Jan. 1, 1952 J. J. WOLFERSPERGER 2,581,316

HIGH RATING FIRE TUBE BOILER AND METHOD OF BOILER OPERATION

Filed Oct. 1, 1945

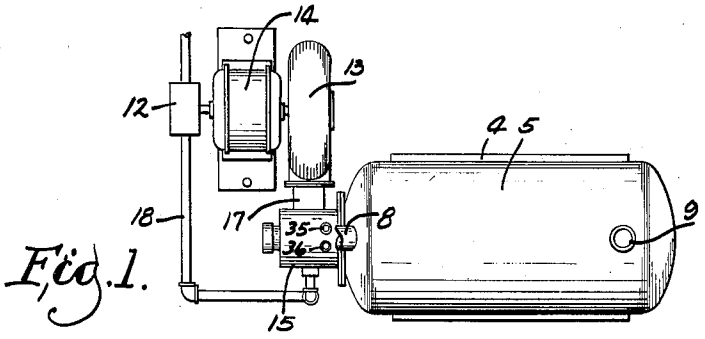


Fig. 1.

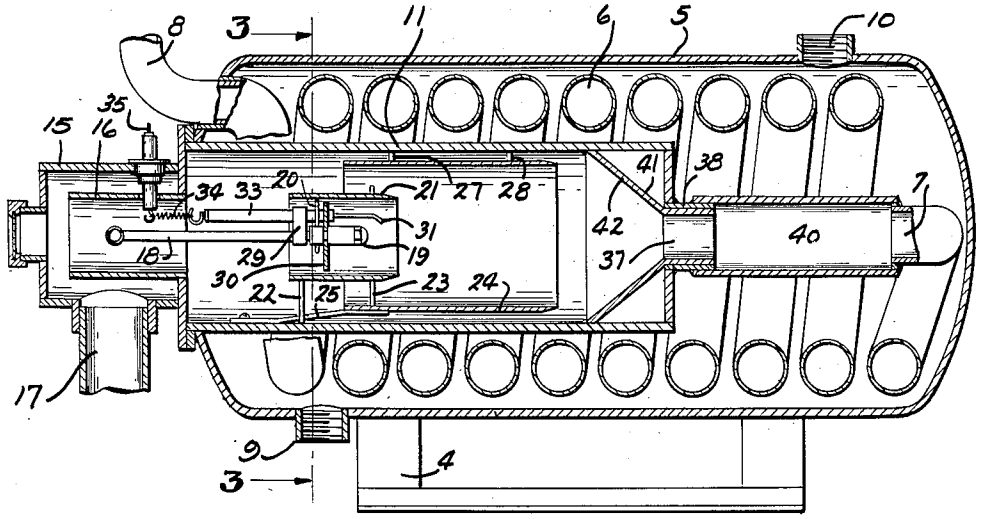


Fig. 2.

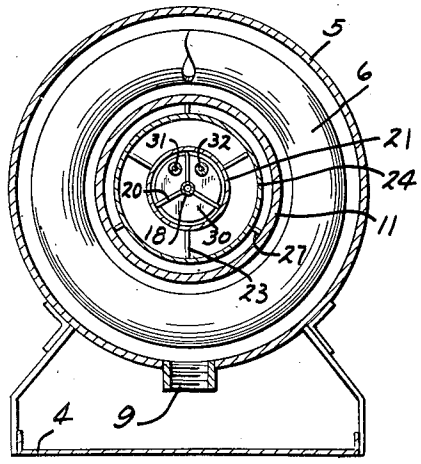


Fig. 3.

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Patented Jan. 1, 1952

2,581,316

UNITED STATES PATENT OFFICE

2,581,316

HIGH RATING FIRE-TUBE BOILER AND METHOD OF BOILER OPERATION

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Application October 1, 1945, Serial No. 619,671

12 Claims. (Cl. 122—134)

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This invention relates to improvements in high rating fire tube boilers and methods of boiler operation.

