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(54) **A method and an appliance for the utilization of the heat of condensation of the water content of flue gases.**

(57) In a method and a device for the recovery of heat of condensation of aqueous vapours in flue gases from the boilers of a district heating plant, in which a steam-driven heat pump is used for the transmission of the heat content of the flue gases to the return water from the consumer circuit before the water is sent back to the boilers, a heat pump is used which has two steps. The first step is operated at a lower temperature than the second step. Discharge steam from the first step is utilized for the operation of the second step. The first step comprises a compressor heat pump driven by a steam expansion engine. The second step comprises a steam jet compressor. There is obtained a comparatively low temperature at the giving-off of the heat of condensation recovered, which is a condition for achieving a high effect factor necessary for obtaining reasonable installation costs.

A method and an appliance for the utilization of the heat
of condensation of the water content of flue gases

Field of the Invention

5 The present invention relates to a method for the
recovery of heat of condensation from steam to water
in flue gases from the boilers of a hot water supply plant,
e.g. a district heating plant, in which method a steam-driven
heat pump is used for the transmission of the heat content
of the flue gas to the return water for the said plant
10 before it is conveyed back into the boilers.

Technical Background of the Invention

The amount of heat that can be recovered from the flue
gas in the form of heat of condensation is of the order of
magnitude 5-6% of the calorific value when firing with
15 oil and 12-13% of the calorific value when firing with
methane gas. To this amount of heat must be added the
thermal energy supplied to the heat pump. This thermal
energy first and foremost depends on the energy factor of
the heat pump, which in a mechanically driven heat pump
20 may amount to values between 3 and 4 at the temperatures
prevailing at jumps of temperature between 20°C and 50°C.
At bigger jumps of temperature it is possible, at the cost
of a lower energy factor, to utilize a bigger portion of
the heat of condensation in the H₂O contents of the
25 flue gas, and vice versa. It is always necessary, however,
to have at disposal a discharge temperature from the heat
pump which is at least 10°C higher than the temperature
of the return water to be heated.

If the heat pump is driven by means of electric
30 energy supplied from outside the amount of heat to be
conveyed to the return is increased, depending on the
temperature of the return water, by 30 to 50% of the
amount of heat recovered. This means that the resulting
temperature increase in the return water will amount to
35 up to 18% of the total temperature increase from the
return water to the supply water in the district heating
plant. Since, however, electric energy is considerably
more expensive than energy from the fuel employed in the
boilers of the district heating plant, it is desirable that

the driving energy for the heat pump is supplied by the
boilers of the plant because all waste heat is utilized
without loss. Steam energy cannot, however, be utilized
with the same energy factor as electric energy, whereby
5 the heat to be conveyed to the return water is to be
increased relative the amount of heat recovered. As the
increased supply to the return water renders a higher
delivery temperature of the converted heat necessary and
thereby calls forth a higher energy demand in the heat pump,
10 problems may result with such plant with respect to the
utilization of the heat of condensation.

Brief Description of the Invention

It is the object of the invention to reduce these
problems.

15 According to one aspect of the invention there is
provided a method for the recovery of heat of condensation
liberated by the condensation into water of steam contained
in flue gases from the boilers of a hot water supply
plant in which a steam-driven heat pump is used for the
20 transmission of the heat content of the flue gas to the
return water for the said plant before it is conveyed
back into the boilers, characterized in that

(a) the heat pump contains two steps of which the first
step comprises a compressor heat pump driven by a steam
25 expansion engine and the second step comprises a steam
jet compressor,

(b) the first step is operating at a lower temperature
than the second step.

30 In the temperature range in which the heat pump
function is to take place, the compressor heat pump step
and the steam jet compressor step supplement each other
in a surprisingly advantageous manner since the biggest
jump of temperature is caused by the aid of the compressor
heat pump, whereas the second step, in which the jump of

temperature is smaller, is caused by the steam jet compressor which is more advantageous with respect to preliminary expenses. As the steam expansion engine can be driven as a counter-pressure engine, the mechanical part of the heat pump can be made compact. As both of the steps in the heat pump arrangement are utilized in the ranges in which they function efficiently, a good efficiency is obtained, whereby one can expect a moderate energy supply from the condensed driving steam and a moderate delivery temperature of the recovered amount of heat.

According to a special embodiment of the invention the discharge steam from the first step is utilized at least partially for the operation of the second step, whereby a separate condenser for the first step may be eliminated.

According to a preferred embodiment of the invention the two steps are placed in parallel, a heat-bearing medium absorbing the heat of condensation from the flue gas being conveyed first through the evaporator of the second heat pump step, the return water being conveyed first through the condenser of the first heat pump step. By this arrangement it is avoided that heat energy having been pumped up in one of the steps is pumped further up in the other step.

