HEAT RECOVERY METHOD AND APPARATUS

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ABSTRACT

A hot water heater or similar heating device includes equipment for pre-cooling hot flue gas while preheating water for the water heater. It further includes a heat and mass exchanger for transferring heat and water from the pre-cooled flue gas to combustion air for the hot water heater. The pre-cooler may comprise a separate device or may be incorporated as part of a condensing water heater. The heat and mass exchanger may use membranes having condensing sides and evaporating sides, which allow water to pass from the condensing sides to the evaporating sides. It may further comprise troughs for wetting the membranes.
Figure 3A (Prior Art)

Figure 3B (Prior Art)
HEAT RECOVERY METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

[0001] Field of the Invention

[0002] The present invention relates to methods and apparatus for improving the efficiency of systems such as gas hot water heaters by a process of humid flue gas heat recovery.

[0003] Discussion of Related Art

[0004] Most industrial processes use large quantities of fuel and electricity that ultimately produce heat, much of which is wasted either to the atmosphere or to water. A variety of methods and equipment have been developed to reuse some of this waste heat. This may save up to approximately 20 percent of a facility’s annual fuel bill and, in some instances, reduce pollution emissions and plant maintenance. However, in other applications it may increase pollutants (e.g., preheating combustion air increases combustion temperatures which can increase NOx) and maintenance.

[0005] Waste heat’s usefulness is determined by its temperature; the higher the temperature the higher the quality or value. Most waste-heat-recovery devices transfer heat from a high-temperature effluent stream to a lower-temperature input stream. This can either increase the temperature of the input stream, or change the input stream from a liquid to a vapor, as in a water heater or boiler. All these devices can be broadly categorized as heat exchangers.

[0006] Heat recovery equipment must take into account temperature, pressure ranges, corrosiveness of the effluent and input streams, presence of materials that could foul the heat exchange surfaces, and thermal cycling. Extreme values of any of these may dictate the use of special materials and design, resulting in high implementation costs. In addition, the waste-heat source and the site for use of the recovered heat should be reasonably close.

[0007] In a process that requires heat as input, using waste heat can displace fuel or electricity that would otherwise have to be purchased. Of course, the waste heat recovered has to account for enough fuel savings to make up for capital and operational costs of the heat-recovery equipment.

[0008] In actual industrial facilities several processes may exist that could use the waste heat. The higher the temperatures of the waste heat the more potential gain that would be available.

[0009] This list identifies process input and output characteristics that can help give a relative sense of possible energy savings from waste-heat recovery.

[0010] The greater the temperature, flow rate and moisture content, the greater the quantity of heat in the stream.

[0011] The proximity of waste-heat to possible processes that could use this heat influences total energy savings, due to heat loss in fluid transit from the source, and the energy required to move the fluid.

[0012] Latent heat from the condensation of moisture in exhaust gas can be significant; however condensation is often undesirable due to low condensing temperatures and the potential for corrosion down-stream of the heat-recovery device.

[0013] Waste-heat recovery can save up to 20% of the energy costs in industrial facilities, as noted earlier. Most of the energy savings will affect fuel consumption, however, electrical heating of ancillary equipment may also be affected.

[0014] Most gas or oil water heaters on the market today are simply a hot water storage tank, cold water in, hot water out, insulated tank, combuster, a gas or oil regulator valve and a center flue gas to hot water heat exchanger tube using natural buoyancy of hot flue gas. See, for example, FIG. 3A (prior art). Because the exhaust gases can still be hot when leaving the system there are known several patents that add ambient air to the flue gas to cool down the flue gas requiring a blower and additional ducting: see U.S. Pat. Nos. 5,697,330 and 7,159,540.

[0015] To increase efficiency, a blower can also be added to overcome any pressure drop created by an internal baffle in the heat exchanger tube, see U.S. Pat. No. 7,032,543.

[0016] There is at least one known flue gas treatment that removes carbon monoxide with the use of a catalyst converter, see U.S. Pat. No. 7,055,465.

[0017] U.S. Pat. No. 4,175,518 describes a water heating system with a preheater which utilizes hot flue gases to preheat not only incoming cold water, but also for recirculating and preheating water from the storage tank of the system. Preheaters for hot water heating systems are not new. It has been suggested many times in the past that hot flue gases may be used in order to preheat incoming water for a hot water tank.

[0018] Today a popular water heater on the market is the Condensing Water Heater, (CWH). See, for example, FIG. 3B (prior art). The drawback to the CWH is that often hot water use is sporadic so that small amounts of cold water are brought in and the burners are on for a much longer time than the water coming in. This means there is often little to no incoming water to preheat the hot exhaust gas and thus little efficiency gain. These condensing water heaters apparatus and methods are well known for adding additional heat exchange with cold water entering or in the tank cooling the flue gases to below their dew point temperature causing water to condense out (see U.S. Pat. Nos. 4,541,410 and 4,651,714).

