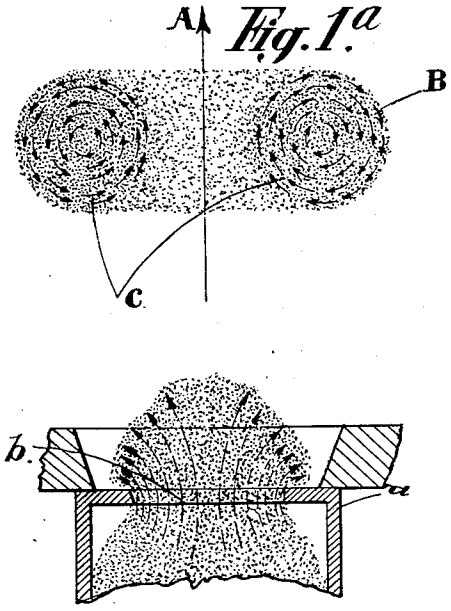


Fig. 2.

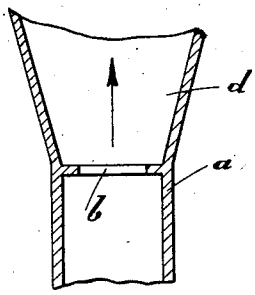


Fig. 3.

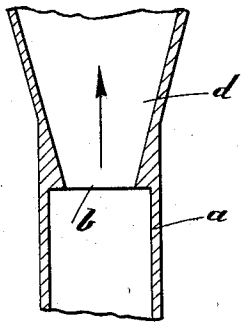


Fig. 4.

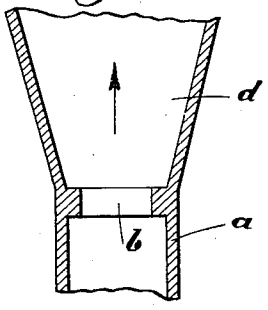


Fig. 5.

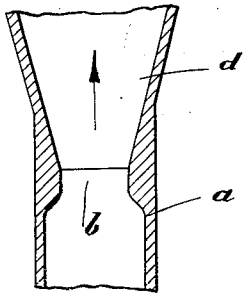


Fig. 6.

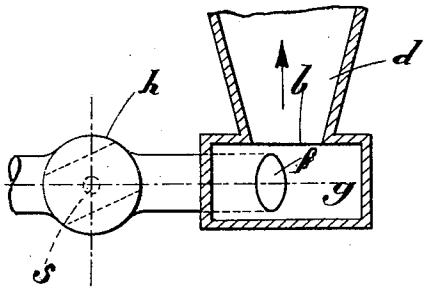
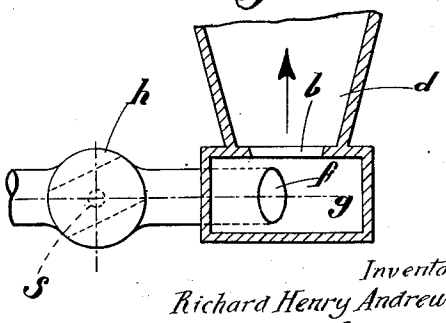


Fig. 7.



Inventor.
Richard Henry Andrews.
by Miles L. Norris
Attorney

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UNITED STATES PATENT OFFICE

RICHARD HENRY ANDREWS, OF PARIS, FRANCE

PROCESS AND APPARATUS FOR FIRING FURNACES

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The present invention covers an improved method of firing furnaces with pulverized coal, oil or gas, hereinafter called "fuel" consisting essentially in imparting to a combustible mixture or a constituent thereof during its injection into the furnace, a special form of gaseous motion known in physics as "vortex ring motion".

This invention also covers different means of producing vortex motion in the furnace.

Vortex ring motion in a gaseous medium is that peculiar form of motion resulting from an impulse or sharp puff of gas passing through a constricted orifice of suitable diameter, preferably sharp-edged, like an orifice in a thin plate. Such an impulse through said orifice produces a whirl of annular shape, the commonest example of which is the smoke ring known to all smokers.

Geometrically, a vortex ring may be described as a whirl of annular shape, in which the particles of gas rotate in radial planes passing through the center line of the orifice, which is also the center line of the whirl and its vector of motion. In other words, the shape is that of a tore.

