A high-efficiency hot-water boiler for a heating system of a building is provided. The boiler includes a boiler enclosure that contains a furnace area compartment within an insulated sealed casing, a first watertube compartment within a sealed casing, a second watertube compartment within a sealed casing, and an air-to-air preheat exchanger within a sealed casing. A plurality of separate, closely-spaced watertubes extends within each of the compartments and provides paths for working fluid to flow through the compartments for purposes of transferring heat to the working fluid. A burner is located within the furnace area compartment forcombusting an air/gas mixture. The casings include openings for directing the passage of the products of combustion to make a first pass through the furnace area compartment, a second pass through the first watertube compartment and a third pass through the second watertube compartment and then through the air-to-air preheat exchanger to preheat fresh combustion air before being exhausted from the enclosure via the flue. An air/gas mixer and a burner ignition system are also disclosed.
HIGH-EFFICIENCY GAS-FIRED FORCED-DRAFT CONDENSING HOT WATER BOILER

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a boiler that forms part of hot water supply or heating system of a building, and more specifically, the present invention relates to a gas-fired condensing boiler providing improved heat transfer and ultra-high thermal and operating efficiencies.

[0002] A typical boiler for use in providing a supply of hot water, or other so-called working fluid, for heating a relatively large-sized commercial or industrial building, for instance, a school, apartment building, office building, or the like, includes an enclosed furnace where a fuel is combusted to produce heat. A tank or pipes filled with water or other fluid extend within an enclosure through or adjacent the furnace so that heat is transferred to the water/working fluid. Typically, the water/working fluid flows through a loop external of the boiler and is returned to the boiler as "return" water/working fluid at a predetermined return water/temperature, is heated as it flows through the boiler enclosure, and leaves the boiler as "supply" water/working fluid to the loop at an elevated temperature. Combustion gases exit the furnace and are exhausted via a flue to ambient atmosphere.

[0003] The size or capacity of a boiler is typically expressed in terms of BTUs (British Thermal Units) or BTUH (BTUs per hour). This can also be expressed in terms of MBH (thousands of BTUs per hour). One particular contemplated embodiment of the present invention is primarily directed to boilers producing about 3,000 MBH smaller, such as within the range of 3,000 MBH to 2,000 MBH. However, it should be understood that the boiler of the present invention is not limited to such range and that such range is provided merely for purposes of example.

[0004] The thermal efficiency of a boiler relates to its ability to maximize heat transfer. Thus, this is expressed in terms of percentage and provides an indication of the percentage of heat generated within the furnace that is actually transferred to the water/working fluid as opposed to being lost "up the flue" to ambient atmosphere.

[0005] Many boilers compromise thermal efficiency by discharging flue gas at a predetermined temperature above its dew point. The advantage of this is that condensation is prevented from being formed within the heat exchanging portion of the boiler and the collection and discharge of condensate is not required. However, thermal efficiency is greatly compromised.

[0006] Another type of boiler known to have fairly high thermal efficiency is so-called "condensing" boilers. A condensing boiler uses heat generated by combusting gas or fuel within a boiler enclosure to directly heat circulating water and re-abstracts condensed latex heat in exhaust gas to improve thermal efficiency. The boiler converts the latent heat of condensation into useful energy instead of expelling it with exhaust gases.

[0007] Water droplets form on the walls and tubes of heat exchangers of condensing boilers. As an example of the amount of condensation produced in a condensing boiler, a typical condensing boiler generating about 100 MBH of heat for one hour will produce about one to two gallons of liquid condensate. This condensed water is required to be collected and discharged from the boiler. The condensation is slightly acidic, typically having a pH of about 3.5 to 4.5, and some jurisdictions require the condensation to be neutralized before disposal.

[0008] Although known condensing boilers may be satisfactory for their intended purpose, there is a need for an energy efficient condensing boiler having improvements with respect to maximizing heat transfer and thermal and operating efficiencies thereby reducing energy costs while also meeting air quality requirements with low NOx combustion. Preferably, such a boiler should be able to provide about 3,000 MBH to about 2,000 MBH or other amount of heat for purposes of heating commercial and industrial buildings as well as residential buildings.