It is the object of the invention to develop increased horse power relative to the size of the installation without substantial sacrifice of efficiency. In terms of rating, ten square feet of heat transfer surface per boiler horse power is taken as standard or 100%; a boiler horsepower represents 33,475 B. t. u. per hour, or the heat required to evaporate 34½ lbs. of water per hour from and at 212° F. Merely decreasing the surface area, as by reducing the length of the fire tube, will increase the rating but result in a corresponding increase of flue gas temperature at the discharge end of the fire tube and consequent loss of energy and efficiency. These considerations have heretofore limited fire tube boiler ratings in commercial practice to a maximum of about 200%, more or less. In contrast, the present invention has provided boilers so compact as to be rated up to 2000% without substantial efficiency reduction and with even higher ratings apparently possible.

The present application is a companion to my Patent No. 2,499,207, and to my application No. 543,878, filed July 7, 1944, now abandoned. Further objects of the present invention will appear more particularly in the following disclosure.

In the drawings:

Fig. 1 is a plan view of apparatus embodying the invention.

Fig. 2 is an enlarged detail view of the boiler and burner organization in vertical axial section.

Fig. 3 is a view taken in section on the line 3—3 of Fig. 2.

The boiler comprises a small tank 5 carried on any suitable support 4. Fire tube 6 is coiled within tank 5 in a helix having an axially disposed inlet 7 near one end and a connection through the opposite end of the tank to flue 8. Taps are provided in the tank at 9 and 10 for inlet and outlet of water or other fluid heated.

The mixing and ignition chamber 11 is, for convenience, compactness, and heat economy, preferably disposed inside of the coiled fire tube with its admission end exposed outside of the end of tank 5. To this chamber fuel and air are supplied under substantial pressure from fuel pump 12 and blower or air compressor 13, driven by any suitable means, as by motor 14.

Casing extension 15 and sleeve 16 are disposed at the end of chamber 11. The compressed air

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pipe 17 enters the casing extension 15 and the air thence passes through the sleeve 16 into chamber 11. The fuel pipe 18 enters laterally through the casing extension and the sleeve and leads axially into chamber 11 to the fuel nozzle 19. For the purposes of this invention the fuel is preferably oil and the nozzle 19 is any suitable atomizing nozzle. However, other fuels may be used.

The nozzle 19 is supported centrally in chamber 11 by spider arms 20 (Fig. 3) which carry the nozzle, from an inner sleeve 21. Sleeve 21 is, in turn, supported by spider means 22 and 23 from chamber 11 and from intermediate sleeve 24. Intermediate sleeve 24 is anchored at 25 to the wall of chamber 11 and spaced therewithin by peripheral projections 27, 28. This latter sleeve is axially offset from sleeve 21 and more closely approaches the diameter of the chamber 11 than that of sleeve 21. Both sleeves are preferably bevelled inwardly at their discharge ends.

Mounted on nozzle 19 is a disk 30 which is peripherally spaced from the inner surface of inner sleeve 21 but materially restricts and controls air flow through such sleeve. Through this disk extend the ignition electrodes 31, 32 which are mounted in insulating tubes 33 supported by holder 29 and connected by spring conductors 34 to respective terminals 35, 36.

Through a nipple 38 at the end of chamber 11 projects a tube 37 constituting a flow-restricting throat. This tube opens into a combustion chamber 40, affording communication between the mixing chamber 11 and the admission end 7 of fire tube 6. The combustion chamber may, in some circumstances, be omitted, but in all but the lowest ratings is not only desirable but essential.

The tubular throat 37 is preferably part of a casting 41 which, instead of being made of refractory material, is preferably of steel or alloyed heat-resisting material substantially filling the end of chamber 11 and provided with a conically tapering surface 42 leading to the throat. Welded joints are provided between casting 41 and chamber 11 and between nipple 38 and combustion chamber 40, and between chamber 40 and fire tube 6.