According to the invention it is advantageous when the first step is caused to operate within a bigger temperature range than the second step, the mutual proportionation of the two steps being adjusted via the heat exchanger temperature to the evaporator of the second step in such a manner that the steam jet compressor precisely utilizes the waste steam from the first step. It is hereby possible to obtain an equilibrium between the two steps at which somewhat more than half part of the temperature range is borne by the first step and at which the energy of the steam is utilized fully.

The invention also comprises a device for carrying out the method according to the invention. The device for district heating plants for the recovery of heat of

condensation from the water content of flue gases from the boilers of the district heating plant, in which a steam-driven heat pump transmits the heat content of the flue gases to the return water of the district heating plant before it is returned to the boilers according to the invention is characterized in that the heat pump has two steps of which the first step comprises a steam expansion engine driving a compressor heat pump, whereas the second step comprises a steam jet compressor, the steam discharge from the first step preferably being connected to the inlet to the second step.

Detailed Description of the Drawing

In the following the invention will be described more fully with reference to the only drawing which schematically shows a district heating boiler plant in which the heat of condensation from the flue gas is utilized.

The district heating boiler plant with a smoke cooling device which is steam-driven from the boilers of the plant schematically shown in the drawing comprises a water boiler 1 shown with a built-in steam generator 2. The steam generator may alternatively be separate from the water boiler and be provided with its own burner. Boiler 1 delivers heated supply water to a consumer circuit 3. From boiler 1 a flue gas discharge 4 leads into two or more flue gas scrubbers 5 and 6 through an economiser arrangement (not shown), whereby the combustion air is heated and the flue gases correspondingly cooled.

The first scrubber 5 receives flue gas at a temperature of about 60°C and delivers the flue gas to scrubber 6 at a temperature near the dew point of the flue gas, which is 40-45°C. Each scrubber has a circulation circuit for scrubber solution which may be an aqueous solution of ammonium sulphite-bisulphite, NH_4OH or NH_2OH . By means of a heat exchanger 7 the scrubber solution leaving scrubber 6 cools the circulating solution in scrubber 5. The scrubber solution from scrubber 6 thus additionally heated is then conducted through the evaporator 8 belonging to a second heat pump 9 and

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subsequently through the evaporator 11 belonging to the first heat pump 10, before it is distributed in cooled state by means of a nozzle arrangement 12 over the filling of the scrubber with reactor bodies 13. In scrubbers 5 and 6 the ascending flue gas meets countercurrently the descending cooled scrubber liquid which at the bottom of the scrubber will be approximately in equilibrium with the flue gas at about the dew point of the latter. The first heat pump 11 is driven by means of a steam expansion engine 14, e.g. a reciprocating steam engine or a turbine, which can deliver its waste steam to be further expanded in a steam jet compressor 15 in the second steam pump 9 or to be condensed in a condenser 18 cooled by the return water.

In order to cool the condensers 16 and 17, respectively, of the two heat pumps 9, 11, return water is conducted from the district heating supply circuit first through condenser 16 and then through condenser 17 to steam jet heating pump 9 before it is conveyed for its final heating to the water boiler. It is possible to use the circulation water as the heat transmitting medium in the steam jet heat pump 9 since hereby simultaneously air possibly dissolved in the circulation water may be vented. Such venting may contribute to reducing corrosion of the pipes of the consumer circuit.

Power for operating the heat pump arrangement is provided by means of the steam which is generated either in a separate steam boiler or by the aid of the boiler tube arrangement 2 built-in into a separate box of boiler 1. The driving steam is delivered at about 15 bar and at a moderate superheating. The steam expansion engine operates in the pressure range of 15 bar to 2 bar and there is estimated an expenditure of 20 kg of steam per kWh produced for the compressor in the mechanical heat pump. Some or all of the waste steam delivered at 2 bar can be conveyed on to the steam jet heat pump 9, or the steam jet heat pump 9 may be operated using steam from the steam generator 2.

The mechanical heat pump operates in the temperature range of 20°C to 70°C at an energy factor of 3.25, which requires a steam supply of 5.33 kg per kg water of condensation (steam factor $\mu = 5.33$).

The steam jet heat pump operates in the temperature range of 35°C to 70°C and requires a steam factor of 7.22.