BRIEF SUMMARY OF THE INVENTION

[0009] According to the present invention, a high-efficiency hot-water boiler for a heating system of a building is provided. The boiler includes a sealed boiler enclosure that contains a furnace area compartment within an insulated sealed casing, a first watertube compartment within a sealed casing, a second watertube compartment within a sealed casing, and an air-to-air preheat exchanger within a sealed casing. A plurality of separate, closely-spaced watertubes extend within each of the furnace area, first watertube and second watertube compartments and provide paths for working fluid to flow through the compartments for purposes of transferring heat to the working fluid. A burner is located within the furnace area compartment for combusting an air/gas mixture and producing products of combustion. The casings include openings for directing the passage of the products of combustion through the enclosure to a flue. The openings extend between the furnace area compartment and the first watertube compartment, the first watertube compartment and the second watertube compartment, and the second watertube compartment and the air-to-air preheat exchanger and are positioned to enable the products of combustion to make a first pass through the furnace area compartment, a second pass through the first watertube compartment and a third pass through the second watertube compartment and then through the air-to-air preheat exchanger to preheat fresh combustion air before being exhausted from the enclosure via the flue.

[0010] According to another aspect of the present invention, a burner for a high-efficiency hot-water boiler is provided. The burner includes a hollow, cylindrical, elongate metal fiber burner head having a distal end and a proximal end and an air/gas mixer located adjacent a proximal end of the burner head for uniformly distributing an air/gas fuel mixture within the burner head. The mixer has a central hub and hollow spokes extending radially therefrom. The central hub is adapted to receive a supply of gas and direct it into the hollow spokes, and the mixer defines channels between the spokes through which a supply of combustion air flows transversely through the mixer into the burner head. The spokes have gas outlets in the sides thereof that discharge gas into the flow of combustion air such that the gas is discharged in a direction substantially perpendicular to the flow of combustion air.

[0011] According to an additional aspect of the present invention, a two-stage ignition system and method for igniting a burner is provided. The two-stage ignition system uses an ignition flame to ignite a main gas pilot flame which, in turn, ignites said burner. The two-stage ignition system includes an electrically-operated pilot ignition gas valve for providing gas to an ignition tube for creating the ignition
flame with a spark igniter. The two-stage ignition system further includes a separate electrically-operated main pilot gas valve for separately providing gas to a main pilot gas divider that exists on only a small portion of the metal fiber burner. During a first period, the ignition flame fueled by the electrically-operated pilot ignition gas valve ignites the main gas pilot flame at the main pilot gas divider which is fueled by the separate electrically-operated main pilot gas valve, and after the main gas pilot flame is ignited, the system automatically de-energizes the electrically-operated pilot ignition gas valve to extinguish the ignition flame. During a second period, gas is introduced into the burner head via a main gas burner supply line, and the burner is fully ignited by the main gas pilot flame. After the burner is ignited, the system automatically de-energizes the electrically-operated main pilot gas valve to extinguish the main gas pilot flame.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The features and advantages of the present invention should become apparent from the following description when taken in conjunction with the accompanying drawings, in which:

[0013] FIG. 1 is a perspective view of a boiler enclosure according to the present invention;

[0014] FIGS. 2A-2D are a left side elevational view, front and rear end elevational views, and a top plan views of the boiler enclosure of FIG. 1;

[0015] FIG. 3 is a schematic view illustrating the internal layout of components within the boiler according to the present invention;

[0016] FIG. 4A and 4B are front and side elevational views of a watertube used in the boiler according to the present invention;

[0017] FIGS. 5A, 5B and 5C are views of a burner of the boiler according to the present invention; and

[0018] FIGS. 6A, 6B and 6C are views of a "wagon wheel" shaped component of the burner used to uniformly mix and distribute a mixture of air and gas within the burner.

DETAILED DESCRIPTION OF THE INVENTION

[0019] A boiler 10 according to the present invention includes an enclosure, or cabinet, 12 best illustrated in FIGS. 1 and 2A-2D. Typically, the boiler 10 is connecting to a loop (not shown) in which water or liquid fluid is continuously, continually, or intermittently circulated. For example, the loop can include pipes, radiators or the like through which heated water circulates to heat various areas of a building. The loop also includes pipes or the like to return water to the boiler for reheat and recirculation through the loop. Accordingly, the enclosure 12 includes a return inlet 14 and a supply outlet 16 for the re-circulating water.

