INNOVATIVE FLUE GAS HEAT ABSORPTION SYSTEM FOR BUILDINGS WITH BIOMASS FIRED BOILER

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Abstract. The innovative flue gas heat absorption system for buildings with biomass fired boilers was developed in order to increase the efficiency and coefficient of performance of the heating systems, to reduce heat loss and environmental pollution by decreasing the amount of emitted flue gas and hazardous particles in it. Together with increased thickness of heat insulation, the efficiency of the described heating system proportionally reduces the fuel consumption.

Keywords: heat insulation, microclimate of buildings, energy efficiency, wood fuel.

Introduction

The presented system consists of the traditional heating system that is supplied with enough air to ensure complete burning of fuel to produce maximum volume of heat and to make cleaner flue gas. The flue gas is cooled by flowing through a massive underfloor structure of shafts which gradually transfer heat to heat up premises. During the flue gas condensation process latent heat of steam is recovered and utilized. It provides an opportunity to operate the heating system with a high coefficient of performance for biomass with increased level of moisture burning. A concrete floor heated with liquid heat carrier is installed above the flue gas shafts providing optimal surface temperature of the floors. A plastic pipe is installed in the flue gas shaft to be used as a flow-through water heater. During the hot flue gas flow along the pipe, heat is partially transferred to water increasing its temperature.

The publication describes an experimental research performed multiple times. Different types of wood were used as fuel. The weight, size, moisture content and thermal capacity of the timber were determined. During the burning process the temperature in different points of the system was recorded. The coefficient of performance and efficiency of the heat utilization of the heating system was determined.

Materials and methods

1. Experimental studies of the innovative flue gas heat absorption structure operation

A similar solution was used in the experimental object of the Doctoral thesis by E. Visockis and in other studies [1-4]. The experimental object of the investigations described in this publication is substantially modified and expanded. Based on the ground, the innovative flue gas heat absorbing system structure was made, consisting of a heat insulated concrete mass floor incorporating a flue gas flow shaft (see Fig. 1).

2. The system operation principles

By means of a flue gas pump built in the chimney from the heating system, flue gases are sucked into the underfloor shaft through the long pass of flue gases through massive concrete structures, and the water-pipe heat exchanger dissipating a part of the heat. Flue gas is partially condensed, and with the help of artificial draught is sucked into the chimney and emitted into the atmosphere. The flue gas pump productivity is controlled by a potentiometer. If due to some reason the flue gas pump fails to function, the valve of the short pass flue gas flow opens and the hot flue gas is discharged directly into the chimney. When the chimney is heated up and produces enough natural draught, the short pass may be closed and the hot flue gases flow through the long pass. The heated concrete floor mass for an extended period dissipates into the room the heat recovered from the flue gases. To align the heated floor surface temperature, in the upper layer of the floor, in the area where the cooled flue gases cannot sufficiently warm up the floor surface, a liquid coolant tube was built. In a housing built in the heating system liquid coolant is warmed up and through the heat exchanger heating surfaces it warms up 100l water boiler for domestic purposes and a part of the heated floor. This solution increases the heating system efficiency factor. The comfort level of the heated room is provided by using a smaller amount of fuel. Less fuel gases are produced, they are cooler and cleaner. In the underfloor a heat exchanger of innovative design was placed. It consists of a 100 m long plastic tube having a diameter of 20 mm, wall thickness of 2 mm. It works as an instantaneous water heater. Flue gases flow into an underfloor shaft. The pipe contains 22 l water. According to consumption, fresh cold water flows into the tube and going a 100 m long route through the shaft being heated with hot flue gases. Hence, it is heated up to the temperature usable for household needs.