In practice, the whirl may become more or less distorted from its perfect theoretical shape, and its motion may be complicated by a helical component around its center line, or by motion of any other character.

Vortex ring motion has certain characteristic features of considerable interest from the standpoint of turbulent combustion in a furnace. These will be outlined later, after a brief review of a few of the laws governing combustion, in their relation to furnace firing.

The evolution of pulverized-coal boiler practice towards the use of direct-radiation evaporating surfaces and water-cooled walls has made a return to turbulent combustion and short flame travel inevitable. But present methods of firing purporting to give turbulent combustion are entirely inadequate, since it is not yet possible to burn any grade of fuel indiscriminately in completely water-cooled furnaces. Moreover, furnace volumes necessary for complete combustion of the fuel are excessive.

Yet it is theoretically possible to burn any fuel under any conditions, even under water, provided two essential conditions are fulfilled: First, perfectly intimate mixture of fuel and air at the beginning of combustion, in order to give the highest possible combustion rates and temperatures at the start; secondly, perfect turbulence during combustion, in order to prevent the accumulation of the products of combustion around the particles or molecules of fuel.

For all practical purposes, the first condition can be approached without much difficulty. But the second condition is infinitely more difficult to attain, and cannot be even remotely approximated by any of the mechanical means of fuel injection used in present boiler practice.

Yet turbulence is by far the most important factor in producing rapid combustion rates. At the temperatures attained in industrial furnaces, the chemical combination of carbon and oxygen, after they have come in contact, is almost instantaneous. The only appreciable check to the velocity of flame propagation is the accumulation of the products of combustion around the surface of the burning fuel.

Combustion is therefore merely a problem: First, of diffusion of the available oxygen; secondly, of the speedy removal of the burnt gases from the vicinity of the particles or molecules of fuel, to make way for the oxygen. Turbulence is the only means whereby this double object may be attained, and perfect turbulence should give perfect, that is, practically instantaneous, or explosive combustion.

One form of perfect turbulent motion in a gaseous mass would consist of an infinite number of eddies of infinitesimal diameter. For any finite values of linear velocities of the gas, centrifugal force in such eddies would be infinite, and any solid particles borne by gas having such motion would be continually thrown out of one eddy and into another. They would, therefore, be continually swept by gases moving at

high velocity with respect to themselves, and would never remain long in contact with the same gas particles. They would, therefore, have the maximum chance of finding the oxygen necessary to consume them.

Unfortunately, perfect turbulence is impossible to obtain in practice. But the degree of perfection in turbulence, and, therefore, the combustion rate attainable, are probably direct functions of the average diameter of the eddies in the gas; for the larger the diameter of these eddies, the weaker will be their centrifugal force, and the less will be the tendency of solid particles of fuel to become separated rom the gaseous mass that carries them.

In the light of the foregoing theory, the defects of present methods of so-called turbulent firing are evident. These methods are mainly based on the principle of imparting to the mixture of air and fuel a helical motion around the centerline of the combustion chamber, either before the mixture is injected into the combustion chamber, by a suitable orientation of the air flow into or out of the burner, or afterwards, by the combined action of several flame jets. The result is a low-velocity whirl, whose diameter, already too large at the start, tends to increase rapidly while the linear velocity decreases. As a result of these tendencies, at a relatively short distance from the mouth of the burners, all that remains of the original whirl is a slow-moving mass of gas rotating sluggishly around the axis of the combustion chamber. This motion is much closer to parallel-stream-line flow than to perfect turbulence, and is scarcely more favorable to rapid combustion. Furthermore, this condition is particularly marked in the tail of the flame where turbulence would be more valuable than in any other part of the furnace, because of the dilution of the oxygen.

The foregoing argument leads to the conclusion that a method of fuel injection imparting to the mass of burning fuel and air a motion composed of eddies of high velocity and short diameter, distributed as uniformly as possible throughout the combustion chamber, should give vastly superior combustion rates than any existing method.

As mentioned above, vortex ring motion has certain characteristics of particular value in connection with furnace firing:

1. The eddies composing vortex rings are small in diameter, and the gaseous molecules move at high velocities, as compared to ordinary types of whirling motion.

2. When vortex rings have been projected through the constricted orifice, they propel themselves through the surrounding medium by friction upon the latter. When they are produced by a very sharp impulse, these rings may travel considerable distances at high velocities.