[0020] As shown in the drawings, the enclosure 12 can have a compact, relatively-rectangular configuration, although other configurations are possible. Simply for purposes of example and to provide an explanation of the relative size of one contemplated embodiment of the boiler 10, and not be way of limitation, the enclosure 12 may have a footprint of approximately 12 feet by 3 feet and a height of about 6 feet, and the boiler 10 may weight about 4,000 to 5,000 lbs. Of course, the boiler can be made to greater or lesser dimensions and weight depending upon its intended end use.

[0021] Preferably, the enclosure 12 is formed by numerous readily removable access panels 18 to make the interior of the boiler 10 accessible for service and inspection. The modular construction of the boiler also makes it easy to expand or reduce the size of the boiler, as specifically desired by the end user. The furnace area access panels of the boiler 10 are preferably constructed of heavy gauge stainless steel having about two inch thick high-temperature ceramic fiber insulation and are bolted and tightly sealed to the boiler frame. The outer steel surface of the enclosure 12 is preferably made with sixteen gauge and a powder coated finish.

[0022] In the illustrated embodiment, a supply nozzle 20 through which heated water is supplied to an exterior loop of a heating system of a building is located at the top of the front 22 of the enclosure 12 adjacent a control panel/display 24 of the boiler 10. Oppositely, a return nozzle 26 through which return water is fed to the boiler 10 is located at the bottom of the rear 28 of the enclosure 12. A drain connection 30 also extends through the rear 28 of the enclosure 12 directly underneath the return nozzle 26 and provides a path for discharging working fluid from the boiler 10, such as required during watertube replacement and/or other boiler maintenance service. A flue connection 32 for venting exhaust combustion gases is located on a top wall 34 of the enclosure 12 and is located adjacent the rear 28 of the enclosure 12. A combustion air inlet 36 for providing ambient air to be ultimately mixed with natural gas or propane and combusted in a burner located within the furnace of the boiler 10 is also located on the top wall 34 of the enclosure 12 adjacent the front 22 of the enclosure 12. A hot water relief valve 38 also extends through the top wall 34 of the enclosure 12. Finally, the side wall 40 of the enclosure 12 includes a flame observation port 42 through which the flame of the burner extending within furnace area of the boiler 10 can be readily viewed.

[0023] The inner workings of the boiler 10 are best illustrated in FIG. 3. As discussed previously, water or other working fluid is returned to the boiler 10 via return inlet 14 and travels via defined paths through the boiler absorbing heat until it exits the boiler 10 via supply outlet 16. In addition, ambient air is drawn into the enclosure 12, is preheated, and then mixed with a supply of natural gas or propane. The mixture is combusted by a burner 44 within a furnace area 46 of the boiler 10 to produce heat. The resulting products of combustion (i.e., hot combustion gases) pass via a defined path through the boiler 10 and are ultimately exhausted via a flue or like duct connected to flue connection 32 of the enclosure 12. The paths taken by the water or like working fluid, the ambient air, the natural gas or propane, and the combustion gases through the boiler 10 and enclosure 12 are discussed in detail below.

[0024] Turning first to the water or like re-circulating working fluid of the boiler, it is provided as return water at a predetermined temperature via return inlet 14 into a base header 48. The base header 48 is a relative large diameter pipe or manifold that extends substantially horizontally from the rear 28 of the enclosure 12 along the bottom of the boiler toward the front 22 of the enclosure. The base header 48 extends under the furnace area 46 of the boiler and terminates shortly in front of the furnace area 46 adjacent the front 22 of the enclosure.

[0025] A plurality of closely-spaced, upstanding water-tubes 50 interconnects to the base header 48 and provides a path for the working fluid of the boiler to an upper header 52. The upper header 52 is similar in size and function to the base header 48, except that it extends substantially horizontally.
along the top of the enclosure 12 and extends through the front 22 of the enclosure 12 to the supply outlet 16.

[0026] In the embodiment illustrated in FIG. 3, the boiler 10 has three distinct compartments through which the watertubes 50 extend. These compartments include a furnace area compartment 54 and two adjacent compartments 56 and 58. In the illustrated embodiment, there are eleven separate watertubes 50 extending through each of the compartments 56 and 58, and there are seventeen separate watertubes 50 extending through the furnace area compartment 54. Thus, in the illustrated embodiment, there are a total of thirty-nine separate watertubes 50 that provide a path for the working fluid of the boiler 10 from the base header 48 to the upper header 52.