[0019] The water heaters of the conventional type described above often lose less than ideal levels of combustion efficiency and undesirably high levels of emitted pollutants such as Nitrogen Oxide and Carbon Monoxide.

SUMMARY OF THE INVENTION

[0020] The present invention improves the thermal efficiency of a water heater (or similar heating equipment) when the equipment is in operation, and not just when cold water is available to cool flue gases. Providing high efficiency is accomplished by reducing the flue gas temperature below its dew point temperature or lowering its enthalpy to near the outdoor air temperature enthalpy whenever in operation. This is accomplished by a second stage Heat and Mass Exchanger (HMX) that heats and humidifies input combustion air while cooling and condensing flue gas. A first stage heat exchanger or condensing hot water heater initiates the flue gas cooling and/or condensing process. The condensing starts at a much higher temperature than previous water heaters due to the added humidity in the combustion air and thus a higher dew point temperature of the flue gas.

[0021] The present invention lowers the Nitrogen Oxide and Carbon Monoxide of the combustion process by increasing the absolute humidity of the combustion air.
Nitrogen Oxide and Carbon Monoxide becomes a side benefit of the high humidity created to lower flue gas enthalpy. 0022 The present invention further transports water from the HMX condensing channels through membranes to the evaporative channels directly. This provides an efficient means to transfer heat and transfer water from the condensing side to the evaporation side with little or no water makeup needed.

0023 The invention delivers the desired amount of water at any time through the unique design of a trough.

0024 The present invention provides an improved heat recovery process and apparatus for transferring "waste" heat from the exhaust gases for a water heater, boiler, furnace, or other heating equipment, where the waste heat is used to heat or preheat water, air or some other substance that is needed (such as water in a water heater) and to heat and humidify the air supplied to a combustion chamber, through the use of flue gas latent heat.

0025 The heat recovery method of the invention makes use of pre-cooling and a heat and mass exchanger that create the following advantages:

0026 1. High Efficiency all the time, rather than just when a large amount of hot water is being used;

0027 2. Raised condensing temperature, which results in higher temperature condensing waste heat to heat with;

0028 3. Less pollution due to moisture in combustion;

0029 4. Higher efficiency heat and mass transfer in the HMX;

0030 5. Trough reservoir that delivers correct amount of water all the time;

0031 6. Better burning;

0032 7. Can be located outside water heater, which allows retrofitting.

0033 The present invention provides heat recovery apparatus comprising a counter flow heat and mass exchanger (HMX) for a water heater, boiler, furnace, and other heating equipment.

0034 The HMX apparatus was specifically designed to be an efficient cooler for the flue gas, and simultaneously to saturate the input combustion air before this air enters the combustion apparatus. In addition and because of the higher efficiency through the HMX, pollution is dramatically reduced due to the high levels of water vapor creating a more even burning process during combustion. Additional water will not be needed, because the proposed heat recovery process and apparatus constantly claims water condensed in the flue gas.

0035 Drain water can come from two sources: water condensed from the flue gas in the water heater or heat exchanger by heating or preheating water, and condensed water from the flue gas in HMX (minus what is evaporated by the combustion in the heat and mass exchanger). At higher outdoor air temperatures the HMX may produce more evaporation than condensing, creating a need for water to be added.

0036 The HMX has counter flowing evaporation and condensing channels on opposite sides of a heat exchange membrane, which:

1) allows heat transfer through the voids in the membrane filled with water, due to the thin polymer wick construction (or other suitable materials), but minimizes heat transfer laterally along the plate;

2) allows mass (water) transfer from condensing channels to evaporative channels through the membrane, due to the membranes structure or ability to hold water by capillarity of membrane construction.

0037 The membrane also has perforations between the condensing side of the membrane and the evaporative side or the membrane in defined areas, providing water flow from the condensing channels to the evaporative channels in which indirect evaporative cooling takes place. This direct transfer of water from the condensation side to the evaporation side reduces the heat and mass transfer resistance. Along the plate the hot flue gas temperature is transferring both sensible and latent heat and condensing in direct contact with water evaporating and heating combustion air. This makes for very efficient heat and mass transfer as condensing on one side of the membrane and evaporation directly on the opposite on the other side of the membrane results in more direct transfer of sensible and latent heat.

0038 This system works by continuous cycling of water by, evaporating it into the combustion air stream while condensing it from the flue gas. This cycling of water is kind of like a heat pipe that evaporates and condenses a refrigerant. In both cases energy is transferred from one source to another through evaporation and condensing.

0039 The HMX provides an indirect evaporative cooler having efficient wicking action via a trough, allowing easy wetting of the surface area of the wet channels without excess water (which would cool the water rather than the air).

