A fuel-burning heater is provided which comprises a shallow bed of refractory particles, a pervious support underlying the bed and a fan for blowing a mixture of air and a gaseous fuel through the support into the bed so that the latter is fluidised. The fuel burns in the bed and the exhaust gases pass upwardly to a flue. Above the level of the slumped bed there may be a window through which heat can be radiated. Alternatively the space above the bed may be completely enclosed laterally by a water jacket. At full output, particles are thrown up from the bed, radiate heat to the water jacket or through the window, absorb heat from the exhaust gases and eventually fall back to the bed.
FUEL-BURNING HEATER

SUMMARY OF THE INVENTION

This invention relates to a heater of the kind in which fuel is burnt in air to release heat which is transferred to a body which is required to be heated. The body to be heated may be outside the heater, in which case heat may be transferred thereto by radiation, or within the heater, in which case heat may be transferred to the body by radiation, conduction and/or direct contact of the burning fuel or hot exhaust gases therefrom with the body. Direct contact between the body and the burning fuel or exhaust gases is appropriate in many cases where the body is solid, but in a case where the body to be heated is a fluid, for example water or air, heat is normally transferred to the fluid by conduction, the heater including a heat exchanger structure for containing the fluid.

It is not practicable to arrange a heater of the kind referred to so that all of the potential heat energy possessed by the fuel will be transferred to the body to be heated. A significant proportion of the energy released by combustion of the fuel will be carried away from the heater by the exhaust gases, the temperature of these gases being greater than that of the fuel and air supplied to the heater. The efficiency of such a heater, by which we mean the percentage of the amount of heat released by combustion which is transferred to the body to be heated, is considerably less than 100%.

In a case where the heater includes a heat exchanger structure for transferring the heat of combustion to a fluid, the efficiency can be improved by increasing the surface area of the heat exchanger structure which is presented to the exhaust gases. This expedient, however, necessarily involves increasing the size and cost of the heater. In a case where heat is transferred wholly or mainly to the body by radiation, improvement of the efficiency is difficult, since the exhaust gases themselves do not radiate heat even though they may be at a relatively high temperature.

One proposal which has been made in an attempt to improve the efficiency of a fuel-burning heater is to provide in such a heater a bed of refractory particles which is fluidised when the heater is operating, means for feeding fuel and air into the bed so that combustion occurs therein, and a heat exchanger which is immersed in the bed. Heat released by combustion of the fluid is carried to the heat exchanger by the refractory particles which are in rapid and continuous motion. Heat is thus transferred to the heat exchanger in an efficient manner.

One disadvantage of this known form of boiler having a fluidised bed is that combustion of the fuel will not occur in the bed until the latter is heated at least to the minimum combustion temperature of the fuel. It has thus been found necessary to provide auxiliary burners capable of heating the bed to the required temperature within a reasonable time. It will be evident that a part of the heat supplied by the auxiliary burners will be transferred to the heat exchanger and to the water contained therein. The provision of such auxiliary burners and control means therefor contributes significantly to the cost of this known form of heater.

A further disadvantage of the known form of heater hereinbefore described concerns operation of the heater below its maximum output. If the rate of supply of fuel to the bed is reduced, the temperature of the bed falls since the heat-absorbing capacity of the heat exchanger will be unchanged. If the rate of supply of fuel is significantly reduced, the temperature of the bed falls below the minimum combustion temperature and the heater will cease to operate.

It is an object of the invention to provide a fuel-burning heater which is more efficient than or less expensive than comparable heaters of known construction.

It is also an object of the invention to provide a fuel-burning heater wherein combustion occurs under such conditions that the emission of pollutants is substantially reduced or avoided without impairing the efficiency of the heater.

According to the invention there is provided a fuel-burning heater comprising a shallow bed of refractory particles, a pervious support underlying the bed, and feed means for feeding fuel and air into the bed through the support whereby the bed can be fluidised and the fuel burned therein.

When the heater is operating, the refractory particles are in continuous random motion and, since the bed is relatively shallow, each particle will frequently reach the upper surface of the bed from which position it can radiate heat. Owing to the intimate contact between the gases in the bed and the particles, heat is efficiently transferred from the bed to the particles and the burning fuel does not reach a temperature significantly higher than that of the particles.

The heater may include means defining a window above the level of the bed through which heat can be radiated from the bed to a body outside the heater. Alternatively, the space above the bed may be completely enclosed laterally by a heat exchanger through which a fluid to be heated is passed. In the latter case, heat would be radiated from the bed to the heat exchanger structure and transmitted by conduction to the fluid.

According to the invention there is further provided a method of operating a heater comprising a bed of refractory particles and feed means for feeding air and fuel into the bed, wherein air and fuel are fed into the bed and burned therein at a rate such that the bed is fluidised and refractory particles are thrown upwardly from the bed and permitted to fall back into the bed.

Thus, according to the method of the invention, refractory particles circulate continuously through the bed and the space above the bed. This circulation considerably reduces the temperature of the exhaust gases leaving the heater since the particles temporarily in the space above the bed loose heat by radiation, and possibly by contact with a surface of the heater which presents a boundary of said space, so that the temperature of the particles falls below that of the surrounding exhaust gases. Accordingly, the particles temporarily in the space above the bed extract heat from the exhaust gases.