[0027] An example of one of the watertubes 50 located in the furnace area compartment 54 is shown in FIGS. 4A and 4B. The watertube 50 is a single length of hollow tubing having opposite open ends, 60 and 62, between a generally undulating intermediate section 64. The end 60 is connected to the base header, and the end 62 is connected to the upper header 52. As the working fluid passes upward through the watertube 50, it travels across the width of the furnace area compartment 54 several times thereby maximizing heat transfer. The larger undulation 66 provides space for the burner 44 as best shown in FIG. 3. As discussed above, there are seventeen identical watertubes 50 closely spaced together in the furnace area compartment 54.

[0028] The watertubes in compartments 56 and 58 are similar to that illustrated in FIG. 4A, except that the undulations are of uniform size since they do not need to accommodate a burner. FIG. 3 shows that there are twenty-two identical watertubes in compartments 56 and 58. Thus the boiler design includes the use of only two different shapes of watertubes. The number of watertubes per sealed compartment and/or the number of compartments may be modified as desired.

[0029] For purposes merely of example, the watertube 50 can be made of 316L stainless steel, weigh about fifty pounds or more, and have a constant outer diameter of about 1.5 inch and a constant inner diameter of about 1.25 inch thereby providing a tube wall thickness of about 0.125 inch. Of course, other dimensions can be utilized. The undulating design of the watertube 50 provides the watertube 50 with a needed amount of flexibility to prevent damage from thermal shock and by stresses caused by uneven internal circulation. Thus, an advantage of the above referenced watertube design is that it can be used with forced hot water heating systems designed for higher working fluid temperatures and greater temperature drops.

[0030] Preferably, each watertube is individually replaceable, and replacement can be accomplished without welding or rolling. Also, preferably the ends, 60 and 62, of the watertubes 50 are formed (i.e. not provided by way of separately-manufactured fittings welded to the ends of the tube) with circumferential flanges 68 and a reduced outer-diameter throat section 70 adjacent the flanges 68 so that the watertubes can be closely-spaced where they are connected to the headers, 48 and 52. For instance the outer-diameter of the circumferential flange 68 can be equal to or less than the outer-diameter of the intermediate section 64 of the watertube. This enables the intermediate undulating sections 64 to be closely spaced together within the compartments, 54, 56 and 58, further enhancing heat transfer and operating efficiency.

[0031] As stated above, fresh combustion air and the products of combustion also follow a path through the boiler 10. Fresh combustion air is initially drawn into the enclosure 12 through the combustion air inlet 36 via the action of an adjustable speed air blower 72. As best illustrated in FIG. 3, the inlet 36 is located on the top wall 34 adjacent the front 22 of the enclosure 12, and the blower 72 is located adjacent the rear 28 of the enclosure. Accordingly, as the fresh combustion air passes from the inlet 36 adjacent the front 22 of the enclosure 12 to the blower 72 located adjacent the rear 28 of the enclosure 12, the fresh combustion air is preheated by heat radiating from the sealed casings of the compartments 54, 56 and 58. This preheated combustion air is then forced by the blower 72 into an inlet 74 of a combustion air preheat exchanger 76 housed and located adjacent compartment 58 within the enclosure 12 of the boiler. Thus, before the fresh combustion air enters the exchanger 76, it has already made one pass along the length of the boiler 10 within the enclosure 12.

[0032] The purpose of the combustion air preheat exchanger 76 is to further preheat the combustion air via heat exchange with the spent hot flue combustion products just before the combustion products are exhausted from the boiler 10 up the flue. Accordingly, as the fresh combustion air passes through the combustion air preheat exchanger 76 from the inlet 74 to an outlet 78 of the exchanger 76, the temperature of the fresh combustion air is further increased. This preheating of the fresh combustion air takes place entirely within the confines of the enclosure 12 of the boiler 10.