0040 There are a couple ways to increase the efficiency of a gas hot water heater. High efficient hot water heaters on the market today gain their efficiency by preheating the cold water going into the water heater with the exhaust gas leaving the water heater. When exhaust or now flue gas is cooled to a low enough temperature water vapor from burning the fuel, (oxidizing or combining the \( \text{H} \) with \( \text{O}_2 \), to get \( \text{H}_2\text{O} \)), partially condenses adding a significant amount of heat to the cold water coming in. Therefore even the latent heat (condensing water vapor), is used to heat the water. Condensing water vapor adds a significant amount of heat to the system considering that it takes 1 Btu to cool one pound of water \( 1^\circ \text{F} \). and 1040 Btu to condense that same one pound of water vapor. Adding the latent heat has a significant effect on the thermal efficiency. This is all built into the internal design of water heaters according to the present invention.

0041 The present invention significantly raises the dew point temperature of the flue gas making it possible to at a minimum preheat the hot water and in many cases heat the hot water to its high temperature. The proposed high efficiency heat recovery method starts the moment the hot exhaust gases pass through the counter flow heat and mass exchanger (HMX). It is not dependent on cold water that may be short-lived or not present, such as when bringing the water heater up to temperature without any cold water being added.

0042 Within the HMX low temperature flue gas has its energy transferred to the combustion air through temperature and humidity exchange. The flue gas temperature is cooled to below its dew point temperature or more importantly lowering its enthalpy to near the input combustion air temperature enthalpy whenever it is in operation.

0043 Raising the combustion air temperature requires less heating of the air fuel mixture, and is therefore more efficient. What is more surprising is that adding humidity to the combustion air will also reduce the fuel needed. The
added humidity increases the mass flow of the input combustion air at a higher temperature requiring less fuel to heat the hot water.

[0044] Water vapor has other positive effects. For example, it comprises polyatomic molecules (three atoms H₂O as opposed to two atoms like O₂ or N₂), that can radiate and be radiated to. This ability to radiate reduces hot spots in the burning process giving more complete burning with about half the amount of NOx, an endothermic or energy draining reaction. This is similar to but better than an automobile engine that uses a small amount of Exhaust Gas Recirculation or CO₂ plus H₂O recirculation to lower its NOx. The higher efficient burning at lower temperatures also decreases the carbon monoxide in the same way as reducing NOx.

[0045] The present heat recovery method and apparatus can also include implementing the Maisotsenko Cycle or M-Cycle (see paper: L. Gillan, “Maisotsenko cycle for cooling process”, Clean Air, 9 (2008) 1-18), which is also suited for the HMX, especially in the winter time, when the dew point temperature is low. This more thermally efficient process cools the input combustion air near its dew point in the working air dry channels, and humidifies working air in its wet channels. This is in preparation for cooling and condensing water from the combustion exhaust gas and further heating and humidifying the input air that is now combustion air.

[0046] The air psychrometric saturation line slopes such that cool air has a greater change in energy for a given humidity ratio change than at higher temperatures. This means that in a Humid Air Recovery (HAR) HMX there will be more condensation than evaporation, producing distilled water. The design of this HAR HMX takes into account the higher rate of condensation from the combustion exhaust gas than the water evaporated by allowing condensate to pass directly through the plate.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0047] FIG. 1 is a block diagram illustrating a preferred embodiment of an HMX Humid Air Recovery (HAR) system for a gas hot water heater according to the present invention.

[0048] FIG. 2A is a schematic diagram of a preferred embodiment of a HAR system, using a membrane.

[0049] FIG. 2B is a schematic diagram of the embodiment of FIG. 2A, showing water held by the membrane.

[0050] FIG. 3A (prior art) is a schematic diagram showing a conventional non-condensing water heater

[0051] FIG. 3B (prior art) is a schematic diagram showing a conventional Condensing Water Heater (CWH)

[0052] FIG. 3C is a schematic diagram showing a hot water heater similar to that of FIG. 3B, but with an HMX HAR system according to the present invention.

[0053] FIG. 4 is an isometric diagram showing a preferred embodiment of an HAR system utilizing a counterflow HMX and troughs to provide water.

[0054] FIG. 5 is an isometric drawing showing the bottom of a trough of FIG. 4 coated with an impervious coating.

[0055] FIG. 6 is an isometric drawing showing a stack of the troughs of FIGS. 4 and 5 with overflow perforations.

[0056] FIG. 7 is an isometric diagram of an HAR system utilizing a counterflow HMX and troughs, utilizing an end cap for the trough stack.

[0057] FIG. 8 is a schematic diagram showing a counterflow HMX according to the present invention.

[0058] FIG. 9 is a schematic diagram showing an HMX according to the present invention, wherein input combustion airfirst travels along dry sides of membranes.

[0059] FIG. 10 is a schematic diagram of an HMX similar to FIG. 9, with the input combustion air eventually split into two streams and turned to travel counterflow.

[0060] FIG. 11 is a schematic block diagram of a system for providing a combustor with saturated combustion air according to the present invention.