Preferably the air and fuel are fed to the bed at a rate such that when the bed is cold the particles are fluidised, but when the bed reaches its normal operating temperature particles are thrown upwardly from the bed. Owing to the intimate contact between the particles of the bed and the incoming gaseous mixture, the temperature of this mixture rises to a approximately that of the bed as the gases enter the bed. Owing to thermal expansion of the gases, the gas velocity within the hot bed will be three to four times that in the cold bed. Accordingly, the rate at which fuel and air are fed
can be selected to provide a relatively low gas velocity within the cold bed which is sufficient to fluidise the latter but not to throw particles upwardly from the bed, and a higher gas velocity in the hot bed which is sufficient to cause circulation of particles from the bed into the space above same. The rate at which heat is lost by the particles considered collectively is relatively small when the bed is merely fluidised, and is relatively high when a proportion of the particles is continuously circulating through the space above the bed. Accordingly, the rate of heat loss is low when the bed is cool and the bed can be heated up rapidly to the normal operating temperature without the use of auxiliary heating means.

Preferably the feed means is adjustable to permit of variation of the rate of flow of gases through the bed to provide selectively for operation of the heater with circulation of a proportion of refractory particles through the space above the bed, and operation without such circulation of the refractory particles or with circulation of a smaller proportion. If circulation of refractory particles from the bed is terminated, the rate of heat transfer from the bed is substantially reduced and the bed can be operated at a substantially lower rate of fuel consumption without the temperature of the bed falling below the minimum combustion temperature of the fuel.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view, partly in vertical cross-section, of a water-heating boiler incorporating a primary bed in which combustion takes place and a secondary bed associated with a heat exchanger structure.

FIG. 2 is a similar view of a further form of boiler.

FIGS. 3 and 4 show fragmentary views illustrating alternatively forms of secondary bed which may be incorporated in the boiler of FIG. 1,

FIG. 5 is a plan view of the part shown in FIG. 4,

FIG. 6 is a plan view of the heater shown in FIG. 7,

FIG. 7 is a view in vertical cross-section of a further form of heater which is adapted to emit radiant heat.

DETAILED DESCRIPTION

The boiler illustrated in FIG. 1 is intended to consume a gaseous fuel and to transfer the heat of combustion to water which occupies a passageway 10 formed in a heat exchanger structure which includes a generally cylindrical water jacket 11. The water jacket is supported on a body 12 which is conveniently formed in two parts, an upper part 13 and a lower part 14. In the upper body part 13 there is formed an annular water passageway 15 which forms a downward extension of the passageway 10 in the water jacket. A water inlet 16 formed in the upper body part communicates with the passageway 15 and a water outlet 17 is formed in an upper part of the water jacket.

The water jacket 11 surrounds and defines a generally cylindrical combustion chamber 18 which communicates at its upper end with a circular gas outlet duct 19. The water jacket 11 is formed with a number of integral fins 20 which project radially into the combustion chamber from the inner eall of the water jacket.

The upper body part 13 is formed with a central opening in which there is mounted a support in the form of a plate 21 which is of a pervious nature and thereby adapted to admit air and gaseous fuel to the combustion chamber 18. On the support plate 21 there is disposed a bed of refractory particles 22 which can be fluidised by the flow of air and gaseous fuel upwardly through the porous plate. The periphery of the bed is defined by a retaining ring 23 which extends around the periphery of the plate 21 and projects above the upper surface thereof by a distance of approximately 1 inch. When the bed 22 is static, as shown in FIG. 1, the depth thereof is somewhat less than the height of the retaining ring 23 above the upper surface of the porous plate 21. It will be noted that the slumped bed has a depth less than half the height of the combustion chamber 18.

As indicated at 24 in FIG. 1, a further quantity of refractory particles accumulates around the outside of the retaining ring 23 when the heater is in use, as will be described hereinafter. The particles 24 lie between the retaining ring and the water jacket 11 and act as a thermal insulator to prevent significant heat flow directly from the retaining ring to the water jacket.

The boiler further comprises feed means for feeding a mixture of gaseous fuel and air through the porous plate 21 into the bed 22. The feed means comprises a fan 25 mounted directly on the output shaft of an electric motor 26. The fan is disposed in a chamber which is directly beneath the porous plate 21 and is defined between the upper body part 13 and the lower body part 14. The motor 26 is positioned in an inner chamber 27 formed in the lower body part. The inner chamber 27 communicates with the fan chamber through a circular opening around the periphery of which there is disposed a tubular fuel inlet ring 28. The fuel inlet ring is connected by a pipe 29 with a fuel control valve 30 through which gaseous fuel would be supplied to the heater.

The fuel control valve 30 is disposed in an outer chamber 31 formed in the lower body part 14 and separated from the inner chamber 27 by a circular inner wall 32. The outer chamber is enclosed by an outer wall 33 in which openings 34 are provided to admit air to the heater for combustion of the fuel. A further series of openings 35 is formed in the inner wall 32 to admit air from the outer chamber 31 to the inner chamber 27. The openings 34 and 35 are formed at the lower extremity of their respective walls, and a baffle 36 projects upwardly from the bottom of the outer chamber 31 between the opening 34 and the openings 35 so that air entering the heater follows a tortuous path from the openings 34 over an upper end of the baffle 36, then downwardly to the openings 35 and upwardly once more through the opening surrounded by the fuel inlet ring 28. This arrangement is adopted to reduce the emission from the heater of noise generated by the fan 25. The outer chamber 31 may be filled with a loosely packed fibrous or other material having good sound-absorbing properties.