[0033] The preheated fresh combustion air passes through the outlet 78 of the exchanger 76 into an air duct 80 that extends adjacent the top of the boiler over the compartments 54, 56 and 58 to a burner box 82. At this point, the preheated fresh combustion air is mixed with natural gas or propane from a main gas supply line 84 via a gas/air mixer 86. This gaseous fuel mixture is provided into a burner combustion head 88 and is burned to generate heat. As shown in FIG. 3, the burner combustion head 88 extends through the open space provided by the large undulations 66 of the watertubes 50 extending within the furnace area compartment 54. The products of combustion fill the furnace area compartment 54 transferring heat to the working fluid within the watertubes 50 passing through compartment 54. In turn, this reduces the temperature of the combustion products.

[0034] The furnace area compartment 54 has an opening 90 adjacent the base of the compartment 54 that provides a path for the combustion products to flow into the adjacent compartment 56. Thus, after making one pass through the furnace area compartment, the combustion products make one pass through compartment 56. In compartment 56, the combustion products flow in a generally upward direction through the close array of watertubes 50 extending within compartment 56 transferring heat to the working fluid within the watertubes 50 which thereby further reduces the heat of the combustion products.

[0035] The compartment 56 has an opening 92 adjacent the top of the compartment 56 that provides a path for the combustion products to flow into the adjacent compartment 58. Thus, after making a pass through compartment 56, the combustion products make a pass through compartment 58. In compartment 58, the combustion products flow generally downward through the close array of watertubes 50 extending within compartment 56 transferring heat to the working fluid
within the watertubes 50 which thereby further reduces the heat of the combustion products.

[0036] The compartment 58 has an opening 94 adjacent the base of the compartment 58 that provides a path for the combustion products to flow into the combustion air preheat exchanger 76. Thus, after making a pass through compartment 58, the combustion products make a pass through the combustion air preheat exchanger 76 where heat is transferred from the combustion products to the fresh combustion air as discussed previously. This further reduces the temperature of the combustion products which are then directed up the flue to ambient atmosphere.

[0037] Thus, in summary, fresh combustion air travels the length of the enclosure 12 twice (from air inlet 36 to blower 72; then through exchanger 76 and duct 80 to burner box 82) so that it can be preheated to a desired temperature before being mixed with natural gas or propane. After combustion of the air/gas fuel mixture, the products of combustion make one pass through the furnace area compartment 54, one pass through watertube compartment 56, and one pass through watertube compartment 58 before passing through the combustion air preheat exchanger and then up the flue.

[0038] The above described arrangement of watertubes, watertube compartments, preheating of combustion air, and combustion products flow through the boiler permits the boiler to be of high efficiency. For example, the boiler 10 can achieve a minimum of 90% thermal efficiency at standard loop operating temperatures in which the return water enters the boiler at 106°F and leaves the boiler at 180°F. Such a boiler can reach 98% thermal efficiency with lower return temperature systems.

[0039] Also, by way of example, the fresh combustion air preheating arrangement described above for the boiler 10 can raise the temperature of fresh combustion air at ambient temperatures to about 200°F to 250°F, and the temperature of combustion products exhausted from the boiler 10 up the flue can be at a temperature of about 130°F to 180°F.

[0040] The dew point for flue gas is 132°F. The flue gas will be reduced to this temperature when working fluid within the boiler is lower than 135°F. In this case, condensation forms only on the exterior surfaces of the watertubes 50 where the film temperature becomes less than the dew point of the flue gas. The boiler 12 includes condensate pans below each compartment to collect the condensate and a condensate drain to provide a path for drainage of the condensate from the boiler.

[0041] When the boiler 12 is operated at boiler water temperature greater than the dew point of the flue gas, condensation will continue to condense in the air-to-air exchanger 76 where the fresh combustion air temperature is below the dew point of the flue gas. The condensation within the air-to-air exchanger 76 enables high thermal efficiencies to be achieved by the boiler 12 despite boiler water temperatures being greater than dew point of the flue gases.

[0042] Another novel aspect of the present invention relates to a flue ignited gas pilot ignition assembly which provides a two stage pilot ignition system. The gas pilot ignition assembly is shown in FIGS. 5A-5C and serves the function of igniting the burner 44 of the boiler 10. As best shown in FIG. 5A, a pilot gas train assembly 96 controls the delivery of gas to the ignition assembly and includes a manual gas shut-off valve 98, a gas supply regulator 100, an electrically operated pilot ignition gas valve 102, and an electrically operated main pilot gas valve 104. These components are operated sequentially to properly provide an ignition source for the main gas burner 44.