**DETAILED DESCRIPTION OF THE INVENTION**

Reference Number List

[0061] 1. 301 Input Combustion Air
[0062] 2. 302 Saturated Combustion Air
[0063] 3. 303 Combustor
[0064] 4. 304 Hot Flue Gas
[0065] 5. 305 Precooled (Warm) Flue Gas
[0066] 6. 306 Flue Gas Out (Cool)
[0067] 7. 307 Heat and Mass Exchanger HMX
[0068] 8. 308 Pre-cooler
[0069] 9 Water Heater
[0070] 10. Pump
[0071] 11. Cold Water In
[0072] 12. Cooling Water
[0073] 13. Heated Water
[0075] 15. Cool Water to Tank
[0076] 16. Liquid (Condensate)
[0077] 17. Drain Water
[0078] 18. Trough
[0079] 19. Membrane (Plates)
[0080] 20. Fan
[0081] 22. Heat
[0082] 23. Evaporated Water
[0083] 24. Membrane Water
[0084] 25. Trough End Cap
[0085] 26. Dry (condensing) Side of Membrane
[0086] 27. Trough Overflow Perforations
[0087] 28. Channel Guide
[0088] 29. Impervious Coating
[0089] 30. Wet (evaporating) Side of Membrane
[0090] 32. Condensing Water Heater
[0091] 34. HMX Humid Air Recovery System
[0092] 35. Flue Gas Coil
[0093] 36. Tank Water
[0094] 37. Flue Gas Channels
[0095] 38. Combustion Air Channels
[0096] 39. Tank of Hot Water Heater
[0097] 40. Non-condensing Water Heater
[0098] 41. End Element
[0099] 42. Fuel
[0100] 300 Combustor System
[0101] FIG. 1 is a block diagram illustrating a preferred embodiment 34A of a Humid Air Recovery (HAR) water heater system, including a Heat and Mass Exchanger (HMX) 7 and a Pre-cooler 8 (in this case a pre-condenser) for a gas Hot Water Heater 9 according to the present invention. FIGS. 2A and 2B illustrate the process.

[0102] In a preferred embodiment of HAR HMX system 34, Input Combustion Air 1 is forced into Heat and Mass Exchanger (HMX) 7 by Fan 20, where it is heated and saturated with Water 24 becoming Saturated Combustion Air 2. Water 24 is heated by Precoooled Flue Gas 5. The water may...
comprise Condensate 16 and/or an independent source of water such as shown in FIGS. 4-7.

**[0103]** Saturated Combustion Air 2 then enters Combustor 3 where it is combusted with Fuel 42 and used to heat Cool Water 15 within Tank 39 of Water Heater 9. The somewhat cooler Hot Flue Gas 4 then enters Pre-cooler 8 where it is cooled to below its dew point temperature by Cooling Water 12 (generally comprising Cold Water 11 and/or Cool Water 15), and becomes Precooled Flue Gas 5 (aka warm flue gas). Thus, Hot Flue Gas 4 preheats Cold Water 11 or heats Cool Water 15, and is itself cooled to become Precooled Flue Gas 5. Water condenses from Hot Flue Gas 4 and becomes Condensate 16. Precooled Flue Gas 5 and Condensate 16, (if the flue gas is cooled below its dew point temperature), are provided to HMX 7. Because Cool Water 11 may not be flowing at all times when Water Heater 9 is calling for heat, Pump 10 may be provided to pull Cold Water 11 or Cool Water 15 into Pre-cooler 8 (as Cooling Water 12). Cooling Water 12 is warmed within Pre-cooler 8 and returns to Tank 39 as Heated Water 13.

**[0104]** Precooled Flue Gas 5 is further cooled in HMX 7 causing additional condensation (not shown). Condensate 16 may drain to Trough 18 (See FIGS. 4-7) in HMX 7 ensuring an adequate water supply when outdoor weather conditions are hot and dry. Excess water from Trough 18 becomes Drain Water 17 that is drained from the system.

**[0105]** In a typical non-condensing water heater, FIG. 3A (prior art), Cold Water 11 into Water Heater 9 is delivered through a Tube 31 where it starts to mix in Water Heater 9 Tank 39 becoming Cool Water 15. Input Combustion Air 1 enters the bottom of the Water Heater 9 where it enters Combustor 3. The exhaust Flue Gas 4 passes through Water Heater 9, heating the water and leaving. Hot Water 14 leaves the tank for use.

**[0106]** In a typical Condensing Water Heater 32, FIG. 3B, (there are many varieties), Input Combustion Air 1 is directed into Combustor 3 through an induced draft Fan 20 that pulls Hot Flue Gas 4 to the top of Flue Gas Coils 35. Water 36 is heated, cooling the flue gas below its dew point temperature creating Condensate 17 that is collected and drained from the system.