The fact that the tapering wall surface 42 leading to the throat is within the end of chamber 11 protects it from such cooling by the water of the boiler as might otherwise condense fuel on its surface. It, in turn, is protected from excessive heat by the sheath of air which surrounds the flame until the throat 37 is reached.

The throat is preferably of such dimensions as to have cross sectional area $\frac{1}{10}$ to $\frac{1}{15}$ that of

the burner tube 11 and a length at least equal to, and preferably about one and one-half times its own diameter. The combustion chamber is of somewhat greater diameter than the throat diameter or the fire tube diameter and is preferably of a length approximately three times its diameter. Since the relative proportions shown are significant, some actual dimensions of a practicable device of the construction illustrated will be given. In that device, the throat diameter is two inches. The diameter of combustion chamber 40 is three inches and its length 8 inches. In the particular device shown, the length of the 2½" fire tube is about 30 feet and its diameter about 2⅜" I. D. but these dimensions may be varied according to design.

Heat transfer per unit of surface has long been known to increase in almost direct proportion to velocity of flow but practical advantage of this fact has not heretofore been realized in boiler equipment of this type. I proportion the section and length of the passage through my boiler and use relatively high air and fuel inlet pressures to achieve flow at so high a velocity that heat developed is transferred very rapidly to the water through a short fire tube of limited area with no excessive heat at any point in the boiler. Despite the short length of tubing used, flue gas temperature has been found in many embodiments of this invention to be very low and to increase only about 10 to 15 degrees F. for each 100% increase in rating.

In my boiler, it is my purpose that the use of refractory be eliminated or reduced to a minimum, and that excessively high temperatures in the burner tube on the one hand and carbon deposits on the other hand be eliminated because of the temperature control effected through the construction and mode of operation of the device.

To eliminate these difficulties, it will be noted that I provide a single source of air under pressure and hermetically seal the entire passage from the air source to the boiler outlet to the flue. Taking full advantage of the hermetically sealed conduit, I use from one to two pounds to several pounds of air pressure and sufficiently high fuel pressures to deliver the fuel into the air, thereby developing a rate of gas flow at the entrance 7 to the fire tube from approximately 450 to approximately 2000 feet per second, a rate of flow unheard of in fire tube boilers.

The amount of air passing through the inner tube 21, subject to the control of disk 30, is just adequate to support stable ignition. The relatively large cross section of chamber 11 keeps velocities relatively low at all points therein. An annular body of additional air reaches the burning fuel through tube 24 and another annular flow of air passes about the outside of tube 24 and envelops the flame to shield chamber 11 and casting 41 from the flame. However, pending complete mixture of the added air with the over-rich mixture ignited at the burner, no excessive amount of heat is developed. The tapered surface 42 and throat 37 to which it leads are of great service in promoting perfect admixture of the diluting air with the over-rich mixture in which the flame is being propagated. The relative flow of fuel and air will, of course, be controlled to achieve as nearly perfect combustion as possible. The velocity of flow in the throat is so rapid that the mixing in the throat and complete combustion are effected almost instantaneously.

In a perfect mixture of air and fuel, flame is

said to propagate at the rate of 1000 feet per second. In some embodiments of this invention I find velocities at the entrance to the fire tube of almost double this value. Moreover, since the gases delivered by the throat already contain some products of combustion, the flame propagation therein cannot occur at the optimum rate of 1000 feet/sec. Thus the importance of the enlarged combustion chamber 40 following the short constricted throat 37 is that is prevents such excess velocities as would exceed the rate of flame propagation and hence pull the flame from the unburned fuel, while maintaining a velocity adequate to achieve full combustion.

Actual examples are as follows:

An embodiment of this invention was operated as a water heater at 1500% rating with 20 sq. ft. of heating surface and an output of 30 boiler horse power. The air pressure used was 4 pounds per square inch. Gas velocities at the throat outlet were approximately 257 feet/sec. and at the fire tube inlet approximately 800 feet/sec. The observed flue gas temperature was only 510° F. The average boiler of the prior art has a fire tube inlet velocity of 40 to 60 ft./sec. and operates at 100–200% rating with flue gas temperatures comparable to those of my boiler at 1500% rating.

Another embodiment of this invention was operated as a steam boiler at over 2000% rating with 28.5 sq. ft. of heating surface and 60 boiler horse power output. Air pressure was 12 lb. Gas velocities at the throat outlet were approximately 218 ft./sec. and at the fire tube inlet approximately 1960 ft./sec. Flue gas temperature at this high 2000% rating was only 390° F.

The following general particulars are given:

The air pressure will ordinarily exceed one-third pound per square inch for a 300% rating and will run from two to twelve pounds in boilers up to 2000% rating. The oil or other fuel pressure must exceed air pressure in each case and, to achieve oil atomization, commonly amounts to 100 pounds/sq. in.

Burner tube 11 has an area usually amounting to 6 to 7 square inches per gallon per hour of fuel oil consumed.

The cross section of the throat 37 is .43 sq. inch to 1.5 sq. in. per gallon per hour of fuel consumed.

The air flowing around disk 30 through the inner sleeve may typically approximate 1 to 3% of the total volume; air flowing between the inner and intermediate sleeves 64 to 72%; air outside the intermediate sleeve 26 to 34%.

Fire tube internal cross sectional areas range from less than 1 sq. inch per horse power at the lowest ratings (actually .64 to .74 sq. in. at 300% rating) down to dimensions of the order of .06 sq. in. per horse power at 2000% rating. Per gallon of fuel oil consumed per hour these sections range from less than 2.5 sq. in. maximum down to about .20 sq. in.

In all embodiments, the size of the combustion chamber, both as to cross section and length, is so chosen with reference to air pressures used, fuel consumed, rating desired, and throat dimensions that the major part of all combustion occurs in the combustion chamber rather than in the chamber 11 or the fire tube, the velocities in the combustion chamber being substantially as high as will permit full flame propagation. In actual practise, only about two per cent of the fuel is consumed in burner tube 11 and a negligible amount in the coil of the fire tube, almost the entire combustion being effected in chamber

40. Thus all heat in excess of that required to support combustion is carried into the fire tube where it is utilized to maintain the high velocity requisite to the dissipation of such heat into the boiler water.

Particularly where economies in weight or space are important, the compactness of the high rating boiler herein disclosed is valuable. There is no apparent limit on the ratings for which embodiments of the invention may be designed, provided air and fuel under appropriate pressures are made available. The higher the air pressure, the higher the velocity at which the products of combustion can be forced through one or more fire tubes of restricted cross sectional area. Incorporation of the mixing and combustion chambers within tank 5 not only saves space but controls the temperature of the walls of the immersed chambers.

Since my invention has been described particularly with reference to the structure used, the method aspects will be summarized:

Fuel under super-atmospheric pressure is mixed with just sufficient high pressure air at relatively low velocity to permit stable ignition. More air is added and the velocity simultaneously increased, the increase in velocity being rapid and preferably carried to such an extreme that for a brief interval (in the throat 37) the velocity may approach the rate of flame propagation. Up to this point the flame has been contained within an envelope of air which, in the throat, is in process of being introduced by the turbulence in the throat into the rich mixture in which combustion is being supported. Under these conditions there is no difficulty, despite the high velocity, in maintaining combustion during the brief interval of passage through the throat. A desirable perfection of mixture being there achieved, the consequent expansion and relative retardation of flow in the combustion chamber is followed by substantially instantaneous combustion. Immediately thereafter, flow is again accelerated, using the abrupt expansion of the gases to assure their high velocity flow through the restricted cross section of the immersed fire tube at a rate and for a distance such as to deliver all their heat, in excess of about 350 to 500° F., to the boiler fluid. Success depends, of course, quite largely upon the immersion of the fire tube, for the heated fluid must be capable of receiving heat at the extremely high rate at which it is rejected by the flue gases at the high velocity maintained.

The invention has particular application to boilers wherein the fire tube cross section area ranges from a maximum of about .9 square inch per boiler H. P. at a rating of about 225% down to .056 sq. in. or less per boiler H. P. at a rating of 2000% or more. The smaller the tube section in relation to flow, the higher will be the fuel and air pressure required at the inlet of the hermetically sealed system. Apart from mere increase in pressure differentials as between the system inlet and outlet, a device operating at substantial super-atmospheric pressures has advantages in efficiency due to greater density of the gases involved.

I claim:

1. In combination, a fire tube boiler operable at a rating in excess of about 225% and comprising a boiler tank, fire tube means having a total cross section no larger than $\frac{2}{10}$ square inch per boiler H. P. and at least partially submerged therein and having a flue gas outlet, separate mixing and combustion chambers and an intervening throat smaller in cross section than either of said chambers and shorter than either, and through which the chambers communicate with each other, said chambers and throat being in series with said tube means, an igniter in the mixing chamber, and means for supplying all required air and fuel under super-atmospheric pressure to said mixing chamber, said throat, combustion chamber and fire tube means constituting a continuous conduit completely closed from the mixing chamber to said outlet.

2. The device of claim 1 in which the means for supplying air comprises a compressor having an output air pressure of at least one-third pound per square inch and the means for supplying fuel comprises a pump having an output pressure in excess of that of the compressor.

3. A fire tube boiler comprising in a hermetically sealed system for continuous flow, a mixing chamber, a throat of smaller cross section than the mixing chamber and disposed at the outlet thereof, a combustion chamber of larger cross section than the throat and into which the throat opens, and a fire tube leading from the combustion chamber and provided with a flue gas outlet; together with a tank of liquid to be heated and in which at least a major portion of said tube is contained in a position immersed in such liquid; the mixing chamber having a central nozzle, an igniter, means for supplying fuel to the mixing chamber through the nozzle at substantial super-atmospheric pressure, means for supplying air to the mixing chamber about said nozzle at substantial super-atmospheric pressure but less than that of the fuel, baffle means for diverting and segregating a predominantly major portion of the air from the immediate vicinity of the nozzle, said air supply means delivering a sufficient quantity of air to the immediate vicinity of the nozzle to support combustion, said latter quantity of air being immediately mixed with said fuel to permit the burning of the fuel to be initiated by the igniter, said baffle means terminating between the nozzle and the throat for the release and exposure of the segregated air to the burning fuel mixture, and the throat being adapted to promote abrupt and substantially complete admixture of the burning fuel with said segregated air for immediate combustion in the combustion chamber of the remaining fuel.

4. The combination set forth in claim 3 in which the fuel supplying means supplies liquid fuel at a predetermined rate, and the cross section of said throat is no greater than 1.5 square inches per gallon of fuel per hour.

5. The combination set forth in claim 3 in which the mixing chamber is provided with means for supplying, under pressure, liquid fuel at a predetermined rate, and the fire tube has a cross section less than three square inches per gallon of fuel per hour.

6. The combination set forth in claim 3 in which the fire tube comprises a helical coil in the tank, and at least the combustion chamber is disposed in the tank inside such coil, the cross section of said throat being no larger than 1.5 sq. in. and the fire tube no larger than 3 sq. in. per gallon of fuel per hour, the cross section of the combustion chamber being not substantially greater than required to effect complete combustion.

7. A method of burning fuel in a fire tube boiler which comprises mixing the fuel at sub-

stantial super-atmospheric pressures with just sufficient air to support combustion, igniting the fuel, and promptly after ignition and during initial acceleration of the flame completing the addition and mixing of all air required for complete combustion while abruptly accelerating the air and fuel to a rate of flow momentarily approaching the rate of flame propagation in the mixture, relatively retarding the flow to prevent the rate of flow from exceeding the rate of flame propagation after thorough admixture of air and fuel is achieved, abruptly completing combustion at the relatively retarded rate of flow, and delivering heat from the products of combustion while flowing them at relatively increased velocity through the boiler fire tube.

8. A method of burning fuel in a boiler having a fire tube, which method comprises compressing air to a pressure of at least one-third pound per square inch, delivering fuel to a portion of such air, igniting the fuel, mixing with said portion and the burning fuel all the air required for complete combustion of said remaining fuel, the addition of such air constituting said fuel a fully combustible mixture and the air being added during continuous initial flame acceleration and while abruptly accelerating flow prior to substantial combustion, suddenly expanding the mixture and relatively retarding its flow during substantial completion of combustion of the fuel, and thereafter relatively reaccelerating said flow in the fire tube.

9. The method set forth in claim 8 in which not to exceed about 2% of the fuel is burned prior to said abrupt acceleration.

10. In combination in a high rating fire tube boiler, a boiler tank, fire tube means extending through such tank and ending in a flue vent, a combustion chamber at least partly within the boiler tank and opening into the fire tube means, an annular wall of tapering section providing a restricted throat opening into the combustion chamber and much smaller in cross section than the combustion chamber, a mixing chamber ten to fifteen times larger in section than the throat and for which the said wall provides an end, the mixing chamber communicating through the throat with said combustion chamber, means for supplying air to the mixing chamber at a pressure in excess of one-third pound per square inch, means for supplying fuel to the mixing chamber at a pressure exceeding that of the air, and means for igniting the fuel in the mixing chamber, said air supplying means including separate primary air and secondary air delivery passages, the primary air passage opening into said chamber adjacent said fuel supplying means and having an air capacity only sufficient to support combustion of a small percentage of such fuel, the secondary air delivery passage opening into the mixing chamber between said fuel supplying means and said throat, for delivery of secondary air about the ignited mixture of fuel and primary air, the mixing chamber, throat, combustion chamber and fire tube means comprising a conduit heremetically sealed, from the air-supplying means in the mixing chamber to said vent, the throat being in a location immediately beyond the point where the secondary air passage opens into the mixing chamber, whereby the fuel burning in the presence of all of said air, but mixed with only a small portion thereof, is forced into the throat prior to the consumption of more than a few per cent of the fuel to abruptly mix the remainder of the air in the throat and to assure abrupt combustion in said combustion chamber and to develop high gas velocity in said fire tube means for a high rate of heat delivery thereto.

11. The device of claim 10 in which the fuel supplying means comprises an atomizing nozzle and means for delivering a liquid fuel thereto, the throat section being between .43 square inch and 1.5 square inches per gallon of fuel per hour and the fire tube section between .20 square inch and 2.5 square inches per gallon of fuel per hour.

12. The combination with a fire tube having a flue gas outlet, of a fuel and air admission chamber, a throat and a combustion chamber in series connection and in communication with said fire tube for the delivery of products of combustion thereto, an igniter in the admission chamber, means for supplying fuel to the admission chamber at a pressure in excess of one-third pound per square inch, means for supplying to the admission chamber all of the air required for the combustion of such fuel at a pressure of at least one-third pound per square inch and less than that at which fuel is supplied, said admission chamber, throat, combustion chamber and fire tube constituting a continuous and hermetically closed passage from said air-supplying means to said outlet, the ratio of the cross section of the throat to the fuel supplied by the fuel supplying means being no greater than a ratio of 1.5 square inches per gallon of liquid fuel per hour and the throat being smaller in cross section and shorter in length than either of said chambers, and the ratio of the cross section of the fire tube to the rate of fuel supply being no greater than a ratio of 3 square inches per gallon of liquid fuel per hour, the air supplying means comprising a baffle for withholding nearly all of the air unmixed with the fuel until the air and fuel in the admission chamber approach the throat, the throat being located in the path of the burning fuel and unmixed air, and abrupt mixture of such air with the burning fuel taking place in the course of the acceleration required to traverse the throat, said acceleration being produced by the reduction in section between the mixing chamber and the throat, and abrupt and substantial completion of combustion taking place in the combustion chamber for effecting a high flue gas velocity and rate of heat transfer in the fire tube.

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