In contact with the inner face of the inner wall 32 there is provided an air-control ring 37 formed with a series of openings 38 which can be aligned with the openings 35, or at least partly obscured by turning the ring relative to the lower body part 14 to reduce the rate of flow of air into the heater. The fuel control valve 30 is arranged to control the rate of flow of gaseous fuel to the fuel inlet ring 28 in accordance with the rate of flow of air through the outer chamber 31 so that the proportion of fuel in the mixture of gaseous fuel and air supplied to the bed 22 is maintained at a preselected value. This would normally be a little lower than the
stoichiometric proportion to ensure complete combustion of the fuel.

The fuel inlet ring 28 is formed with a series of small openings through which fuel can pass to the air stream from the inner to the outer chamber. The fan 25 propels the gaseous mixture through the porous plate 21 and also mixes the gaseous fuel and air so that a substantially homogeneous mixture enters the bed.

A circular block 39 is supported in the fan chamber immediately above the fan 25 by radially-projecting limbs 40 which enter sockets formed between the upper body part 13 and the lower body part 14. The purpose of the block 39 is to so constrict the gas flow passage through the fan chamber that the velocity of the gases therein is maintained above the flame speed in the mixture, thereby avoiding the risk of combustion spreading back through the fan chamber.

The water jacket 11 is insulated externally by a layer of thermal insulation 41 enclosed by a protective casing 42. The upper body part 13 is insulated from the lower body part 14 by a ring 43 of insulating material.

The heater further includes an automatic control means (not shown) which includes an "on/off" switch. When the heater is switched on, the motor 26 is energised immediately. After a delay sufficient to permit the fan to reach its normal running speed, typically 8 seconds, the control means simultaneously energises a spark ignition device 44 and a solenoid valve which controls supply of gaseous fuel to the boiler to permit flow of fuel through the gas control valve 30 to commence. The ignition device 44 is fitted in an opening formed in the water jacket 11 and projects downwardly through the combustion chamber 18 to a position near to the upper surface of the bed 22, at which position the sparks are produced.

When the boiler is cold, the fan 25 causes the mixture of gaseous fuel and air to flow through the bed 22 at a speed such that the latter is fluidised, but such that the particles do not generally rise above the upper edge of the retaining ring 23. When the mixture of gaseous fuel and air reaches the ignition device 44, the mixture is ignited and a flame stabilises on top of the bed 22. Adjacent to the ignition device 44 there is positioned a flame-sensing probe (not shown) which responds to the presence of a flame in the combustion chamber and immediately above the bed to provide an output signal to the automatic control means which causes the ignition device to be de-energised, the solenoid valve remaining open so that the supply of gaseous fuel continues.

Since, when the bed 22 is fluidised, the particles thereof are in rapid random motion, the flame burning on top of the bed rapidly heats the entire bed. Owing to the intimate contact between the particles of the bed and the gaseous mixture passing therethrough, the temperature of the gaseous mixture within the bed is substantially equal to that of the particles themselves. Thus as the gases enter the bed they are heated and expand, this expansion producing a corresponding increase in the velocity of the gases. Accordingly, as the temperature of the bed rises to the normal operating temperature, which is between 700°C and 1,050°C, the gas velocity within the bed rises to a value which is three to four times the initial value when the bed is cold. The relatively high gas velocity within the bed as the temperature of the latter approaches the normal operating temperature is sufficient to cause refractory particles to be thrown upwardly from the bed, i.e. above the upper edge of the retaining ring 23. When the boiler is operating normally, particles circulate from the bed into the combustion chamber and impinge on the fins 20 and on the inner wall of the water jacket 11 before dropping back to the bed. Particles which fall downwardly adjacent to the water jacket 11 fall outside the retaining ring 23 onto the accumulation 24 which therefore has a sloping upper surface down which particles roll back into the bed 22.

Heat is transferred to the fins 20 and water jacket 11 firstly by radiation from the bed 22, secondly by direct contact of exhaust gases passing upwardly through the combustion chamber, thirdly by radiation from particles thrown upwardly from the bed and fourthly by direct contact of such particles on the fins and water jacket. Due to the intimate contact which takes place between the particles in the bed and the particles occupying the space above the bed, on the one hand and, on the other hand, the burning air and fuel and the products of combustion, heat is efficiently transferred to the refractory particles which in turn transfer the heat to the fins and water jacket. Experiments carried out with apparatus as described with reference to FIG. 1 indicate that between 50 and 60 percent of the heat of combustion is transferred by the particles of the primary bed 22 and by direct contact of the exhaust gases with the fins and water jacket.

In order to increase the efficiency of the boiler there may be provided a secondary bed of refractory particles 45 which extracts further heat from the exhaust gases. The secondary bed 45 is supported on a pierced metal distributor plate 46 which extends across the gas outlet 19 at the lower end thereof adjacent to the combustion chamber 18. On the upper face of the distributor plate there may be placed a layer of fine metal gauze, the apertures thereof are smaller than the particles of which the secondary bed is composed so that such particles are prevented from falling into the combustion chamber.