**[0107]** A Condensing Water Heater 32 can replace Pre-cooler 8 in FIG. 2, such that the systems needs only HMX 7 as shown in HMX Humid Air Recovery 34B in FIG. 3C. This eliminates the need for Pump 10.

**[0108]** FIG. 2A is a schematic diagram of a preferred embodiment of Humid Air Recovery, using a Membrane 19. Hot Flue Gas 5 provides Heat 22 in the form of higher temperature and condensate to Membrane 19 becoming Flue Gas Out 6. Evaporated Water 23 is taken up by Input Combustion Air 1 becoming Saturated Combustion Air 2. FIG. 2B is a schematic diagram of the embodiment of FIG. 2A, showing Water 24 held by Membrane 19 which is evaporated by Heat 22 to become Evaporated Water 23 into Input Combustion Air 1 becoming Saturated Combustion Air 2. Water 24 may also be wicked onto the surface of Membrane 19 facing Input Combustion Air 1 (the wet side of membrane 19).

**[0109]** FIG. 3A (prior art) is a schematic diagram showing a conventional Non-condensing Water Heater 44. FIG. 3B (prior art) is a schematic diagram showing a conventional Condensing Water Heater (CWH) 32. Fuel in 42 is not shown.

**[0110]** In a typical Non-condensing Water Heater 40 or CWH 32, the condensing temperature of Hot Flue Gas 4 would be about 131°F. This is based on the amount of water created by the oxidation of the hydrogen. This temperature is so low that it can only be used to somewhat preheat Cold Water 11 entering Water Heater 9 but typically not sufficiently heat Cool Water 15 within Tank 39. Non-condensing Water Heater 40 uses about 70% of the heat from Hot Flue Gas 4, as it passes straight up the center of Tank 39.

**[0111]** CWH 32 does well when Cold Water 11 is entering Tank 39, as Hot Flue Gas 4 takes a circulatory path 35 within Tank 39. The efficiency of CWH 32 quickly drops off to about 80% efficiency or less when Cold Water 11 is not entering Tank 39.

**[0112]** FIG. 3C is a schematic diagram showing a Hot Water Heater 9 similar to that of FIG. 3B, but with an HMX HAR system according to the present invention. FIG. 3C shows the advantages of the present invention. When humidity is added to Input Combustion Air 1 in HMX 7, Saturated Combustion Air 2 is formed. The Hot Flue Gas 4 dew point temperature rises to about 160°F. This temperature is typically hot enough to either heat or preheat Cool Water 15. Hot Water Out 14 of Water Heater 9 is often only set about 130°F so that it will not be too hot and cause burns at the water faucets. This allows the 160°F condensing flue gas to sufficiently heat the water. In addition, because the water is causing Hot Flue Gas 4 to condense, the latent heat of vaporization can heat a significant amount of water to a much higher temperature.

**[0113]** In order to better understand this Humid Air Recovery method, Table 1 has four mathematical simulations: run1 a typical Water Heater 9; run2 using only the HMX 7; run3 using a Pre-Cooler, (no condensing) with an HMX 7; and run4 using a Pre-cooler 8 with an HMX 7.

### Table 1

<table>
<thead>
<tr>
<th>Part 1</th>
<th>Combustion Air</th>
<th>Outdoor Air In</th>
<th>Gas Burned</th>
<th>Dry Air</th>
<th>Humidity Out of HMX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Run 1,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mass , lb/min</td>
<td>Firing Rate, btu/hr</td>
<td>Temp Dry Bulb, F.</td>
</tr>
<tr>
<td>Water Heater Only</td>
<td>1</td>
<td>0.00869</td>
<td>110, 523</td>
<td>68</td>
<td>0.0080</td>
</tr>
<tr>
<td>TABLE 1-continued</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HMX Only</th>
<th>2</th>
<th>0.0869</th>
<th>110,523</th>
<th>68</th>
<th>0.0080</th>
<th>25.05</th>
<th>1.63</th>
<th>150</th>
<th>0.2110</th>
<th>273.92</th>
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<tbody>
<tr>
<td>PreCool/HMX</td>
<td>3</td>
<td>0.0869</td>
<td>110,523</td>
<td>68</td>
<td>0.0080</td>
<td>25.05</td>
<td>1.63</td>
<td>150</td>
<td>0.2110</td>
<td>273.92</td>
</tr>
<tr>
<td>PreCond/HMX</td>
<td>4</td>
<td>0.0869</td>
<td>110,523</td>
<td>68</td>
<td>0.0080</td>
<td>25.05</td>
<td>1.63</td>
<td>150</td>
<td>0.2110</td>
<td>273.92</td>
</tr>
</tbody>
</table>