3. Although produced by an alternating motive force, vortex ring motion is not a form of vibratory motion, in which the gaseous molecules vibrate around a stationary point in space. It is a special form of rolling motion, in which relatively small volumes of gas roll through the surrounding medium. It is, in reality, a combination of rotary and translatory motion. It affords a convenient and efficient means of projecting a certain volume of any gas through any other gaseous medium, of similar or different composition.

4. In common with all other forms of eddy motion, vortex rings tend to grow in volume at the expense of the surrounding medium.

The value of vortex ring motion for furnace firing will be evident from the properties outlined above. In particular, the possibility of projecting into the combustion chamber a large number of high-speed short-diameter eddies carrying fuel and/or air deep into the furnace will prove particularly efficient; for these eddies will be effective not only through their own motion, but through their property of gathering up stagnant gases through which they pass, and by the parasitic disturbances created by their passage, producing a violent stirring of the burning gases.

The simplest form of application of the improved method of firing furnaces according to the present invention consists in the injection into the furnace of all the fuel and air, previously mixed as perfectly as possible, in the form of a single pulsating stream of suitable frequency flowing through a burner comprising a constricted orifice or passage. At each impulse, a definite volume of air and fuel will be projected through the orifice and will take the shape of a vortex ring travelling away from the burner at a velocity which is a function of the exact duration of the impulse, of the average flow, and of the orifice diameter. Such a pulsating flow through an orifice of suitable diameter will set up a train of vortex rings.

Variations of the foregoing solution consist in injecting only part of the mixture of fuel and air, or of the air alone or of the fuel alone when in gaseous form, in a pulsating stream through the orifice, the rest of the mixture, or of the air or fuel alone, reaching the furnace either through the orifice, in a continuous stream, or through any other channels, in the form either of a pulsating, or of a continuous stream. A large number of complex combinations of motion superimposed upon one another may in this way be imparted to the injected fuel mixture.

The pulsations in the supply of the combustible mixture that are necessary for obtaining vortex rings are produced by the following means.

The combustible mixture may be supplied

through a burner or tuyère under forced or induced or natural draught, by means of a duct equipped with some form of valve, rotary or oscillating, or of any other variety, for the purpose of interrupting the supply any desired number of times per minute. At each opening of the valve, a puff of combustible mixture through the orifice of the burner or tuyère will produce a vortex ring. This gives the simplest form of vortex-ring motion, in which all the rings are of substantially the same size and move at the same speed.

Another mechanical means of creating the required pulsations in the combustible mixture supply consists in providing a chamber of variable volume connected with the burner, the volume of said chamber being varied periodically to give the required pulsations.

Various embodiments of the invention are illustrated in the annexed drawings, in which:

Fig. 1 is a sectional view of a burner or tuyère embodying the invention and showing means for creating pulsations in the supply of combustible mixture.

Fig. 1ª is a diagrammatic view corresponding to Fig. 1 and showing the method of formation of vortex rings.

Fig. 2 represents one form of burner with a diffuser, according to the invention.

Figs. 3, 4, and 5 are modifications of the burner mouth and diffuser represented in Fig. 2.

Figs. 6 and 7 represent further modifications in which a combustible mixture arrives in a tangential or radial direction to the burner orifice.

Fig. 8 is a view showing another means used for creating the required pulsations in the supply of "combustible mixture".

Referring now to Fig. 1 of the drawings, *a* represents a burner or tuyère having an orifice at *b*. The combustible mixture is subjected to periodical pulsations with the result that it issues from said burner orifice *b* in the form of a vortex ring *c*, as shown in Figure 1ª. This vortex ring travels away from the burner orifice in the direction of the arrow A. (Fig. 1ª). The particles of the combustible mixture in said vortex ring rotate in radial planes and in the direction of the small arrows B.