Equilibrium in the utilization of the steam can be obtained when
5 58% of the condensate cooling takes place in the steam engine-driven heat pump whereas 42% of the condensate cooling takes place in the steam jet-driven heat pump. The resulting steam expenditure hereby will be 3.1 kg of steam per kg of aqueous steam condensed from the flue gas.
10 The balance aimed at is obtained at a condensate temperature limit in the flue gas of 38.5°C , assuming that the dew point in the flue gas supplied is 45°C . By the utilization of the heat of condensation in a flue gas having the dew point 60°C (when combusting methane gas) the condensate temperature
15 limit has to be moved substantially upwards, which renders it possible to operate the steam jet aggregate within the temperature range of $40\text{--}70^{\circ}\text{C}$ whereby the steam factor is reduced from 7.22 to 4.64. Hereafter there is obtained balance in the expenditures of steam when the steam
20 engine driven heat pump yields 46.8% of the condensation work, 53% of the condensation work being provided by the steam jet aggregate. The critical condensate temperature limit here is 47°C which means that the steam jet aggregate at the same differential temperature can operate at a minimum
25 temperature of, e.g., 45°C and a delivery temperature of 75°C . The resulting steam expenditure of the system relative the amount of condensate thereby may be reduced at a steam factor of 2.5.

Calculated Example 1

30 In an oil-fired district heating plant the temperature of the return water is 60°C and the supply temperature 90°C , corresponding to a heating in the boiler plant of 30°C .

35 At a condensate temperature of 20°C , 76% of the total amount of water in the flue gas may be condensed, or 0.99 kg of water per 10,000 kcal (about 1 kg of oil) and thereby there is recovered further 5.94% of heat relative the heat of combustion.

At a steam factor of 3.1 the amount of heat induced into the return water corresponds to 18.41% of the heat equivalent of the fuel expenditure, and the total amount of heat induced into the return water becomes 24.35% of the emission of heat of the fuel expenditure. The portion of the amount of heat originating from the heat pump plant and emitted from the district heating plant is 22.99% of the total heating of 30°C.

Calculated Example 2

In a methane gas fired district heating plant at a condensate temperature of 20°C there may be condensed 88% of the total amount of water, which in a methane flue gas is about the double of that in an oil flue gas, the amount of water being 2.29 kg per 10,000 kcal. Hereby is recovered further 13,74% of heat relative the heat of combustion.

At a steam factor of 2.5 the amount of heat induced into the return water from the condensed steam corresponds to 34.35% of the heat equivalent of the fuel expenditure, and the total amount of heat induced into the return water becomes 48.13% of the emission of heat of the fuel. The portion of the amount of heat originating from the heat pump and emitted from the district heating plant is 42.28% of the total amount of heat, corresponding to 12.7% of the total heating of 30°C. The larger share of the heating of the district heating water results in that the temperature in the heat exchanger of the heat pump will rise to maximum 72.7°C after which it will be necessary that the part of the heat pump (the steam jet part) which operates at the higher temperatures is arranged for a discharge temperature of about 75°C and an inlet temperature of 45°C.

Claims

1. A method for the recovery of heat of condensation liberated by the condensation into water of steam contained in flue gases from the boilers of a hot water supply plant
5 in which a steam-driven heat pump is used for the transmission of the heat content of the flue gas to the return water for the said plant before it is conveyed back into the boilers, characterized in that:
- (a) the heat pump has two steps of which the first
10 step comprises a compressor heat pump driven by a steam expansion engine and the second step comprises a steam jet compressor,
- (b) the first step operates at a lower temperature than the second step.
- 15 2. A method according to claim 1, characterized in that the discharge steam from the first step is utilized at least partially for the operation of the second step.
3. A method according to claim 1 or claim 2, characterized in that the two steps are placed in parallel,
20 a heat-bearing medium absorbing the heat of condensation from the flue gas being conveyed first through the evaporator of the second heat pump step, the return water being conveyed first through the condenser of the first heat pump step.
- 25 4. A method according to any one of claims 1, 2 or 3, characterized in that the first step is caused to operate within a bigger temperature range than the second step, the mutual proportioning of the two steps being adjusted via the heat exchanger temperature to the evaporator of
30 the second step in such a manner that the steam jet compressor precisely utilizes the waste steam from the first step.
5. A device for a hot water supply plant for the recovery of heat of condensation from the water content of flue gases
35 from the boilers of the said plant, in which a

steam-driven heat pump transmits the heat content of the flue gases to the return water of the district heating plant before it is returned to the boilers, c h a r a c t e r i z e d in that the heat pump has two steps of which the first step comprises a steam expansion engine driving a compressor heat pump, whereas the second step comprises a steam jet compressor, the steam discharge from the first step preferably being connected with the inlet to the second step.