**Part 2**

**Flue Gas Pre-Condenser**

<table>
<thead>
<tr>
<th>Run</th>
<th>Cond Temp, F.</th>
<th>4, Temp, F.</th>
<th>Gas Rate, lb/hr</th>
<th>Enthalpy, Btu/lb</th>
<th>5, Temp Out, F.</th>
<th>Enthalpy, Btu/lb</th>
<th>Water Preheated In Pre-Condenser</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>131.7</td>
<td>400</td>
<td>0.1170</td>
<td>240.91</td>
<td>400</td>
<td>240.91</td>
<td>135</td>
</tr>
<tr>
<td>2</td>
<td>163.2</td>
<td>400</td>
<td>0.3315</td>
<td>506.59</td>
<td>400</td>
<td>506.59</td>
<td>135</td>
</tr>
<tr>
<td>3</td>
<td>163.2</td>
<td>400</td>
<td>0.3315</td>
<td>506.59</td>
<td>164</td>
<td>415.21</td>
<td>135</td>
</tr>
<tr>
<td>4</td>
<td>163.2</td>
<td>400</td>
<td>0.3315</td>
<td>506.59</td>
<td>158</td>
<td>350.89</td>
<td>135</td>
</tr>
</tbody>
</table>

**Part 3**

**Flue Gas HMX**

<table>
<thead>
<tr>
<th>Run</th>
<th>6, Temp, F.</th>
<th>Humidity Ratio, lb/lb</th>
<th>Enthalpy, Btu/lb</th>
<th>Air Exhaust, lb/min</th>
<th>Drained, lb/min</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400.0</td>
<td>0.1170</td>
<td>240.91</td>
<td>0.188</td>
<td>0.00</td>
<td>82,0%</td>
</tr>
<tr>
<td>2</td>
<td>146.1</td>
<td>0.1856</td>
<td>244.03</td>
<td>0.188</td>
<td>0.23</td>
<td>81,7%</td>
</tr>
<tr>
<td>3</td>
<td>129.2</td>
<td>0.1082</td>
<td>152.06</td>
<td>0.1679</td>
<td>0.35</td>
<td>89,5%</td>
</tr>
<tr>
<td>4</td>
<td>107.4</td>
<td>0.0545</td>
<td>86.17</td>
<td>0.168</td>
<td>0.43</td>
<td>95,0%</td>
</tr>
</tbody>
</table>

In Water Heater only, run1, the flue gas is cooled only in Water Heater 9 and exits the system at about 400° F. See FIG. 3A for a typical configuration. The condensing temperature of the flue gas is about 131° F. This results in an efficiency of about 82%. High for a Non-condensing Water Heater 40, and typically would require Cold Water 11 entering the Tank 39.

In run2 with the HMX only, (not shown but for the case where an HMX is connected to a Non-condensing Water Heater 40) more water is evaporated than condensed because of the cooling of the Hot Flue Gas 4 down from 400° F. and condensing starts at about 160° F. As with all heat exchangers the energy removed on one side must equal the energy gain on the other. On the cooling side the Input Combustion air 1 will be heated but most of the heat gain will be through evaporation of water while becoming Saturated Combustion Air 2. In this run more water is evaporated into the combustion air stream than can be condensed from the flue gas due to desuperheat of the Flue Gas 5. Nothing is gained as far as efficiency is concerned as the flue gas enthalpy leaving the system is about the same as run1, lower temperature but saturated. Over all the efficiency is about the same as run1 or maybe a little less, 82%. What is needed in this embodiment is cooling of Hot Flue Gas 4 before the HMX 7, or putting flue gas heat to use such as for heating the water in the Water Heater 9 or Cold Water In 11.

Run 4 demonstrates that when Pre-cooler 8 cools Flue Gas 5 to just above its condensing temperature the maximum efficiency is limited to about 90%. In run 4 the Hot Flue Gas 4 is pre-condensed in Pre-cooler 8 to about 158° F. This results in an efficiency of about 95%. As mentioned earlier the water can now be heated at much higher temperature with the flue gas at 158° F. rather than 131° F. This is the configuration of FIG. 1 or FIG. 3C.

As can be imagined, this heat recovery method can be used on other devices such as furnaces, boilers, and other applications that have either an internal need for a heat above 140° F., to heat water in the hot water heater case shown, or to heat another fluid. FIG. 11 illustrates a more general system.

HMX 7 can be as simple as a heat and mass exchanger that is able to have condensing on one side of the plate and evaporation on the other. Of course on the evaporation side there must be a means to distribute water from the condensing side or from another source across the plate (e.g., wicking, spraying, gravity delivery, etc.) On the condensing side there must be a means to collect the water and either deliver it to the evaporation side or drain it away.