The combustible mixture may be supplied under pressure to a chamber *g* through an inlet pipe *f* which preferably is connected tangentially to said chamber and pulsations of said mixture may be caused by means of a rotary valve *h* in the inlet pipe *f* and rotatable on an axis *s* extending diametrically of said pipe and rotated by any suitable means so as to be opened at timed intervals. Pulsations may also be produced by providing means for varying the volume of the chamber *g*. A suitable means for this purpose is shown in Figure 1. As there shown, a light piston *k* is movable lengthwise of said chamber and carried by a piston rod *n* which extends beyond the outer open end of said chamber and guided in a spider extending transversely of the open end of said chamber. A spring *o* surrounding said piston rod and having its opposite ends bearing against the piston and said spider tends to move the piston *k* toward the orifice *b* and the face of a constantly rotating snail cam *l* bears against a roller *m* carried by the piston rod *n*. As the cam *l* rotates in the direction of the arrow the piston rod will be drawn outwardly against the tension of the spring *o* until the roller *m* trips over the high portion *p* of the cam, whereupon the spring *o* will quickly move the piston *k* toward the orifice *b*.

The burner may optionally be provided with a mouthpiece or diffuser as shown at *d* (Fig. 2) for the purpose of directing the vortex rings after they have left the burner, or of expanding or otherwise shaping them, or even for the purpose of facilitating the ignition of the fuel.

The constricted orifice or passage *c* should preferably be sharp-edged, for example, as an orifice in a thin plate, in order to give the most rapid vortex-ring motion. However, it may be necessary to depart somewhat from the sharp-edged construction, either to lengthen the life of the burner, or to reduce the speed of translation of the vortex rings. For these reasons, the edges of the orifice *b* may be rounded off, as shown in Fig. 5, or cut at an angle, as shown in Figure 3, or otherwise modified; or the axial length of the orifice may be increased from a very small value to one of several inches, forming properly a constricted passage, as in Figs. 4 and 5.

Figs. 6 and 7 indicate possible departures from the simplest design of the burner, in which the combustible mixture is injected into a chamber of the burner through a pipe *f* at an angle with the axis of said burner, either radially or tangentially; in the latter case, to give the combustible mixture a whirling motion.

The mechanical means indicated in Figs. 1 and 8, or means of similar character, permits the creation of a large number of combinations of motion in the furnace gases; for example, if the combustible mixture were forced into the burner in a continuous stream, as would be the case if the valve *h* were omitted, this combustible mixture would leave the burner in the form of vortex rings in accordance with the movements of the piston *k* (Figure 1) or its equivalent elastic wall section *j* (Figure 8) and between the

pulsations, the combustible mixture would issue from the burner in the form of a continuous stream periodically shot through by vortex rings; in other words, a combination of continuous translatory motion with vortex motion would be produced.

An extremely advantageous combination of means is the combined use of an oscillating or rotary valve in the supply duct, as described above, (see Figures 1, 6 and 7) to produce pulsations of relatively high frequency—of the order of 500 to 2500 per minute—and a variable-volume chamber connected to the burner equipped with a reciprocating piston or elastic membrane, (see Figures 1 and 8) or their equivalent, for the purpose of producing pulsations of lower frequency but of considerably high power, superimposed upon the train of small high-frequency vortices. This combination is illustrated in Fig. 1 which shows the use of a rotary valve *h* in the supply pipe *f* together with a reciprocating piston *k* in the variable volume chamber.

It is obvious that the relatively low frequency impulses are produced by the movable wall in the burner whereas the relatively high frequency impulses are produced by the valve *h* which is likely to possess far less inertia than the movable wall of the burner.

Vortex-ring motion may also be used in connection with the firing of stoker- and hand-fired furnaces, for the purpose of injecting air above the fuel bed in such a way as to produce a high degree of turbulence in the combustion chamber.

This invention has been disclosed in its preferred forms, but it is to be understood that nothing hereinbefore stated is to be construed as a limitation, because changes and alterations may easily be made by those skilled in the art without departing from the spirit of the invention or the scope of the appended claims.

What I claim is:

1. A process for firing furnaces consisting in introducing into the furnace a combustible mixture in the form of vortex rings, and igniting the same.

2. A process for firing furnaces consisting in giving the combustible mixture a whirling motion, introducing it into the furnace in the form of vortex rings, and igniting the same.

3. Apparatus for firing furnaces comprising a combustion chamber having an inlet orifice, and means for introducing through said orifice and into the combustion chamber of the furnace a combustible mixture in the form of vortex rings.

4. Apparatus for firing furnaces comprising, in combination, a burner provided with, a constricted passage, and means for introducing through the passage of said burner a combustible mixture in the form of vortex rings.