As the exhaust gases pass from the combustion chamber 18 to the gas outlet 19, they pass through the secondary bed 45 and fluidise the latter. When the boiler is operating normally, the temperature of the bed 45 is lower than that of the exhaust gases within the combustion chamber, heat is transferred from the gases to the particles of the secondary bed. These particles are in rapid random motion and heat is rapidly transferred from the particles to the water jacket 11 which surrounds the bed, such transfer being effected mainly by direct contact between particles and the surface of the water jacket. In order to improve heat transfer from the particles of the secondary bed to the water jacket, the latter may be formed with integral fins 47 which project into the bed.

Experiments carried out to date have shown that by means of a secondary bed as shown in FIG. 1, 75 to 90 percent of the heat of combustion can be transferred to water flowing through the water jacket. Typically the temperature of the exhaust gases leaving the secondary bed is in the region of 300°C.

A boiler as illustrated in FIG. 1 and having a motor 26 with a 15 watt output, and a fan of 7 inch diameter, has a heat output when operating normally of 35,000 b.t.u. per hour.

The heat output can be substantially reduced by reducing the rate of supply of air and gaseous fuel without permitting the temperature of the bed 22 to fall.
below the minimum combustion temperature of the fuel. As the rate of supply of fuel and air is reduced, and the temperature of the bed falls, the proportion of particles which are thrown upwardly from the bed decreases rapidly. Thus the rate at which heat is transferred to the water jacket decreases rapidly, with a relatively small drop in the temperature of the bed.

In the case of a boiler intended to provide heat at a fairly low rate, for example in the region of 30,000 b.t.u. per hour, the fan conveniently has a relatively small diameter and in order to avoid high fan speeds, which give rise to excessive noise, a two-stage fan may be employed to overcome the pressure drop through the primary and secondary beds.

The height of the combustion chamber 18, as measured from the upper surface of the static primary bed 22 to the distributor 46, is typically within the range 4 to 6 inches, this being sufficient to avoid particles thrown up from the primary bed reaching the distributor plate. Preferably, the height of the combustion chamber is not substantially greater since the larger the volume of the combustion chamber, the louder the noise which is produced on ignition of the gaseous mixture of air and fuel in the combustion chamber when the heater is being brought into operation.

The preferred form of porous plate 21 is a porous ceramic material. Such material has a relatively low thermal conductivity and would therefore prevent significant heat loss from the bed in the downward direction. Other refractory porous materials could be employed, for example a sintered chemically-inert metal such as stainless steel or nichrome. Advantageously the plate 21 has a low emissivity so that it will not readily absorb radiant heat from the bed. The plate may be formed entirely of a material having a low emissivity, or the plate may include an upper layer which has a low emissivity. For example, the plate may incorporate as an upper layer a pierced aluminium sheet. The aluminium will become oxidised during operation of the heater, but the aluminium oxide thus formed has a low emissivity and will reduce absorption by the plate of heat radiated from the bed. The provision of a pierced sheet as an upper layer of the plate 21 will further reduce the transfer of heat from the bed to the plate by forming static zones of ceramic particles adjacent to the plate and between the holes pierced in the aluminium sheet, such static zones acting as a thermal insulator. It is desirable to reduce flow of heat into the plate 21 from the bed of refractory particles, in order to avoid the mixture of gaseous fuel and air reaching the combustion temperature whilst passing upwardly within the plate 21.

The refractory particles of which both the primary and secondary beds are composed may be silica sand. Alternatively, a mixture of silica sand and limestone may be used. Limestone has the ability to retain sulphur present in the fuel and thus prevent or reduce the emission of oxides of sulphur to the atmosphere in the exhaust gases.

Since the refractory particles may degrade over a long period of use, it may be necessary to replenish the bed, for which purpose the ignition device 44 may be removed to provide an opening through which fresh refractory particles can be introduced into the combustion chamber. Alternatively, the water jacket 11 may be fitted with a removable plug through which access can be obtained to the combustion chamber.

An important advantage of the boiler illustrated in FIG. 1 is that combustion takes place at a temperature within the range 700°C to 1,050°C. In many known forms of fuel-burning apparatus, combustion of a fuel is carried out in such a manner that temperatures of the order of 2,000°C or even higher are attained. Under such conditions oxides of nitrogen are formed with the result that the exhaust gases emitted to the atmosphere include a small proportion of oxides of nitrogen. Aldehydes may also be present in the gases exhausted from known combustion apparatus. Under the relatively low temperature conditions subsisting in a heater in accordance with the present invention when operating, the production of oxides of nitrogen and of aldehydes is at least considerably reduced, and possibly eliminated.

In order to operate the boiler illustrated in FIG. 1 at reduced output, the air control ring 37 may be adjusted to reduce the rate at which air flows into the boiler. The fuel control valve 30 would automatically adjust the fuel flow rate in a corresponding manner. Alternatively, an electrically-operating controller may be provided for controlling the speed of the motor 26.

Referring now to the boiler shown in FIG. 2, parts thereof which correspond to parts hereinbefore described with reference to Figure are indicated by like reference numerals with the prefix 1 and the preceding description is deemed to apply thereto, with the exception of the differences hereinafter described.