One preferred HMX method was shown in FIG. 2A where Membrane 19 separates Pre-cooler Flue Gas 5 from Combustion Air 1. Water, e.g. Condensate 16, passes through Membrane 19 to the Combustion Air side 30 and Evaporated Water 23 is added to Combustion Air 1. Membrane 19 is made
of a wick material that will hold Water 24, see FIG. 2B, with capillary action (like water absorbed in a towel). The water in the wick membrane separates the flue gas from the combustion air. In a preferred embodiment a stiff wicking material is used such as a polyester spunbond material that is flat bonded. This has several advantages, e.g. there is little heat resistance through Membrane 19, no pump is needed to move water from one side to the other, and the water condensing on the flue gas side becomes the water on the evaporating side. In this way no heat or mass transfer is lost in gathering water, pumping water to the other side and evaporating it.

FIG. 4 is an isometric diagram showing a preferred embodiment of a HAR system utilizing a counterflow HMX 7 with Troughs 18 to provide additional water as needed. In this embodiment, Membranes 19 are separated and supported by Channel Guides 28, which form channels 37, 38. Flue Gas Channels 37 direct Pre-condensed Flue Gas 5 on Condensing side 26. Combustion Air Channels 38 direct Input Combustion Air 1 on Evaporation Side 30 of each Membrane 19 in counterflow. Warm Pre-condensed Flue Gas 5 becomes cool Flue Gas Out 6. Input combustion Air 1 becomes Saturated Combustion Air 2.

Membranes 19 are attached to Troughs 18 having Trough Overflow Perforations 27 to drain excess water from one Membrane to the next Membrane down. Troughs 18 ensure that Membranes 19 are always wetted during startup and when it is hot and dry out, for example with added Condensate 16 from Pre-cooler 8. Trough 18 also can collect excess condensing Water 24 from Flue Gas 5 that is not evaporated into Input Combustion Air 1 as it is condensed on Membrane 19.

FIG. 5 is an isometric drawing showing the bottom of Trough 18 coated with an Impervious Coating 29 to prevent water from dripping through except via Trough Overflow Perforations 27.

FIG. 6 is an isometric drawing showing Trough Overflow Perforations 27 in a stack of Troughs 18. As each Trough 18 fills with water, the Trough Overflow Perforations 27 allow water to drain to the next Trough below. The bottom Trough will allow the water to drain from the system as Drain Water 17.

FIG. 7 is an isometric drawing showing an HMX system 7 configured with Trough End Caps 25 that prevent the water in Troughs 18 from flowing out the ends.

There are many heat and mass exchanger configurations that can be used. FIG. 8 is a schematic of a counterflow HMX. Input Combustion Air 1 passes along saturated Membranes 19 in Combustion Air Channels 38 becoming Saturated Combustion Air 2. It is heated by Pre-condensed Flue Gas 5 in Flue Gas Channels 37, and causing water to condense out as it passes along the opposite side of Membrane 19. Flue Gas 5 becomes Flue Gas Out 6.

Membrane 19 could be an impervious plate with other means to distribute the condensate water from one side of the plate to the other for evaporation.

To create lower temperatures it maybe desirable to use the M-Cycle wherein Input Combustion Air 1 first travels along Dry Sides 26 of Membranes 19 where it is cooled towards its dew point temperature, as shown in FIG. 9. It is then turned to travel counterflow across the Wet Sides 30 of Membranes 19 and becomes Saturated Combustion Air 2 as it picks up heat from both the Input Combustion Air 1 and the Pre-condensed Flue Gas 5 through Membrane 19.

Another schematic of an M-Cycle type of HMX which is useful in embodiments of the present invention is shown in FIG. 10. Input Combustion Air 1 first travels along Dry Sides 26 of Membranes 19 where it is cooled towards its dew point temperature as in the embodiment of FIG. 9. It is then split into two streams and turns to travel counterflow across the Wet Sides of Membranes 30 and becomes Saturated Combustion Air 2 as it picks up heat from both the Input Combustion Air 1 and the Pre-condensed Flue Gas 5.

Fig. 11 is a schematic block diagram of a system 300 for providing a Combustor 303 with Saturated Combustion air 2 according to the present invention. Combustor 303 generates Hot Flue Gas 4, which is cooled by Pre-cooler 8, generating Warm Flue Gas 5. Pre-cooler 8 utilizes a fluid 312 to accomplish precooling.

HMX 307 warms and humidifies atmospheric air 2 (with Warm Flue Gas 5 and Liquid 24) to produce saturated combustion air 2 for combustor 303. Cool Flue Gas 6 is generally vented into the atmosphere.

