Increase the efficiency of the fireplace insert with loop heat pipe

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Abstract. The article is focused on increasing the efficiency of fireplace inserts by means of a device used to preheat the combustion air with a part of the heat from the flue gases. The proposed device is a heat pipe with a closed loop, where its evaporator takes heat from the flue gas in front of the chimney orifice and transfers it via saturated steam to the condenser. This heats the combustion air and thus increases the thermal efficiency of a small heat source.

1 Introduction

Fireplace inserts as a heat source produce heat output by burning fuel. In the form of flue gases, a large amount of waste heat is released through the chimney into the air, which also reduces the efficiency of the fireplace insert itself [1]. It is possible to remove part of the heat from the flue gas, which can be used for heating water by various methods [2]. When using these applications, it can be a problem to ensure the safe operation of the fireplace insert in the system and therefore it is necessary to include safety elements such as safety valves, expansion vessels, etc. Another disadvantage is the need for storage tanks, which not only take up space but also increase investment costs. The most advantageous solution therefore seems to be the use of waste heat directly in the combustion processes.

2 Loop HP

Closed-loop heat pipes are passive heat transfer devices using phase transformation with almost negligible heat loss. The appropriate combination of the working medium used and the construction packaging defines the operating temperature range of the heat pipes [3].
Heat pipes have proven to be an effective solution especially in high temperature applications and insulation, where there is any combination of uneven heat load, limited air flow through the heat generating components as well as space or weight constraints [4].

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3 Device for increasing the efficiency of the fireplace insert

Important factors for calculating the efficiency of a fireplace insert include the combustion air temperature and the combustion air temperature. By inserting a heat pipe with a closed loop into the fireplace insert system, we can use part of the heat escaping in the form of flue gases to preheat the combustion air. Chimney losses are reduced by removing some of the heat from the flue gas, and by transferring this heat through the heat pipe, the combustion air is heated, which also reduces the need for fuel [5].

When designing the device, we used the construction of the fireplace insert: Figure 1. The evaporating part of the heat pipe is located in front of the chimney orifice, where it removes heat from the flue gas, which is transferred in the form of saturated steam through a steam pipe to a condenser located in the combustion air supply channel. Due to the location of the condenser above the evaporator, a gravitational heat pipe was used, where the working medium can move under its own weight.

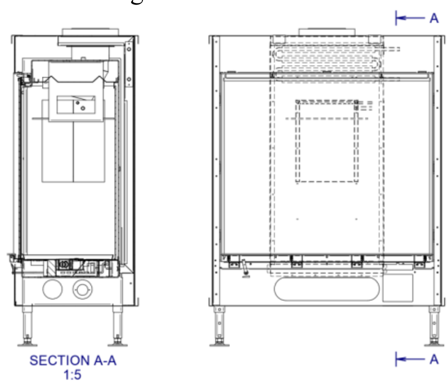

Fig. 1. Location of the HP loop in the fireplace insert.

Figure 2 shows the external dimensions of the evaporator together with the dimensions relating to the location of the evaporator relative to the condenser. Due to the atypical chimney of the fireplace insert used, we had to adjust the flue gas duct from the evaporator space.

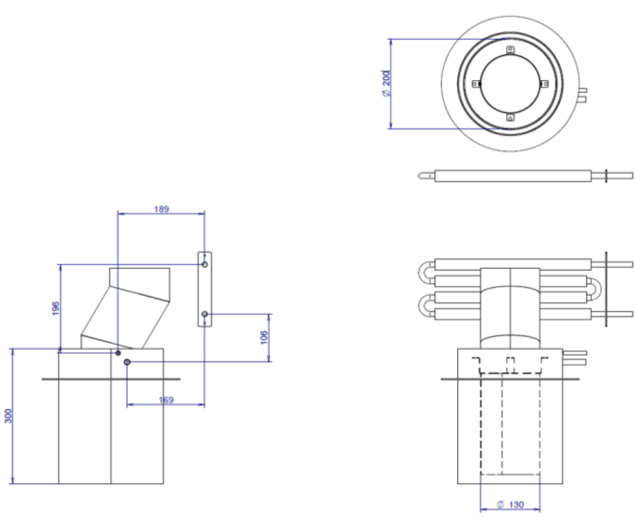

Fig. 2. External dimensions of the loop heat pipe.

In addition to the design, the correct choice of heat pipe material and working medium is also very important [6]. The material of the heat pipe must be subject to several conditions and, in addition to the required high thermal conductivity, compatibility with the working medium must also be ensured. At the same time, the device must not corrode and must withstand higher chimney temperatures. The ideal combination for this application is the use of copper as a wall material and water as a working medium. The results of chemical and metallographic tests show that copper and water are compatible. The release of inert gases occurred only with the use of surfactants to improve the wettability of the copper capillary systems and with the incorrect removal of the residues of these substances.

Figure 3 shows a 3D model of a loop heat pipe. The connecting pipes are thus made of a copper tube, as are the walls of the condenser. Due to the higher heat transfer between the combustion air and the condenser, we increased the area of the condenser with aluminum rolled ribs [7]. Due to the high temperatures at the chimney inlet, we chose stainless steel as the evaporator material, which, like copper, is compatible with the working medium we have chosen.