The boiler shown in FIG. 2 includes a water jacket 111 which is conveniently assembled from two iron castings, encloses a combustion chamber 118 at the lower end of which there is disposed a bed 122 of refractory particles supported on a circular porous plate 121. The water jacket includes fins 148 spaced a short distance above the bed when the latter is static and projecting radially inwardly from the periphery of the bed. The water passageway 110 in the water jacket extends through the fins 148. Further fins 149 project into a gas outlet 119 defined by the water jacket. In the example shown in FIG. 2, the water passage does not extend into these further fins. The upper surfaces of the fins 148 are inclined to avoid refractory particles accumulating thereon.

Beneath the porous plate 121 there is a fan chamber defined between the lower casting of the water jacket 111 and a body casting 112 on which the water jacket is mounted. The body casting defines a single chamber within which a motor 126 is disposed. Air is drawn into this chamber through an inlet duct 150 formed with a venturi at which a fuel inlet is disposed to inject a gaseous fuel into the air flow at the throat of the venturi. This arrangement provides for an initial mixing of the gaseous fuel and air, and mixing is completed by the fan 125. Fuel controls similar to those described with reference to FIG. 1 would be provided to ensure that fuel is supplied to the inlet duct 150 only when an ignition device (not shown) is operative, or combustion is taking place in or immediately above the bed 122. The flow rate of the mixture of gaseous fuel and air may be controlled by controlling the speed of the motor 126.

Operation of the boiler shown in FIG. 2 is similar to that of the boiler shown in FIG. 1. To start the boiler from cold, a mixture of gaseous fuel and air is supplied to the bed 122 at a flow rate which is sufficiently high to just fluidise the bed. As the temperature of the latter rises, so the gas flow rate within the bed increases and particles are thrown upwardly from the bed. When the
bed is at its normal operating temperature particles are thrown upwardly from the bed onto the fins 148 from where they fall into the bed once more.

The boiler illustrated in FIG. 2 may typically have an output when operating normally of 65,000 b.t.u. per hour. In a boiler designed to achieve this output, the motor would typically have an output of 20 watts and the fan 125 would typically have a diameter of 8 inches with ⅛ inch wide blades. It will be noted that there is no secondary bed in the heater shown in FIG. 2, refractory particles thrown up from the primary bed 122 and the fins 149 being effective to absorb heat at the required rate from the exhaust gases.

In FIG. 3 there is illustrated a modification of the heater shown in FIG. 1 to provide an alternative arrangement of the secondary bed. In this modification the fins 47 are omitted and the distributor plate 46 is replaced by a series of bars 152 which extend side-by-side and parallel to each other across the gas outlet 119. As shown in FIG. 3, the bars are each of triangular shape in cross-section and are arranged to provide a series of V-shaped channels 153 with a narrow opening at the bottom of each channel. Below these openings the opposed faces of the bars diverge downwardly. The opening at the bottom of each channel is sufficiently wide to permit the refractory particles of which the secondary bed is composed to fall between the bars into the primary bed when the boiler is not operating.

The primary bed is formed of particles having sizes which fall within a fairly wide range. When the boiler is brought into operation and particles are thrown upwardly from the primary bed, the smaller particles are carried upwardly between the bars 152 into the channels 153. The gas velocity above the bars is such that the particles are not carried upwardly through the gas outlet of the boiler. However, the gas velocity in the opening along the bottom of each channel is sufficient to prevent a significant loss of particles from the secondary bed to the primary bed whilst the boiler is operating normally.

A water passage 154 extends through the interior of each of the bars 152, these water passages communicating with the water passage in the water jacket of the boiler. Heat carried into the secondary bed by the exhaust gases is transferred to the particles of the secondary bed, thence to the bars 152 and so to water contained in the passages 154. The bars also receive heat radiated from the primary bed and this heat also is transferred to water within the passages 154.

In FIGS. 4 and 5 there is illustrated an alternative modification of the boiler shown in FIG. 1, this alternative modified arrangement operating in a manner similar to that described with reference to FIG. 3. In this case there is provided for supporting the secondary bed a circular plate in which there is formed a plurality of parallel rows of circular openings 155 which extend from the upper face of the plate to the lower face thereof. Between each adjacent pair of rows of openings there extends a water passage 154 which communicates with the water passages 154. The bars also receive heat radiated from the primary bed and this heat also is transferred to water within the passages 154.

Each opening 155 tapers downwardly to a fairly small orifice 156 in the lower face of the plate. When the heater is brought into operation, particles are carried upwardly from the primary bed through the orifices 156 to form a secondary bed contained within the openings 155. When the heater is operating normally, the gas velocity through the orifices 156 is sufficient to prevent the particles of the secondary bed falling back to the primary bed. However, when the heater ceases to operate this would normally happen.

Referring now to FIGS. 6 and 7 of the accompanying drawings, the heater illustrated therein is suitable for radiating heat energy in all lateral directions, or in such selected lateral directions as may be required. The heater comprises a body 255 which may conveniently be formed as a metal casting, or as a moulding of a ceramic material, and is preferably formed in two parts, an upper part 256 and a lower part 257, the lower body part 257 is similar to, and may be identical with the lower body part 14 described with reference to FIG. 1. The upper body part 256 is formed with a central circular opening in which there is fitted a pervious support 258 for a bed of refractory particles 259 which lies on the support. Beneath the pervious support is a circular fan chamber 260 which communicates at its centre with a lower chamber 261 formed in the lower body part 257. This lower chamber is bounded laterally by a circular wall 262 in which there is a plurality of air inlet openings 263. Surrounding the lower chamber is an outer chamber 264 which is bounded by a peripheral wall 265 formed with further air inlet openings 266. The peripheral wall 265 may be square, when viewed in plan, or may be any other convenient shape.