5. Apparatus for firing furnaces comprising, in combination, a burner having a constricted passage connecting with the furnace, a diffuser connected to said burner, means for supplying a combustible mixture to said furnace and means for impelling said combustible mixture into the furnace through the constricted passage of said burner in the form of periodic pulsations forming vortex rings.

6. Apparatus for firing furnaces comprising, in combination, a burner having a chamber and a constricted passage connecting said chamber with the furnace, a diffuser connected to the mouth of said burner, means for supplying a combustible mixture into said chamber and means for impelling said combustible mixture into the furnace through the constricted passage of said burner in the form of periodic pulsations forming vortex rings.

7. Apparatus for firing furnaces comprising, in combination, a burner having a chamber and a constricted passage connecting said chamber with the furnace, a diffuser connected to the mouth of said burner, a combustion mixture supply duct issuing in said chamber at an angle to the axis of said burner, and means for impelling said combustible mixture into the furnace through the constricted passage of said burner in the form of periodic pulsations forming vortex rings.

8. Apparatus for firing furnaces comprising, in combination, a burner having a chamber and a constricted passage connecting said chamber with the furnace, a diffuser connected to the mouth of said burner, a combustible mixture supply duct issuing in said chamber, and a valve in said duct periodically interrupting the flow of said combustible mixture into the furnace through the constricted passage of said burner.

9. Apparatus for firing furnaces, comprising, in combination, a burner having a variable volume chamber and a constricted passage connecting said chamber with the furnace, a diffuser connected to the mouth of said burner, and a combustible mixture supply duct issuing in said chamber, and means for varying the volume of the burner chamber and impelling said combustible mixture through the constricted passage of the burner in periodic pulsations forming vortex rings.

10. Apparatus for firing furnaces, comprising, in combination, a burner having a chamber and a constricted passage, a diffuser connected to the mouth of said burner, a piston in said chamber for varying its volume, a piston rod, a roller on said piston rod, a spring between said piston and a fixed part of said chamber tending to push the piston in the direction of the constricted passage of said burner, a cam disc in engage-

ment with said roller acting in opposition to the action of said spring, and a combustible mixture supply duct issuing in said passage, between the constricted passage of said burner and said piston whereby said combustible mixture is urged periodically through said constricted passage by the reciprocation of said piston.

11. Apparatus for firing furnaces comprising, in combination, a burner having a chamber and a constricted passage, a diffuser leading from said passage, a piston movable in said chamber, a fuel and primary air supply duct opening into said chamber, and a valve in said duct for producing pulsations in said supply.

12. Apparatus for firing furnaces comprising, in combination, a burner having a chamber and a constricted passage, a diffuser leading from said passage, a piston in said chamber, means including a cam and roller device for imparting to said piston a sudden movement toward the opening of said burner, a fuel and primary air supply duct opening tangentially into said chamber, and a valve in said duct for producing pulsations in said supply.

13. An improved method for burning fuel which consists in supplying air and fuel through a constricted passage into a combustion chamber in a series of pulsations and igniting the released mixture, whereby a series of vortex rings composed of such combustible mixture are released and traverse the combustion chamber to permit complete combustion.

14. An improved method for burning fuel which consists in supplying air and fuel through a constricted passage into a combustion chamber in a series of pulsations and igniting the released mixture, whereby a series of vortex rings composed of such combustible mixture are released and traverse the combustion chamber to permit complete combustion, and such rings expand both circumferentially and laterally.

15. Apparatus for firing furnaces comprising, in combination, a burner having a chamber and a constricted passage connecting said chamber with the furnace, a diffuser connected to the mouth of said burner, a combustible mixture supply duct issuing into said chamber, and a movable wall portion for said chamber impelling said combustible mixture into the furnace through the constricted passage of the burner in the form of periodic pulsations forming vortex rings.

16. Apparatus for firing furnaces comprising, in combination, a burner having a chamber and a constricted passage connecting said chamber with the furnace, a diffuser connected to the mouth of said burner, a combustible mixture supply duct issuing in said chamber, and a reciprocating piston movable in said chamber impelling said combustible mixture into the furnace through the constricted passage of the burner in the form of periodic pulsations forming vortex rings.

RICHARD HENRY ANDREWS.