Fig. 3. 3D model of a loop heat pipe.

Even when the flue gases reach high temperatures, for better use we must direct their flow so that they stream the inside of the evaporator. By placing the deflector in the evaporator, we prevent the flue gases from flowing in an easier way. Thanks to the creation of a smaller section, we also get higher speeds, which also gives us a higher heat transfer between the flue gases and the evaporator. The location of the deflector is shown in Figure 4

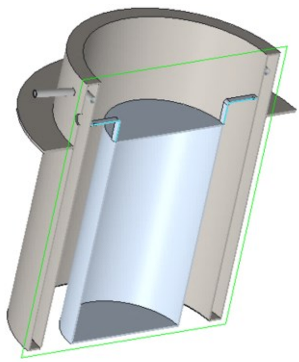

Fig. 4. Deflector located in the evaporator.

4 Results of a mathematical model

The cooperation between the condenser and the evaporator must be ensured in the loop heat pipe, for this reason we have reduced the flue gas temperature from the original 200 °C to 40 °C in the mathematical model in Excel in order to find the cooperation point.

4.1 Evaporating part

We regularly reduced the flue gas temperature (by 10 °C) from the original flue gas temperature of 200 °C to a temperature of 40 °C, which gradually reduced the flue gas temperature t_{12i} at the evaporator outlet.

With a smaller amount of heat removed, the transfer, either by radiation or convection, was also smaller, but gradually increased with greater heat consumption.

Figure 5 graphically shows the heat outputs dissipated by the evaporator together with the temperature of the flue gases at the outlet of the evaporator as a function of the boiling point of the water. It can be clearly seen in this graph that the largest component of the heat that heats the water in the evaporator is the radiant heat output $Q_{r,\ int}$ acting on the inner shell of the evaporator. From the inside of the evaporator, there is a greater heat transfer also by convection.

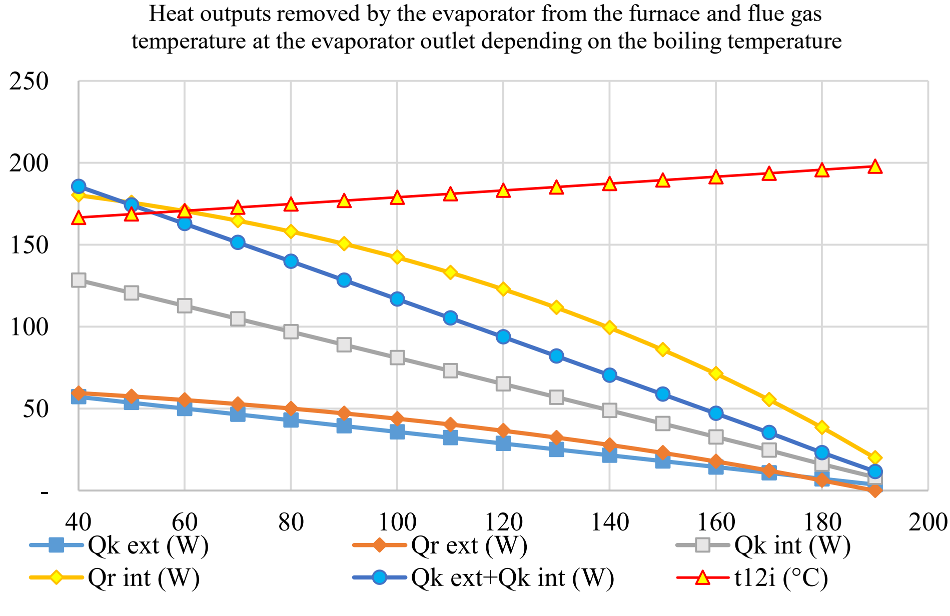

Fig. 5. Heat outputs removed by the evaporator from the furnace and flue gas temperature at the evaporator outlet depending on the boiling temperature.

4.2 Condensing part

As with the evaporator, we gradually increased the temperature of the steam in the condenser Figure 6, which significantly increased the temperature of the combustion air. The calculated values of the heat output Q_{tep} also match us according to the logarithmic method of temperature difference and also using the mathematical function of the operating characteristic [8].

As the inlet steam temperature increased, there was an increasing difference between the temperature of the steam and the combustion air (originally 20 °C), which also increased the heat transfer between the exchanger and the combustion air. At a steam temperature of 190°C, we reached a temperature of preheated combustion air of up to 50 °C.