What is claimed is:
1. A heat recovery method comprising the steps of:
   a) providing a first heat and mass transfer membrane having a condensing side and an evaporating side;
   b) wetting the evaporating side of the heat transfer membrane with an evaporative liquid;
   c) passing hot humid gas along the condensing side of the heat transfer membrane;
   d) passing cool dry air along the evaporating side of the heat transfer membrane;
   e) blowing the gas along the condensing side of the membrane by evaporating the evaporative liquid into the gas passing along the evaporating side of the membrane and saturating the gas passing along the evaporating side of the heat transfer membrane and
   f) passing condensed evaporative fluid through the membrane from the condensing side to the evaporating side.
2. The method of claim 1 wherein the evaporative fluid is water.
3. The method of claim 1, further including the steps of:
   providing a plurality of heat and mass transfer membranes having condensing sides and evaporating sides, and placing the membranes adjacent to each other such that evaporating sides of membranes face each other and condensing sides of membranes face each other;
   applying steps (b)-(f) to the membranes;
   providing channels between the membranes to guide air flow.
4. The method of claim 3 wherein the evaporative fluid is water.
5. The method of claim 3, further including the steps of providing troughs for liquid at the edges of membranes and wicking liquid from the troughs to the evaporating side of the membranes.
6. The method of claim 5, further including the steps of providing overflow perforations through troughs and draining liquid through the perforations.
7. The method of claim 5, further including the step of collecting excess condensate water.
8. The method of claim 4 further including the steps of:
   providing a pre-cooler;
   passing hot flue gas from a hot water heater through the pre-cooler to provide hot humid gas for step (c);
   preheating water with the pre-cooler;
   providing the preheated water to the water heater;
providing the saturated gas from step (e) as combustion air for the water heater.

9. The method of claim 8 wherein the pre-cooler is a pre-condenser.

10. Apparatus for heat recovery comprising:
    a heat and mass exchanger including—
    a plurality of membranes having condensing sides and evaporating sides and placed in a stack with condensing sides facing condensing sides and evaporating sides facing evaporating sides, wherein the membranes allow evaporative liquid to pass through the membranes from condensing sides to evaporating sides;
    wetting apparatus for wetting evaporating sides of membranes with an evaporative liquid;
    condensing-side channels formed between adjacent condensing sides of membranes;
    evaporating-side channels formed between adjacent evaporating sides of membranes;
    a flue gas providing element for flowing hot humid gas through condensing-side channels and transferring heat to the membranes;
    a combustion air providing element for flowing cool dry gas through evaporating-side channels and cooling membranes, cooling flue gas, and saturating combustion gas;

11. The apparatus of claim 10 wherein the membranes include a wicking structure for spreading evaporation fluid over evaporating sides and a capillary transfer structure for passing evaporative fluid through the membranes.

12. The apparatus of claim 11, further comprising troughs at the edges of membranes for providing evaporative fluid to the wicking structures.

13. The apparatus of claim 12 wherein the troughs further include overflow perforations for allowing evaporative liquid to drain.

14. The apparatus of claim 11, further comprising:
    a pre-cooler having a exhaust-gas channel for cooling flue gas from a hot water heater and providing it to the flue gas providing element; and a water channel for preheating water and providing it to the hot water heater, and wherein combustion air from the HMX comprises combustion air for the hot water heater.

15. The apparatus of claim 14 wherein the pre-cooler is a pre-condenser.

16. A hot water heater comprising:
    a tank for water;
    a source of cold water for providing water to the tank;
    a combustor for heating the water in the tank, the combustor configured to intake combustion air and fuel and output hot flue gas;
    a pre-cooling mechanism for heating water and cooling hot flue gas to output pre-cooled flue gas; and
    a heat and mass exchanger including—
    a plurality of plates having condensing sides and evaporating sides and placed in a stack with condensing sides facing condensing sides and evaporating sides facing evaporating sides;
    wetting apparatus for wetting evaporating sides of plates with an evaporative liquid;
    condensing-side channels formed between adjacent condensing sides of plates;
    evaporating-side channels formed between adjacent evaporating sides of plates;
    an element for flowing pre-cooled flue gas from the pre-cooling mechanism through condensing-side channels and transferring heat through the plates to the evaporation side;
    an element for flowing air through evaporating-side channels, saturating the air flowing through evaporating-side channels and providing it as humid combustion air for the combustor.

17. The hot water heater of claim 16 wherein the pre-cooler is a pre-condenser.

18. A device for providing warm humid combustion air to a combustor comprising:
    a pre-cooler;
    a conduit for providing hot flue gas from the combustor to the pre-cooler;
    a conduit for providing a fluid to the pre-cooler;
    wherein the pre-cooler includes apparatus for cooling the hot flue gas with the fluid while warming the fluid and providing warm flue gas;
    a heat and mass exchanger (HMX);
    a conduit for providing input combustion air to the HMX;
    a conduit for providing the warm flue gas from the pre-cooler to the HMX;
    a conduit for providing a liquid to the HMX;
    wherein the HMX includes apparatus for warming the input combustion air with the warm flue gas and humidifying the atmospheric air with the liquid to produce warm, humid combustion air; and
    a conduit for providing the warm, humid combustion air to the combustor.

19. The device of claim 18 wherein the pre-cooler is a pre-condenser.

20. The device of claim 19 wherein the fluid is water and further comprising a hot water heater having a tank configured for heating water in the tank with the combustor and further including a conduit for providing the warmed water to the hot water heater tank.

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