A motor 267 is mounted in the lower chamber 261 and is drivenly connected with the rotor 268 of a fan disposed within the fan chamber. When the motor is energised, air is drawn into the heater through the openings 266 into the outer chamber 264, thence through the openings 263 into the lower chamber 261 and approaches the rotor 268 near to the axis thereof. Air is discharged from the periphery of the rotor along a passage 269 to the underside of the support 258.

In order to reduce the emission of noise from the heater, one or more baffles 270 is disposed within the outer chamber 264. Furthermore, this outer chamber is packed with fibrous or other material adapted to absorb sound.

Air control means is provided for controlling the rate of flow of air into the heater. Such air control means comprises a fixed ring 271 which encircles the wall 262 of the lower chamber, this ring having apertures aligned with the air inlet openings 263. A movable ring 272 is fitted around the ring 271, this movable ring also being formed with apertures which can be aligned either completely or partially with the apertures in the ring 271 to control the air flow. The apertures in the ring 272 can also be moved out of alignment with those in the ring 271 to shut off the air supply. The movable ring 272 is provided with an operating handle 273 which projects to the outside of the body 255. The handle extends through slots formed in the peripheral wall 265 and the baffle 270, which slots have a length such that the required degree of rotational movement can be imparted to the movable ring 272.

For mixing a gaseous fuel with air supplied to the bed of particles 259, there is provided a gas delivery means which includes a ring of pipe 274 formed with a large number of apertures spaced apart around the ring. This ring is fitted in an upper part of the lower chamber 261 immediately surrounding the opening through which this chamber communicates with the fan chamber 260. Gaseous fuel is delivered to the ring 274 through a pipe 275 and fuel which emerges from the ring 274 mixes
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with air passing to the fan 268. Further mixing is caused by the fan so that a substantially homogeneous mixture of fuel and air is delivered to the pervious support 258.

A manually-operable fuel control valve 276 is provided for controlling flow of fuel through the delivery pipe 275, and a solenoid-operated valve (not shown) is provided also for controlling flow of fuel through the delivery pipe, this solenoid-operated valve being electrically-connected with the supply circuit to the motor 267 so that gaseous fuel can be delivered to the ring 274 only when the motor is energised.

If required, an automatic control means as hereinbefore described may be provided to automatically provide a delay between energisation of the motor 267 and delivery of fuel to the ring 274.

The pervious support 258 is in the form of a plate of porous material which is supported on an annular flange 277 formed on the upper part 256 of the body. Preferably the support plate is formed of a ceramic material.

Above the support plate 258 and surrounding the bed of particles 259 is disposed a means for retaining these particles on the support. Such retaining means comprises a ring 278 of refractory material having an upper surface which is inclined upwardly and outwardly away from the bed.

The refractory ring 278 or, as shown in FIG. 6, a rim of the body 255 adjacent to this refractory ring may be the uppermost part of the heater and define a window 279 through which heat can be radiated from the bed out of the heater. The heater would be open so that the bed 259 is exposed to the environment of the heater. A suitable flue would be positioned above the heater to receive exhaust gases rising from the bed and convey same away from the room or the like in which the heater is positioned.

Alternatively, the heater may further include transparent walls which extend upwardly from the ring 278 to define a combustion chamber which communicates at its upper end with a flue. This alternative arrangement ensures that all exhaust gases pass into the flue, and prevents ambient air, which has not passed through the bed of particles 259, from passing up the flue.

In a further alternative arrangement, the space above the bed of particles 259 may be partially enclosed by an opaque wall. For example, the heater may be fitted within an existing fireplace which is open only at the front, heat then being radiated from the heater through the window opening 279 and through the open front of the fireplace. Alternatively, the front of the fireplace may be closed by a transparent wall or screen to reduce or prevent flow of ambient air into the flue.

If required, a secondary bed of refractory particles as described with reference to FIGS. 1 and 3 to 5 may be arranged in a flue associated with the heater illustrated in FIGS. 6 and 7. Such secondary bed would incorporate or be associated with a heat exchanger for extracting heat from the exhaust gases. Typically such heat would be transferred to water but heat may be transferred from the exhaust gases to air which is to be delivered into a room or the like to be heated.

Operation of the heater shown in FIGS. 6 and 7 is similar to that of the heaters shown in FIGS. 1 and 2. When the heater is started from cold, gaseous fuel and air is fed to the bed 259 at a rate such that the particles are just fluidised. The gaseous mixture is ignited above the bed by an electrical ignition device, or by applying a lighted match. The refractory particles absorb heat released by combustion of the fuel and the temperature of the bed rises rapidly. As the temperature of the bed rises, the gas flow rate within the bed increases and as the normal operating temperature is approached, the gas flow rate within the bed is sufficient to throw particles upwardly from the bed into the space above same. The effective cross-sectional area of the flow path available to the exhaust gases is considerably greater a short distance above the bed, than it is within the bed. Accordingly the speed of the exhaust gases falls as they rise from the bed and at a position somewhat above the region occupied by the bed when slumped, the gas speed is insufficient to carry particles upwardly against the influence of gravity.