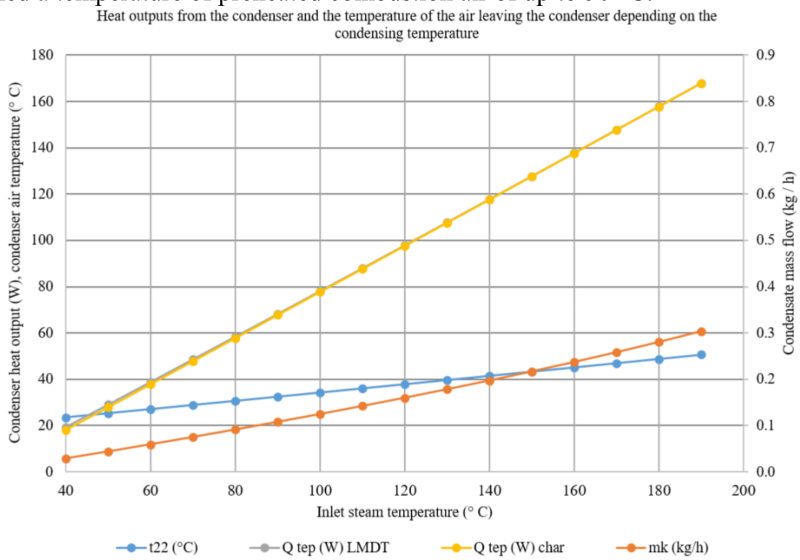

Fig. 6. Heat outputs from the condenser and the temperature of the air leaving the condenser depending on the condensing temperature.

4.3 Evaporator and condenser cooperation

Along with the change in temperature, the mass flow of water also changed, and we used this parameter to find the point of cooperation.

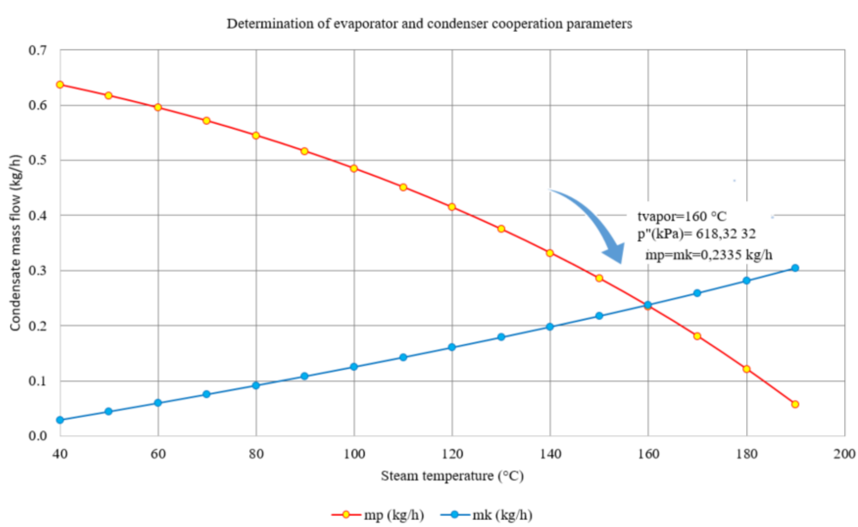

Fig. 7. Determination of evaporator and condenser cooperation parameters.

The condition for cooperation between condenser and evaporator is the same temperature and pressure in both devices. By translating the curves of the mass flow of water in the evaporator m_p and the mass flow of water on the condensate side m_k Figure 7, we obtained the operating point of the exchanger with a steam temperature of 160 °C and a saturated vapor pressure of 618.32 kPa. At this point, the mass flow of steam is equal to the mass flow of condensate in the heat exchanger.

4.4 Increasing the efficiency of the fireplace insert

After determining the parameters of the evaporator cooperation, we recalculated the efficiency of the fireplace insert for a steam temperature of 160 °C. For comparison, we have included in the calculation our initial values, which we also used in the calculation of the exchanger and condenser. Compared to this value, we managed to increase the efficiency by 2.92 %. The calculated values are given in Table 1.

Table 1. Increasing the efficiency of the fireplace insert.

Parameter		without loop HP	with loop HP
t_1	combustion air temperature [°C]	20	45.16
t_2	flue gas temperature [°C]	200	191.58
H_i	calorific value of dry gaseous fuel [MJ.m^{-3}]	34.99	34.99
H_s	combustion heat of dry gaseous fuel [MJ.m^{-3}]	38.78	38.78
q_1	specific heat capacity of dry flue gases [%]	14.19	11.55
q_2	specific heat capacity of water vapor contained in the flue gas [%]	1.50	1.22
η	efficiency [%]	84.31	87.23

5 Conclusion

The great advantage of our device is that it works only when the fireplace insert. If the evaporator is not heated by the flue gas, no steam is generated and the whole process is stopped. Otherwise, if a large amount of heat was transferred from the flue gas to the evaporator, the pressure in the heat pipe system would gradually increase, which would also increase the boiling temperature and thus reduce the amount of steam produced, so it is not necessary to include large a number of security features.

By inserting a loop heat pipe into the gas fireplace insert, we managed to increase the efficiency by 2.92 %. However, this value is only theoretical and a measurement is necessary to verify its accuracy. In the case of fireplace inserts with solid fuel combustion, a more significant increase in efficiency is expected; in the combustion of solid fuels, chimney temperatures reach higher values than in the combustion of gaseous fuel.

The device with loop heat pipe also opens up possibilities for increasing the efficiency of already standing fireplace inserts and small heat sources, where with a relatively small investment we can easily increase the efficiency of the heat source for heating.

According to the constructed mathematical model, our device has great potential in heating with small heat sources, but we are still moving only on a theoretical level and this theory must be verified by experimental measurements.

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