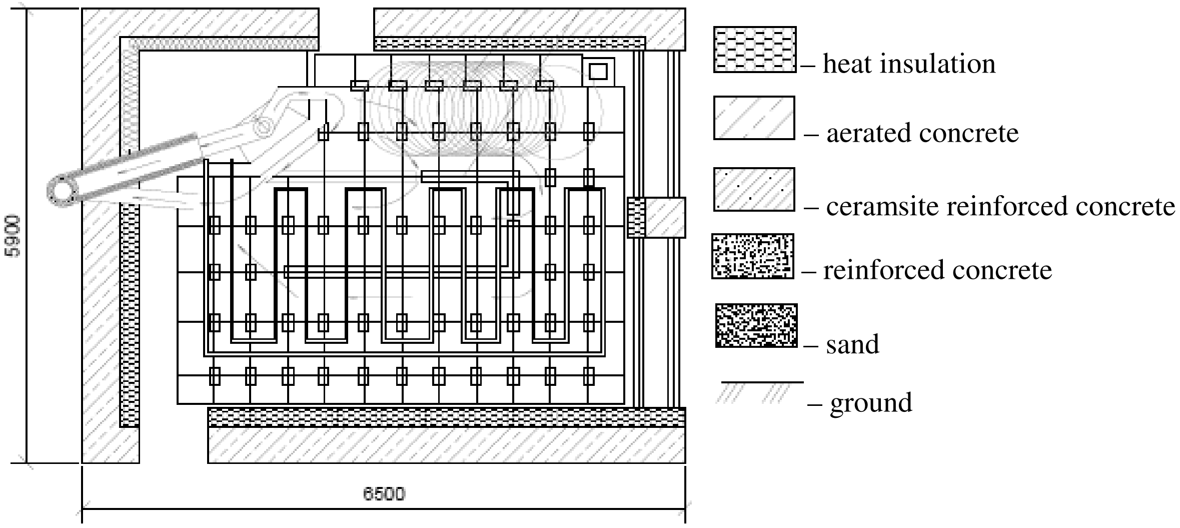

Fig. 1. **Overview of the innovative flue gas heat absorption structure**

3. Description of the experiment

In order to bring the conditions of the experiments as close as possible to the actual situation, these were performed in winter, during the heating season on a daily basis from 1 January to 30 January, 2013.

Each time 7 kg of various wood species firewood with an average humidity 30 % were placed in the furnace. By using electronic measuring equipment the outdoor air temperature, indoor air temperature, air temperature at the inlet of the furnace and on the flue gas pipe surface from the furnace, on the flue gas pipe surface from the underfloor shaft, of incoming and outgoing cold water in the heat exchanger (average 10 ºC) and temperature in effluent from the underfloor shaft were measured. 100 litres of hot water are heated in the boiler to average of 70 ºC. By using an innovative fuel firing device the fuel was set on fire. The experimental measurements were read off at 30-minute intervals, firing duration – 2 hours, duration of reading off indication – 3 hours. Upon summarization of the data obtained from 30 repeated experimental measurements, the average temperatures were calculated (see Table 1) at the average outdoor air temperature of -6 ºC. The obtained curves are displayed in Fig. 2 and 3.

Table 1

Summary of experimental operation parameters of innovative flue gas heat absorption structure

Serial No.	Experiment duration, min.	Average temperature, ºC				
		Room air	Floor surface	Air inflow to furnace	Flue gas inflow from furnace	Water outflow from heat exchanger
1.	0	18	20	18	18	16
2.	30	25	21	22	135	20
3.	60	30	22	25	180	25
4.	90	30	24	26	185	27
5.	120	29	26	26	190	30
6.	150	29	27	-	-	34
7.	180	28	28	-	-	37

Results and discussion

1. Analysis of the data obtained from experimental researches of the innovative flue gas heat absorption structure

Processing of the data obtained from the experiments was performed by using the Excel program. Energy flow distribution describes the areas displayed in Fig. 3.

The dark red area characterizes how much heat is taken from flue gas and accumulated in the underfloor shaft ceramsite reinforced concrete building structures. The blue field characterizes, how much of flue gas heat passes out in the atmosphere.

When sizes of the blue area and the crimson area are compared, approximate estimation can be made about the volume of heat imbibed and accumulated by the underfloor shaft ceramsite reinforced concrete building structures. The green area represents the amount of heat when the temperature of the flue gases discharged from the underfloor shaft increases from the underfloor shaft interior surface primary temperature (+13 ºC) to the initial temperature of indoor air sucked into the furnace (+18 ºC).