[0043] During a “trial for ignition” period, the electrically operated pilot ignition gas valve 102, a spark igniter 106, and the electrically operated main pilot gas valve 104 are electrically energized. Thus, gas is permitted to flow through piping from the electrically operated main pilot gas valve 104 to a main pilot channel divider 108 (see FIG. 5B), mixes with combustion air, and exits through a small portion of the main gas burner 44. At the same time, gas flows through piping from the electrically operated pilot ignition gas valve 102 to a pilot ignition gas/air mixing tube 110 and continues to flow to pilot ignition air holes 112 where gas and air mixes. The gas/air mixture flowing through tube 110 is ignited with the spark igniter 106 creating an ignition flame 114 that in turn ignites a main gas pilot flame 116. See FIG. 5B.

[0044] The electrically operated pilot ignition gas valve 102 and the spark igniter are de-energized after the first half of the “trial for ignition” period. This extinguishes ignition flame 114 and leaves main gas pilot flame 116 on for the second half of the “trial for ignition” period.

[0045] After the “trial for ignition” period, the “main burner trial” period begins. This period begins when gas is introduced into the main gas burner 44 via a main gas burner supply line 84. This supply of gas is ignited within the burner combustion head 88 with the main gas pilot flame 116.

[0046] After the first half of the “main burner trial” period, the electrically operated main pilot gas valve 104 is de-energized and thereby extinguishes the main gas pilot flame 116. After the second half of the “main burner trial” period, the burner 44 is released for normal operation during the run period of the burner 44. The air/gas mixture burns on the surface of the metal fiber burner combustion head 88.

[0047] Another aspect of the boiler of the present invention is the design of the air/gas mixer 86 of the burner 44. As best illustrated in FIG. 6A, the main gas supply line or tube 84 extends transversely through a rear mounting plate 132 of the mixer. The plate 132 mounts exteriorly to the rear of the burner box 82. For example, see FIGS. 3A and 5C. A mixer 86 also includes a mixer head 134 having a so-called “wagon wheel” design. For example, as best shown in FIGS. 6A and 6B, the mixer head 134 has a circular outer periphery 120 and a series of spokes 122 radiating from a closed central hub 124. Gas is supplied through the main gas supply line 84 in the mixer 86 and is directed into internal channels extending within the spokes 122. Preheated combustion air enters the burner box 82 and is directed into the burner 44 through openings 126 of the wagon-wheel mixer 86 between the spokes 122. Gas diffuses out of openings in the sides of the spokes 122 normal (i.e., substantially perpendicular) to the flow of the preheated combustion air. This creates turbulence and causes the gas to be evenly distributed within the air/gas mixture so that combustion can occur uniformly on the burner combustion head 88. The mixer 86 includes additional spokes 128 with apertures 130 for creating addition turbulence for evenly distributing the gas and preheated combustion air within the air/gas mixture.

[0048] The portion of one of the spokes 122 shown broken away in FIG. 6B illustrates the path of gas through tube 84 and then in a radial direction through the spoke 122 to the openings 126 adjacent an opposite end of the spoke. Further, FIG. 6C illustrates one contemplated embodiment of the head 134 of the mixer 86 which is formed by a series of stacked plates
Channels are formed within the stacked array of plates and the openings are formed in the side of the stacked array.

Accordingly, the present invention provides an ultra-high-efficiency gas-fired forced-draft condensing hot water boiler having an improved watertube arrangement, improved combustion air preheating, improved flame-ignited pilot assembly, and improved air/gas mixer. The combustion products make three distinct passes through sealed-casing watertube compartments and an additional pass through an air-to-air heat recovery exchanger before being directed up the flue. The air-to-air heat recovery exchanger is contained entirely within the enclosure of the boiler. The watertube assembly can include a single base header, a single upper header and a plurality (such as thirty-nine) of closely-spaced, flexible, bent (i.e. undulating) watertubes extending therebetween. Condensation is permitted to form on the outer surfaces of the watertubes and is collected and discharged. Finally, the burner can safely be ignited via a unique two-stage pilot ignition system, and combustion air and gas (i.e., natural gas or propane) can be uniformly distributed within the burner head by a unique wagon-wheel mixer.

While a preferred boiler and components and systems thereof have been described in detail, various modifications, alterations, and changes may be made to the present invention without departing from the spirit and scope of the present invention as defined in the appended claims.