Any particles which fall back onto the refractory ring 278 will slide or roll down the upwardly presented face thereof into the bed.

Circulation of refractory particles from the bed through the space above same provides the advantages of an attractive appearance when the bed is operating, and reduced flue gas temperature, since the particles temporarily above the bed extract heat from the exhaust gases, as explained with reference to the heaters shown in FIGS. 1 and 2.

The relatively low gas speed through the bed of particles 259, when the latter is cold, enables the bed to be brought to its normal operating temperature rapidly. This is further assisted by the presence of the refractory ring 278 which, being a poor conductor of heat and opaque to radiant heat energy, restricts loss of heat from the particles.

The depth of the primary bed of refractory particles in each of the heaters illustrated in FIGS. 1, 2, 6 and 7, is preferably not greater than 1 inch, and is typically approximately one-fourth inch. The refractory particles typically have average dimensions within the range 200 to 500 micron. The refractory particles may be silica sand. It has been found that a mixture of gaseous fuel and air supplied at a rate (measured at ambient temperature and pressure) of approximately 5 cubic feet per minute, can be burned completely in a bed having a diameter of 5% inches and a depth of approximately one-fourth inch. The pressure drop across the pervious support and the primary bed is of the order of 1 inch water gauge. Typically the gas flow rate within the bed is one-half foot per second when the bed is cold and 2 feet per second when the bed is hot.

In the heater shown in FIGS. 6 and 7, a reflector may be positioned above and to one side of the bed 259 to reflect heat radiated from the bed in the direction of the reflector back across the space above the bed and out of the heater at the opposite side thereof. It will be noted that, even when the bed is fluidised, the area of a surface forming the upper boundary of the bed is considerably greater than the area of the vertical, radially outwardly facing, surface of the bed.

The heater shown in FIGS. 6 and 7 can be operated below its maximum rate of fuel consumption and heat output. If the rate of delivery of fuel and air to the bed is reduced, the rate at which heat is released within the bed will be reduced. However, the extent to which particles circulate from the region occupied by the slumped bed to a higher region will be reduced and therefore the rate at which heat is radiated from the bed will be correspondingly reduced. The result is that, although the temperature of the bed may fall some-
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what, it does not fall below the minimum temperature at which combustion can take place. For example, the normal operating temperature of the bed may be between 800°C and 900°C. If the rate of delivery of fuel and air to the bed is reduced by one half, the temperature of the bed will fall by approximately 200°C only, the rate of radiation of heat being reduced by approximately one half, since the change in rate of radiation is approximately proportional to the forcepower of the change of change of bed temperature.

The invention may be applied to heaters other than radiant heaters and boilers. For example, bodies such as metal billets may be heated by placing them in a combustion chamber similar to that afforded by the heater described with reference to FIG. 1, but without a water jacket. The billet or other bodies would be placed in a position above but near to the primary bed, and during operation of the heater particles of which the bed is composed would be thrown up into contact with the billets or other bodies. It is also envisaged that the heater may include conveyor means for conveying bodies to be heated through the combustion chamber and over the upper surface of the bed.

Although the particular embodiments illustrated in the accompanying drawings are adapted to burn a gaseous fuel, other forms of fuel could be employed. For example, the heater may be adapted to burn a liquid fuel. Such liquid fuel could be vapourised and the vapor mixed with air before the latter is delivered to the bed. Alternatively, a liquid fuel could be injected directly into the bed, air alone being passed into the bed through the pervious support beneath same to establish fluidisation of the bed.

The heater illustrated in FIGS. 6 and 7 of the accompanying drawings could be operated with a solid fuel. Such fuel, preferably in powdered form, would be delivered to the bed by an automatic feed means whilst air is passed into the bed through the pervious support. The bed would be fluidised by the air passing therethrough, and the particles of solid fuel would float on or in the bed and burn in the air passing through the bed.

Although the heaters described herein by way of example are so arranged that the mixture of fuel and air can be ignited at a position above the bed, it would be possible to bring the heaters into operation by supplying heat to the bed some other manner. For example, during an initial stage air alone may be passed through the inlet means into the bed, such air being heated before reaching the inlet means by electrically energised heating elements or otherwise. When the temperature of the bed had risen above the minimum combustion temperature, the heating elements would be de-energised and the supply of fuel then commenced.

A further alternative arrangement which may be employed where the form of the support for the bed is such that a flame can pass therethrough into the bed, is that a mixture of fuel and air delivered at a low rate to the support may be ignited downstream thereof so that hot gases will pass through the bed and heat the latter. When the bed temperature has reached the minimum combustion temperature, the rate of delivery of fuel and air would be increased so that the flame is blown through the support into the bed.

In certain cases of the open radiant heater illustrated in FIGS. 6 and 7 in which the bed is formed of silica sand, it has been found that when the heater is operating normally some noise is emitted from the bed and thus the temperature of the latter is above a value in the region of 1,000°C. The emission of such noise may be objectionable where the heater is of open construction with the bed directly exposed to the environment.