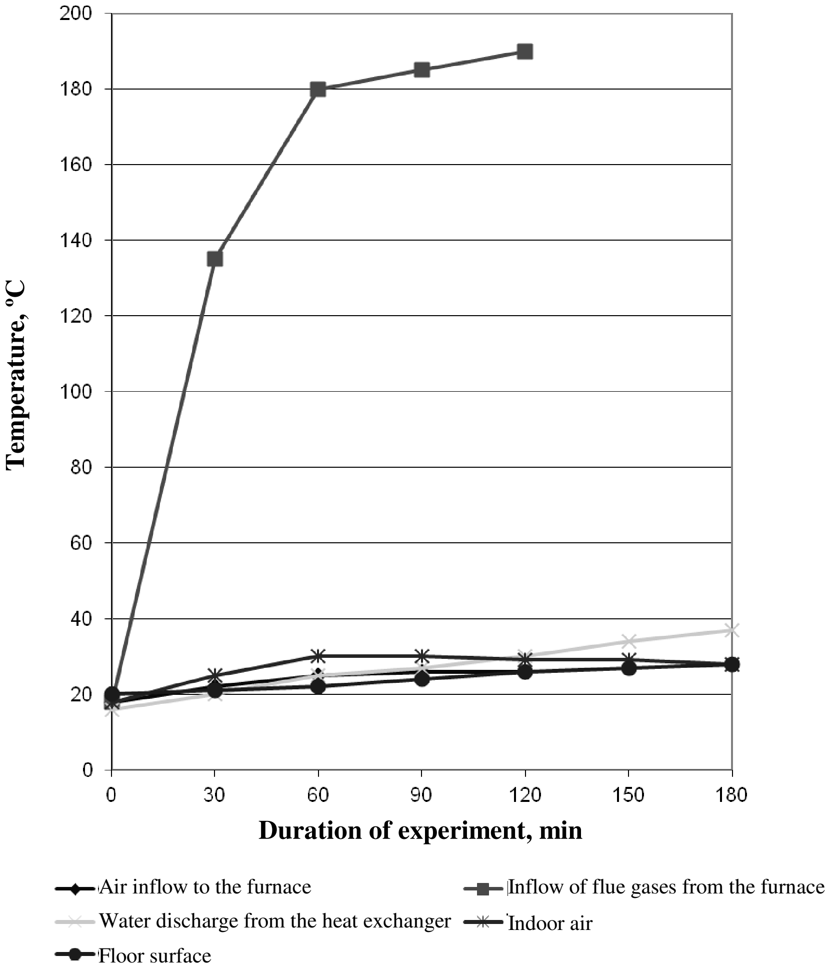

Fig. 2. **Average temperatures of operation of the innovative flue gas absorption structure**

Without regard to other external factors, and theoretically assuming that the heating system could operate with an efficiency factor close to 100 %, it is possible to accept the temperature and humidity of the air sucked into the furnace being equivalent to the temperature and humidity of fuel gases discharged from the heating system. Creation of such subjective circumstances allows accepting, that the jade green area in this experiment specifies how much heat is obtained by cooling not only fuel gases.

It should be noted that the innovative heating system was operated on a regular basis once in twenty-four hours and the primary discharge temperature of flue gases from the underfloor shaft

(+13 ºC) is so low due to the chimney is located outside the heated room and within the time interval between the heating sometimes also its connection with the end part of the underfloor flue gas shaft cools off.

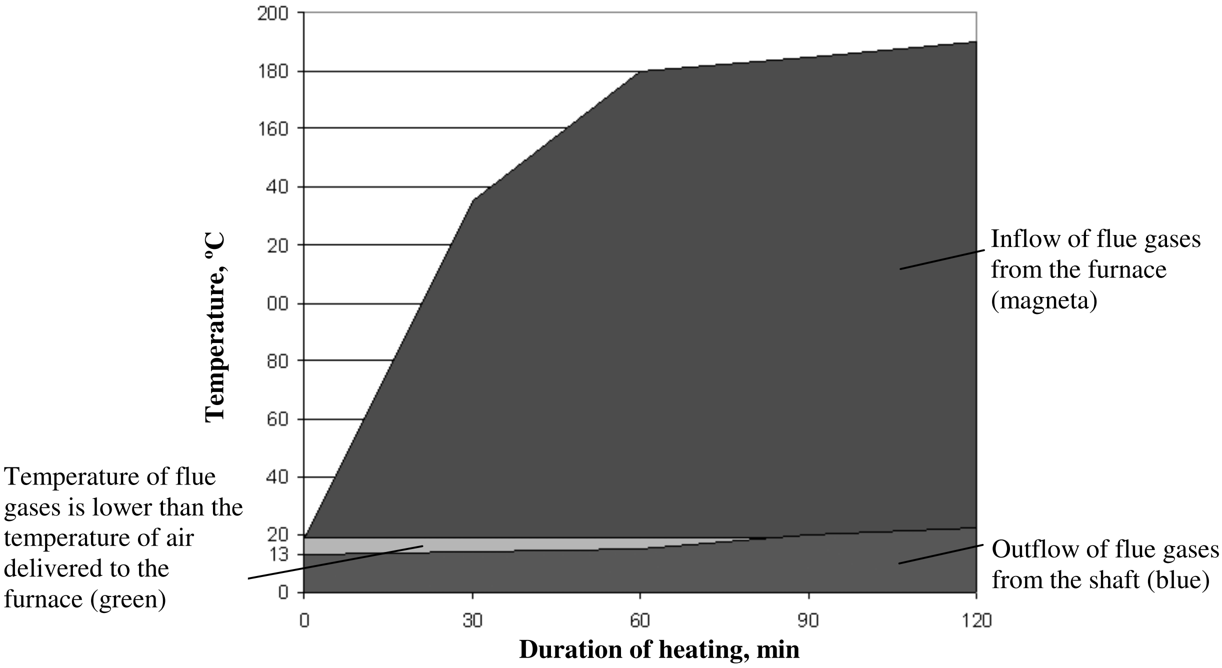

Fig. 3. **Amount of heat regained from flue gas in the result of using the innovative flue gas absorption structure**

2. Calculation of the efficiency factor of the heating system by using the innovative flue gas heat absorption structure

The efficiency factor of the system is made from the relationship of heat delivered through combustion of fuel against the efficiently used heat.

This relationship can be expressed by the following formula:

$$\eta = \frac{Q_I}{Q_K} \cdot 100\,\%\,, \tag{1}$$

where η – efficiency factor, %;
Q_I – used heat, kJ;
Q_K – total amount of heat obtained resulting from fuel combustion, kJ.

Balance of the used heat is made as follows:

$$Q_I = Q_{Gr} + Q_G + Q_T + Q_W\,, \tag{2}$$

where Q_{Gr} – heat consumption by floor structures, kJ;
Q_G – heat consumption by air in the room, kJ;
Q_T – losses through the room enclosing structures (walls), kJ;
Q_W – amount of heat consumed by the water, kJ.

The amount of heat, which in theory can be obtained by burning of fuel with the given moisture [5], if heat from the moisture of the flue gases is not regained, shall be calculated as follows:

$$Q_{KZ} = M \cdot Q_Z = 7 \cdot 12348 = 86436 \text{ kJ}, \tag{3}$$

where M – mass of the burned wood, kg;
Q_z – Net Calorific Value (NCV) of firewood (at a given humidity 30 %).

The amount of heat that can be theoretically obtained through burning of fuel, by fully recovering the heat from the moisture present in the flue gases, shall be calculated as follows:

$$Q_{KA} = M \cdot Q_A = 7 \cdot 17400 = 121800 \text{ kJ}, \quad (4)$$

where Q_A – Gross Calorific Value (GCV) of firewood.

The used amount of heat according to components can be calculated according to elementary thermodynamic relationships, knowing the mass, construction, start and end temperatures of the structures, as well as by calculation of the amount of heat used for water heating and the heat loss through the enclosing structures (walls, windows, doors) at the measured outdoor and indoor air temperature. Total used heat shall be:

$$Q_I = 67840 + 735 + 25140 + 12234 = 105949 \text{ kJ}. \quad (5)$$

Therewith, the efficiency factor for the system by calculation with the Gross Calorific Value shall be:

$$\eta = \frac{105949}{121800} \cdot 100\ \% = 87\ \% . \quad (6)$$

The efficiency factor for the system by calculation with the Net Calorific Value shall be:

$$\eta = \frac{105949}{86436} \cdot 100\ \% = 122.5\ \% . \quad (7)$$

Conclusions

1. By using the developed heat absorption system the heat from flue gases can be recovered, thus increasing the overall efficiency factor up to 122.5 % when calculations are based on the firewood Net Calorific Value. This means that the heat is recovered by flue gas condensation, thus by 22.5 % exceeding the same to be obtained in accordance with the Net Calorific Value, where this, so-called latent heat, is not estimated.
2. Since through full use of all the wood combustion heat in the experiments carried out it would be possible to obtain 121,800 kJ, while according to the measurements 105,949 kJ were obtained, which amount to approximately 87 % of the maximum possible, the system should be continuously improved.
3. Accuracy of the experiments is also affected by the firewood humidity and transition regimes of the boiler operation, which could lead to increased loss due to incomplete combustion.
4. When using wood with lower moisture content, the real benefit might be lower, since the amount of heat recoverable by means of moisture condensation would be reduced. Then the benefit would be derived mainly from the flue gas cooling. This indicates that this system is particularly suitable for fuels with increased humidity.

Acknowledgments

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