1. A high-efficiency boiler for a heating system of a building, comprising:
   a boiler enclosure containing a furnace area compartment within an insulated sealed casing, a first watertube compartment within a sealed casing, a second watertube compartment within a sealed casing, and an air-to-air preheat exchanger within a sealed casing;
   a plurality of separate, closely-spaced watertubes extending within each of said furnace area, first watertube and second watertube compartments for providing paths for working fluid to flow through said compartments for transfer of heat to the working fluid;
   a burner located within said furnace area compartment for combusting an air/gas mixture; and
   openings for passage of products of combustion between said furnace area compartment and said first watertube compartment, said first watertube compartment and said second watertube compartment, and said second Watertube compartment and said air-to-air preheat exchanger;
   said openings positioned to enable the products of combustion to make a first pass through the furnace area compartment, a second pass through the first watertube compartment and a third pass through the second Watertube compartment and then through said air-to-air preheat exchanger to preheat fresh combustion air before being exhausted from the enclosure via a flue.

2. A high-efficiency boiler according to claim 1, further comprising an air blower located within said enclosure adjacent said air-to-air preheat exchanger at an end of said boiler enclosure for directing fresh combustion air into said air-to-air preheat exchanger.

3. A high-efficiency boiler according to claim 2, further comprising:
   a fresh combustion air inlet formed in a wall of said enclosure adjacent an opposite end of said boiler such that, when said blower draws fresh combustion air into said enclosure via said fresh combustion air inlet, the fresh combustion air must travel substantially a full length of said enclosure to reach said blower and said air-to-air preheat exchanger;
   wherein the fresh combustion air is initially preheated in said enclosure due to heat radiating from said casings and is further preheated by heat exchange with the products of combustion as the fresh combustion air passes through said air-to-air preheat exchanger.

4. A high-efficiency boiler according to claim 3, further comprising:
   a burner box located within said enclosure adjacent said opposite end of said enclosure on a wall of said furnace area compartment;
   a duct providing passage of the preheated fresh combustion air from said air-to-air preheat exchanger to said burner box; and
   a mixer located within said burner for mixing the preheated fresh combustion air from said burner box with a supply of natural gas or propane and for uniformly distributing the mixture within said burner.

5. A high-efficiency boiler according to claim 4, further comprising:
   a base header extending substantially horizontal within said enclosure along a base of said enclosure directly underneath said compartments, said base header having a return inlet adjacent said end of said enclosure for receiving a return working fluid and an upper header extending substantially horizontal within said enclosure along a top of said enclosure directly over said compartments, said upper header having a supply outlet adjacent said opposite end of said enclosure for providing a supply of heated working fluid;
   each of said watertubes in said compartments having opposite ends with one of said ends connected to said base header and an opposite end connected to said upper header;
   wherein the working fluid is returned to the boiler via the base header at a return temperature, flows through said watertubes where the working fluid is heated, flows into said upper header from said watertubes, and then out of the boiler at a supply temperature.

6. A high-efficiency boiler according to claim 5, wherein the boiler is a condensing boiler and has a drain, and wherein said drain collects and discharges from said enclosure condensation that forms on exterior surfaces of said watertubes.

7. A high-efficiency boiler according to claim 6, wherein said return temperature is about 160° F., said supply temperature is about 180° F. and a thermal efficiency of the boiler is at least 90%.

8. A high-efficiency boiler according to claim 6, wherein each of said watertubes has an intermediate section between its opposite ends, wherein said intermediate section has an undulating shape that extends substantially across a full width of said furnace area, first watertube, or second Watertube compartment.

9. A high-efficiency boiler according to claim 8, wherein said opposite ends of said Watertubes include a reduced diameter throat section and an outwardly-extending circumferential flange having an outer diameter no greater than an outer diameter of said intermediate section so that said Watertubes can be closely spaced within said compartments.
10. A high-efficiency boiler according to claim 9, wherein said opposite ends of said watertubes are integral formed ends and do not include separately manufactured fitments welded thereto.

11. A high-efficiency boiler according to claim 8, wherein said burner includes a metal fiber burner head that extends between undulations of said intermediate sections of said watertubes in said furnace area compartment.

12. A high-efficiency boiler according to claim 11, wherein only two different shapes of watertubes are contained within said enclosure, wherein said watertubes are made of stainless steel, and wherein each watertube is individually replaceable.

13. A high-efficiency boiler according to claim 12, wherein said enclosure has removable access panels and is of modular construction, and wherein the boiler has a heating capacity of 3,000 MBH to 2,000 MBH.

14. A high-efficiency boiler according to claim 1, wherein said burner is a metal fiber burner and has a two-stage ignition system in which an ignition flame is ignited to ignite a main gas pilot flame and the main gas pilot flame is ignited to, in turn, ignite said burner.

15. A high-efficiency boiler according to claim 14, wherein said two-stage ignition system includes an electrically-operated pilot ignition gas valve for providing gas to an ignition tube for creating the ignition flame with a spark igniter, and wherein said two-stage ignition system further includes a separate electrically-operated main pilot gas valve for separately providing gas to a main pilot gas divider that exists on only a small portion of said metal fiber burner.

16. A high-efficiency boiler according to claim 15, wherein, during a first trial period for igniting said burner, the ignition flame fueled by said electrically-operated pilot ignition gas valve ignites the main gas pilot flame at said main pilot gas divider which is fueled by said separate electrically-operated main pilot gas valve, and wherein, after the main gas pilot flame is ignited, said system automatically de-energizes said electrically-operated pilot ignition gas valve to extinguish the ignition flame.

17. A high-efficiency boiler according to claim 16, wherein, during a second main burner trial period, gas is introduced into said burner via a main gas burner supply line and said burner is ignited by the main gas pilot flame, and wherein, after the burner is ignited, said system automatically de-energizes said electrically-operated main pilot gas valve to extinguish the main gas pilot flame.

18. A high-efficiency boiler according to claim 1, wherein said burner has a gas mixer, wherein said mixer has a central hub and hollow spokes extending radially therefrom, and wherein said central hub is adapted to direct a supply of gas into said hollow spokes.

19. A high-efficiency boiler according to claim 18, wherein said mixer has channels between said spokes through which a supply of combustion air flows through said mixer, and wherein said spokes have outlets in the sides thereof to discharge the gas into the flow of combustion air such that the gas is discharged in a direction substantially perpendicular to the flow of combustion air.

20. A high-efficiency hot-water boiler according to claim 19, wherein said mixer has additional spokes with apertures through which the combustion air flows to generate additional turbulence.

21. A burner for a high-efficiency hot-water boiler, comprising:
   a hollow, cylindrical, elongate metal fiber burner head having a distal end and a proximal end; and
   an air/gas mixer located adjacent a proximal end of said burner head for uniformly distributing an air/gas fuel mixture within said burner head, said mixer having a central hub and hollow spokes extending radially therefrom, said central hub receiving a supply of gas and directing it into said hollow spokes.

22. A burner according to claim 21, wherein said mixer defines channels between said spokes for receiving a supply of combustion air that flows transversely through said mixer into said burner head, and wherein said spokes have gas outlets in the sides thereof that discharge gas into the flow of combustion air such that the gas is discharged in a direction substantially perpendicular to the flow of combustion air.

23. A burner according to claim 22, wherein said mixer has additional spokes with apertures through which the combustion air flows to generate additional turbulence.

24. A method of igniting a metal fiber burner head of a high-efficiency boiler, comprising:
   igniting an ignition flame by energizing an electrically-operated pilot ignition gas valve to provide gas to an ignition tube and by igniting an air/gas fuel mixture in the ignition tube by energizing a spark igniter; simultaneously with said ignition flame igniting step, energizing a separate electrically-operated main pilot gas valve for separately providing gas to a main pilot gas divider that is located on a small portion of the metal fiber burner head;
   after said ignition flame igniting step, igniting a main gas pilot flame with the ignition flame by igniting a air/gas fuel mixture at the main pilot gas divider;
   after said step of igniting the main gas pilot flame, de-energizing the electrically-operated pilot ignition gas valve to extinguish the ignition flame;
   after said step of igniting the main gas pilot flame, uniformly distributing an air/gas fuel mixture to the burner head and igniting the burner head with the main gas pilot flame; and
   after said igniting said burner head, de-energizing the electrically-operated main pilot gas valve to extinguish the main gas pilot flame.

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