We have found that if a quantity of different particles is added to the bed of silica sand, the bed can be operated at a somewhat lower temperature, for example, a temperature within the range 800°C to 1,000°C without the emission of an inconvenient volume of noise. We have found particulate limestone particularly effective in reducing the emission of noise from the bed when operating within this temperature range. Approximately equal quantities of silica sand and limestone may be incorporated in the bed, but we have found that if a small proportion only of the bed is limestone a considerable improvement is achieved. It will be appreciated that limestone present in the bed when the heater is operating will gradually decompose to calcium oxide, but that during periods when the heater is not operating the calcium oxide will react with water vapour and carbon dioxide present in the atmosphere to reform calcium carbonate.

Although particles other than limestone may be added to the bed to reduce the amount of noise emitted therefrom, we prefer to incorporate limestone particles with the silica sand since limestone is readily available and inexpensive, and also because the limestone has the ability to retain any sulphur present in the fuel and thus prevent or reduce the emission of oxides of sulphur to the atmosphere with the exhaust gases. Thus limestone may be incorporated in the bed of a heater in order to reduce the emission of oxides of sulphur, irrespective of whether the limestone is required also to reduce the emission of noise.

A further advantage of heaters in accordance with the present invention concerns the emission of oxides of nitrogen with the exhaust gases to the atmosphere. In many known forms of fuel-burning apparatus, combustion of the fuel is carried out in such a manner that temperatures of the order of 2,000°C or even higher are attained. Under such high temperature conditions, oxides of nitrogen are formed with the result that the exhaust gases emitted to the atmosphere include a small proportion of oxides of nitrogen, unless the exhaust gases are treated by special treatment to remove these compounds. A heater according to the present invention can, and normally is, operated with the bed at a temperature within the range 800°C to 1,050°C so that combustion also takes place within this temperature range. Under these conditions the production of oxides of nitrogen is at least considerably reduced, and possibly eliminated.

Although the depth of the primary bed in each of the embodiments illustrated is preferably not greater than 1 inch, greater depths may be employed. Preferably the depth of the bed is not more than one half the width of the bed. Thus in the case of a bed 6 inches in diameter the depth may be up to 3 inches. In the case of larger beds, depths of up to 6 inches are contemplated.

We claim:

1. A fuel burning heater comprising a bed of refractory particles having a depth, when slumped, which is not greater than 6 inches, a pervious support underlying the bed, and feed means for feeding fuel and air into the bed, at least the air through the support, whereby the bed can be fluidised and the fuel burned therein.
2. A heater as claimed in claim 1 further comprising a heat exchanger structure including a thermally-conductive wall which defines, at least in part, a combustion chamber, the depth of the slumped bed being less than one half the depth of said combustion chamber, and said bed being disposed at the bottom of the chamber, whereby particles thrown upwardly from the bed can impinge on said wall and fall back gravitationally to the bed.

3. A heater as claimed in claim 2 wherein said wall of the heat exchanger structure includes fins which project into the combustion chamber, at least a part of each fin lying vertically above the bed.

4. A heater as claimed in claim 3 wherein said heat exchanger structure is arranged to define a water passage and this water passage extends into said fins.

5. A heater as claimed in claim 1 further comprising means defining a window for permitting radiant heat energy to be emitted from the heater.

6. A fuel-burning heater as claimed in claim 1 comprising a wall structure defining a combustion chamber wherein said bed is disposed at the bottom the combustion chamber, and said wall structure includes a portion formed of a material which transmits radiation in the visible and infra-red regions of the electro-magnetic spectrum, whereby light and radiant heat energy can be emitted from the heater.

7. A heater as claimed in claim 1 wherein said feed means includes control means for adjusting the rate at which fuel and air are fed to the bed, whereby the heater can be operated selectively with circulation of a proportion of said refractory particles through a space above the bed, and without such circulation.

8. A heater as claimed in claim 1 comprising a further pervious support disposed above said first-mentioned bed for supporting a secondary bed, and outlet means defining an outlet from the heater, which outlet means is arranged for permitting only gases which pass through the further support to leave the heater.

9. A heater as claimed in claim 8 wherein said further support is formed with a water passage.

10. A heater as claimed in claim 1 further comprising an electrically-energisable ignition means situated above said bed and having a maximum heat output which is insufficient to heat the bed significantly.

11. A heater as claimed in claim 1 wherein said bed has an upper surface and a peripheral surface, and said upper surface has a greater area than has said peripheral surface.

12. A heater as claimed in claim 1 wherein the depth of said bed, when in a slumped condition, is not greater than 1 inch.

13. A method of operating a heater comprising the steps of providing a bed of refractory particles having a depth when slumped not greater than 6 inches; providing pervious support underlying the bed; feeding air and fuel into the bed and at least the air through the support so that the fuel is burned in the bed at a rate such that the bed is fluidised and refractory particles are thrown upwardly from the bed and permitted to fall gravitationally back to the bed.

14. The method as claimed in claim 13, comprising starting the heater from cold by feeding air and fuel to the bed at a predetermined rate which is sufficient to fluidise the bed when the latter is cold; burning the fuel in the vicinity of the bed to heat the refractory particles; and when the bed is hot, continuing the supply of air and fuel at the same rate, with this being sufficient when the bed is hot to cause particles to be thrown upwardly from the bed.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION


Inventor(s) Douglas Ernest Elliott

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

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British No. 13869/71 filed May 8, 1971

Signed and Sealed this second Day of March 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks