HIGH CAPACITY HEATING SYSTEM BY USING FLUE GAS COOLING DEVICE

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Abstract. High capacity heating system by using flue gas cooling device in building with biomass fired boiler was developed in order to increase efficiency and coefficient of performance of heating system, reduce heat loss and environmental pollution by decreasing amount of emitted flue gas and hazardous particles in them. Increased efficiency of the heating system proportionally reduces fuel consumption.

Keywords: wood fuel, flue gas cooling system, energy efficiency.

Introduction

The experimental system consists of the fireplace (furnace) with heat transfer fluid heat exchanger. That is supplied with enough air to ensure complete burning of fuel to produce maximum volume of heat and as possible cleaner flue gas. The flue gas is cooled by flowing through massive underfloor construction of pits which gradually transfer heat to heat up premises. During flue gas condensation process latent heat of steam is recovered and utilized. It gives opportunity to operate the heating system with high coefficient of performance burning biomass with increased level of moisture. Another surface of concrete floor heated with liquid heat carrier.

A plastic pipe for water flow is installed in the flue gas pit to be used as flow-through water heater. During hot flue gas flow through the pipe heat is partially transferred to water increasing its temperature. The rest of flue gas heat is absorbed in freezer used as flue gas cooling system. Freezer transforms and increases flue gas heat energy and return that to heated room. Flue gas in freezer cooled average below 0 ºC is dry and partly cleaned of harmful admixtures and flowed out to ambience.

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

Materials and methods

Experimental studies of the innovative flue gas heat absorption system operation

The most important innovation in comparison of previously described systems [1-3] is using of cooling device (freezer volume 400liter filed up with 150 kg metal pieces and spiral shape chips) to take out heat from flue gas coming out from underfloor space. Also massive underfloor construction of pits (heated up concrete floor mass approximately 350 kg, thickness 70 mm, size 2.64 m^2) is developed. Flue gas pump with load about 10 % (maximal capacity 125 W and productivity 600 $m^3 \cdot h^{-1}$ regulated by potentiometer) draws flue gas from fire place with nominal capacity 19 kW into the underfloor shaft through the long pass of flue gas through massive concrete structures, and the water-pipe heat exchanger dissipating a part of the heat. Flue gas is partially condensed, and with the forced draught is drawn into the freezer filled up with iron spiral shape chips and pieces of iron. Flue gas temperature decreases below 0 ºC and through the chimney emitted into the atmosphere. The flue gas pump productivity is controlled by a potentiometer. If due to any reason a flue gas pump fails to function, the bypass valve of the flue gas flow opens and the hot flue gas is discharged directly into the chimney. The heated concrete floor mass for an extended period dissipates into the room the heat recovered from the flue gas. In the area where the cooled flue gas don't warm up the floor surface, a liquid coolant pipe 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. Comfort level of the heated room is provided by using a smaller amount of fuel. Less fuel gas are produced, they are cooler and cleaner. The heat exchanger of innovative design was placed into the underfloor. It consists of a 70 m long plastic tube having a diameter of 1 inch, wall thickness of 2 mm. It works as an instantaneous water heater. Flue gas flows into an underfloor shaft. The pipe contains 40l water. Accordingly to consumption, fresh cold water flows into the tube and going a 70 m long route through the shaft being heated with hot flue gas. Hence it is pre heated and flown into boiler, where increases water temperature to be usable for household needs.

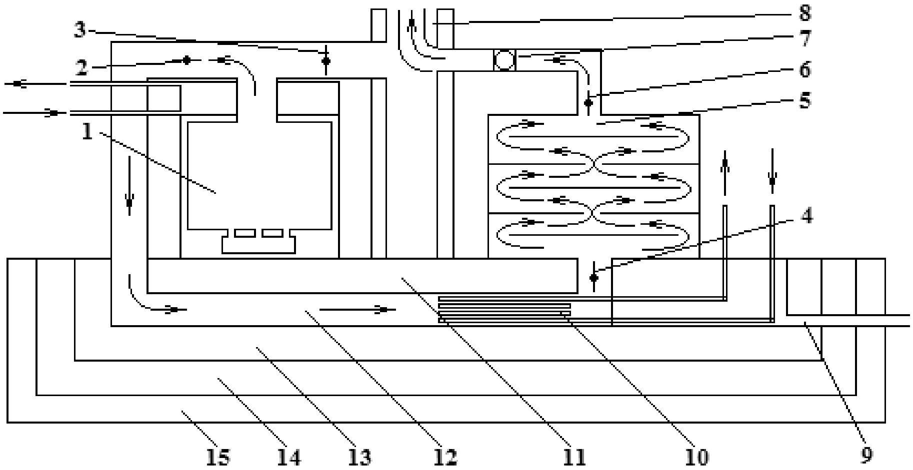

Fig. 1. **Overview of the innovative flue gas heat absorption hybrid technological construction:** 1 – fireplace with fluid heating; 2 – valve to underfloor shaft; 3 – valve to chimney; 4 – valve to freezer; 5 – freezer; 6 – valve to flue gas pump; 7 – flue gas pump; 8 – chimney; 9 – condensate sanitation; 10 – water heat exchanger pipe; 11 – concrete floor; 12 – underfloor shaft; 13 – concrete shaft bottom; 14 – heat insulation; 15 – concrete base

Experiment description

In order to bring the conditions of the experiments as close as possible to the actual situation, these were performed in the winter.

Pine firewood with mass 5 kg and average humidity 20 % was placed in the fireplace. 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, to, middle and from freezer was measured. Experimental measurements were read at 10-minute intervals, firing duration and reading off indication – 1 hour. 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 -1 ºC. The obtained curves are displayed in Figure 2. Temperatures were measured using electronic scientific thermometers “Oregon” SA880SSX. Measuring range: -50…+260 ºC, resolution 0.1…0.5 ºC, accuracy ±1 ºC (0-60 ºC) and ±1.5 ºC (full range).

Table 1

Summary of experimental operation parameters of innovative heating system with flue gas heat absorption solution

Measurement	Time, min.	Flue gas temperature, ºC					Temp. difference, ºC T_b-T_a	Fluid heat carrier temperature , ºC		
		From fireplace T_d	From underfloor shaft, T_u	Before freezer T_b	Midle of freezer T_f	After freezer T_a		In fireplace boiler	*To* heated floor	From heated floor
5kg pine firewood with moisture about 20 % burn on										
1	0	**-0.6**	-1.1	+0.8	-5.2	**-2.5**	3.3	-1	-0.1	-0.3
2	10	**+25**	-0.3	0	-3.6	**-2.8**	2.8	+15	+9.5	-2
Maximal burning intensity										
3	20	**+82**	+1.2	+0.6	-2.5	**-1.5**	2.1	+40	+22	-1.3
4	30	**+126**	+3.1	+1.4	-2.5	**-1.4**	2.8	+42	+37	+22
Most part of firewood burned on										
5	40	**+136**	+4.3	+1.9	-0.3	**-1.7**	2.6	+38	+32	+21.4
6	50	**+119**	+4.6	+1.4	+0.6	**-0.5**	1.9	+35	+30.7	+20.7
Firewood burned on, glowing red coal										
7	60	**+112**	+5.2	+1.1	+1.4	**+1.6**	0.5	+33	+28.5	+20.8

Results and discussion

Analysis of the data obtained from experimental researches of innovative heating system with flue gas cooling in freezer

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, that the temperature and humidity of the air sucked into the furnace being equivalent to the temperature and humidity of flue gas discharged from the heating system. Experimental object allows flue gas temperature cooling substantially below air temperature delivered to fireplace. Freezer performs heat pump function – cooling flue gas, transforming heat by decreasing that temperature and blows warmed up air into the building.

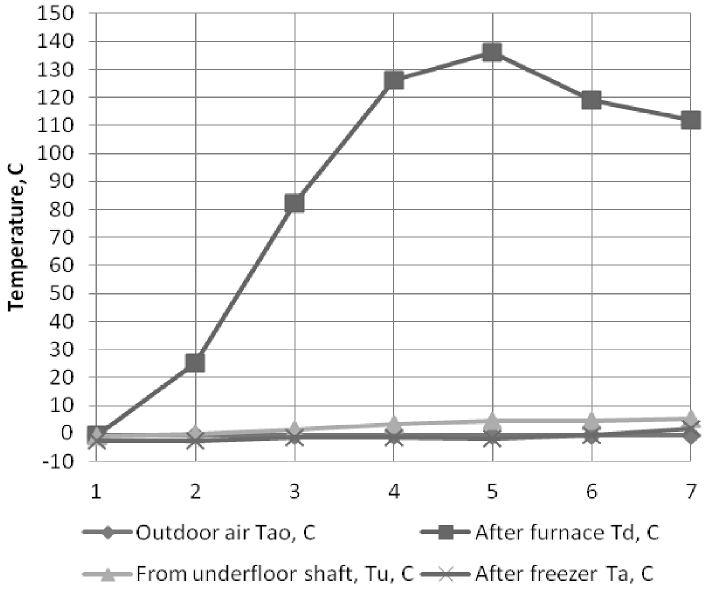

Fig. 1. **Average temperatures of the operation of innovative flue gas absorption structure**

Calculations of efficiency of the heating system by using the innovative flue gas heat absorption structure including freezer

The content of flue gas from burned firewood is determined based on firewood parameters [4]. If the moisture of wood is 20 %, then the total average amount of flue gas from 1 kg burned firewood and the content are following:

- total amount of flue gas V_d =4.69 m^3·kg^{-1};
- nitrogen V_{N2} =2.9 m^3·kg^{-1};
- water vapour V_{H2O}=0.88 m^3·kg^{-1};
- dry gas (CO_2 and SO_x), V_{RO2} =0.91 m^3·kg^{-1}.

The gross Q_a and the Net Q_z calorific values for firewood with water content 20 % are:
Q_a = 15623 kJ·kg^{-1} and Q_z = 14017 kJ·kg^{-1}.

The dew point of flue gas is approximately 55-60 ºC. Therefore the water is condensed, before it reaches freezer. The total recovered heat Q_T in all system consists of heat from vapour condensing (so called “latent heat”) Q_w and heat from gas cooling Q_c.

Water vapour parameters are following [5]:

- specific volume v'' = 1.6 m^3·kg^{-1};
- density ρ = 0.625 kg·m^{-3};
- enthalpy of vaporization r = 2253 kJ·kg^{-1}.

Recovered average heat from condensing of water vapour is following:

$$Q_w = V_{\mathrm{H2O}} \cdot \rho \cdot r = 0.88 \cdot 0.625 \cdot 2253 = 1242.2 \ \mathrm{kJ \cdot kg^{-1}} \tag{1}$$

and

$$q_w = \frac{Q_w}{Q_a} \cdot 100\ \% = \frac{1241.2}{15623} \cdot 100\ \% = 7.95\ \%\ . \tag{2}$$

Theoretical flue gas enthalpy:

$$H_{d0} = \Delta T \cdot \left(c_{\mathrm{CO2}} \cdot V_{\mathrm{RO2}} + c_{\mathrm{N2}} \cdot V_{\mathrm{N2}} + c_{\mathrm{H2O}} \cdot V_{\mathrm{H2O}} \right)\ \mathrm{kJ \cdot kg^{-1}}, \tag{3}$$

where ΔT – temperature difference between delivered air to furnace and air temperature in freezer output, ºC;
c_{CO2} – specific heat of CO_2, $\mathrm{kJ \cdot m^{-3} \cdot K^{-1}}$, (if t = 0 ºC, then c_{CO2} = 1.60, if t = 100 ºC, then c_{CO2} = 1.70);
c_{N2} – specific heat of N_2, $\mathrm{kJ \cdot m^{-3} \cdot K^{-1}}$, (if t = 0 ºC, then c_{N2} =1.295, if t = 100 ºC, then c_{N2} = 1.296);
c_{H2O} – specific heat of H_2O vapour, $\mathrm{kJ \cdot m^{-3} \cdot K^{-1}}$, (if t = 0 ºC, then c_{H2O} = 1.494, if t = 100 ºC, then c_{H2O} = 1.505).

Theoretical air enthalpy:

$$H_{g0} = \Delta T \cdot c_g \cdot V_0,\ \mathrm{kJ \cdot kg^{-1}}, \tag{4}$$

where c_g – specific heat of air, $\mathrm{kJ \cdot m^{-3} \cdot K^{-1}}$, (if t = 0 ºC, then c_g =1.32, if t=100 ^{0}C, then c_g =1.325);
V_0 – theoretical amount of air to burn 1 kg of firewood, $\mathrm{m^3 \cdot kg^{-1}}$ (V_0 = 3.67 $\mathrm{m^3 \cdot kg^{-1}}$).

Recovered heat from flue gas by cooling:

$$Q_c = H_{do} + (\alpha - 1) \cdot H_{g0},\ \mathrm{kJ \cdot kg^{-1}} \tag{5}$$

and

$$q_c = \frac{Q_c}{Q_\alpha} \cdot 100\ \%\ , \tag{6}$$

where α – air excess factor (assumed 1.5).

The results of calculations are summarized in the Table 2.

Table 2

Heat recovering calculation results

Flue gas temperature, ºC			**Enthalpy, kJ·kg^{-1}**		**Recovered heat by cooling Q_c,**		**Recovered heat by condensing water vapour**		**Total recovered heat $Q_T = Q_c + Q_w$**	
From fireplace, T_d	After freezer, T_a,	Difference ΔT=T_d-T_a	Flue gas teoret. H_{d0}	Air theoret. H_{g0}	kJ·kg^{-1}	%	Q_w , kJ·kg^{-1}	Q_w, %	Q_T , kJ·kg^{-1}	q_T, %
-0.6	-2.5	3.1	20.26	15.0	27.8	0.2	0.0 *	0.00*	27.8	0.2
25	-2.8	27.8	181.67	134.7	249.0	1.6	0.0 *	0.00*	249.0	1.6
82	-1.5	83.5	1091.21	406.1	1294.2	8.28	1242.2	7.95	2536.4	16.2
126	-1.4	127.4	845.81	619.6	1155.6	7.40	1242.2	7.95	2397.8	15.3
136	-1.7	137.7	914.19	669.7	1249.1	8.00	1242.2	7.95	2491.3	15.9
119	-0.5	119.5	793.36	581.2	1084.0	6.94	1242.2	7.95	2326.2	14.9
112	1.6	110.4	732.95	537.0	1001.4	6.41	1242.2	7.95	2243.6	14.4

* - there is no condensing. because the temperature of flue gas is less than vaporization temperature and the moisture remains on the furnace surfaces (the combustion is in beginning phase).

Conclusions

1. In the developed phase of combustion, the innovative system can recover approximately 15-16 % of heat in relation with fuel gross calorific value. When the efficiency of furnace is lower, then more useful the described system can be.

2. Accuracy of the experiments is also affected by transition regimes of the furnace operation. which could lead to increased loss due to incomplete combustion. and mass initial temperatures. Also due to different qualities of furnaces. there can be different relation between heat amounts used in boiler and recovered by system.
3. During the period. when the furnace is not working. built in freezer can work as a heat pump and to heat up the water for the household need.
4. When using wood with lower humidity. 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.
5. When calculations of flue gas enthalpy are worked out to ground the efficiency of heating system or boiler. usually only the heat that composes the temperature difference of flue gas is taken into account. It is correct. when flue gas is not cooled below dew point and efficiency is calculated in relation of Net calorific value. When the latent heat of water vapour is recovered. it is necessary to take it into account and to determine efficiency of boiler in relation of gross calorific value.

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