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Numerical Calculation of Heat Transfer in Water Heater

Michal Spilacek, Martin Lisy, Marek Balas, Zdenek Skala

***Abstract*—**This article is trying to determine the status of flue gas that is entering the KWH heat exchanger from combustion chamber in order to calculate the heat transfer ratio of the heat exchanger. Combination of measurement, calculation and computer simulation was used to create a useful way to approximate the heat transfer rate. The measurements were taken by a number of sensors that are mounted on the experimental device and by a thermal imaging camera. The results of the numerical calculation are in a good correspondence with the real power output of the experimental device. That result shows that the research has a good direction and can be used to propose changes in the construction of the heat exchanger, but still needs enhancements.

***Keywords*—**Heat exchanger, heat transfer rate, numerical calculation, thermal images.

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I. Introduction

THE power of numerical calculation and computer simulation provides an extremely convenient and powerful tool to analyze and design devices and procedures in remarkably short time at costs that are usually lower than the cost of traditional methods. In this paper we decided to use the computer simulation to obtain results of the heat transfer rate of a flue gas/water heat exchanger. We want the results to be in a good correspondence with experimental measurements and to provide us a way to improve the construction of the device to be more effective. To achieve this, we combined experimental measurements, calculation and computer simulation.

II. Description of the Experimental Device

The experimental device is originally designed for combustion of biomass. It consists of four main parts and several auxiliary parts. The main parts are (see Fig. 1): fuel feeder (5), combustion chamber (10), water heater (11) and air preheater (1, 2, 3, 4). For the purpose of this article only the gasification chamber and water heater are described. Every part of the device, its operation and regulation it described in [1].

A. Water Heater

The water heater is originally designed for combustion of logs of biomass and for our application is modified to combust syngas from the gasifying chamber. It consists of two main areas: a combustion area with a fixed water-filled grate and a convective area made of vertical and horizontal heat tubes. All walls are water-filled double walls. Other modification allows placing of three thermocouples and a pressure gauge for the measurement of temperatures and pressure respectively. Its nominal power output is 110 kW.

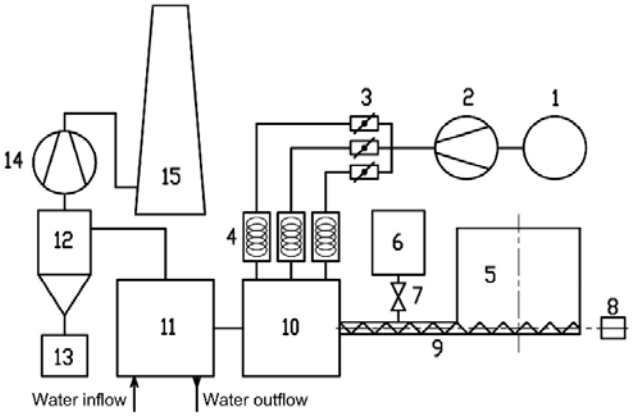


Fig. 1 Experimental Device – Diagram



Fig. 2 Experimental Device - Photo

B. Combustion Chamber

The combustion chamber is designed for combustion of loose wood, mostly wood chips and other similar biomass material. One of the main characteristic of these fuels is a high content of volatile matter. The construction of the chamber allows gasification of wood and subsequent complete combustion of produced syngas. The gasification takes place on an inclined fixed grate. Downwind the inclined grate is a horizontal fixed grate. For the research requirements were implemented many custom changes in the original design, so the measurement of desired units and changes in border conditions for combustion can be easily achieved.

The fuel is fed into the chamber from back side just above the inclined fixed grate. The primary air inlet is below the inclined grate and secondary air inlet above the inclined grate. The fuel then slides on the grate due to the gravity pull and the

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newly fed fuel push. At this stage the fuel is heated, dried and finally gasified. After the inclined fixed grate, the fuel reaches the horizontal fixed grate in form of ashes and is removed from the chamber. Only flame and syngas enter the nozzle of the chamber. At the beginning of the nozzle is the outlet of the tertiary air and after the mixing of syngas and the air can provide a complete combustion of the syngas before it leaves the nozzle.

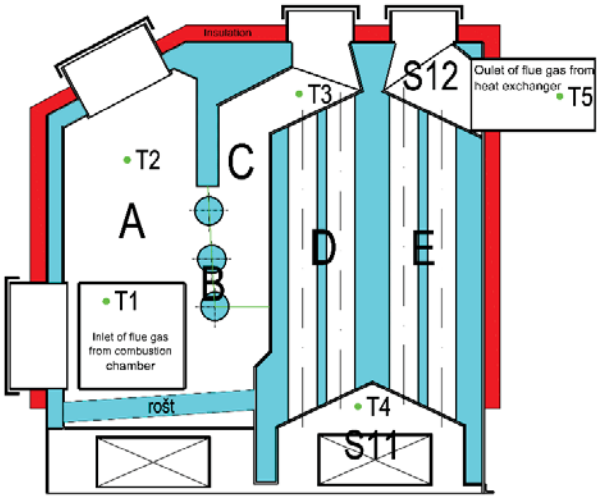


Fig. 3 Water Heater with Shown Sections of Calculation

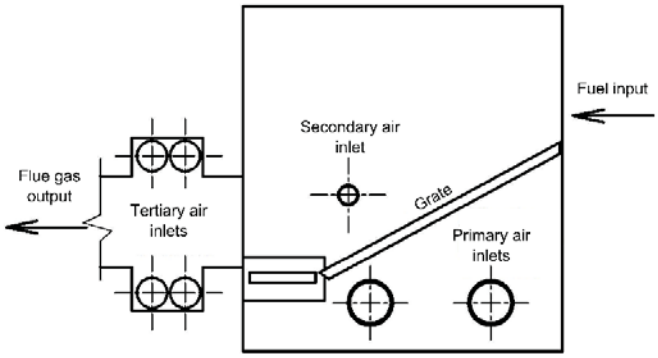


Fig. 4 Combustion Chamber – Diagram

III. Description of the Experiment

A. Introduction

The purpose of the experiment was to determine the state of flue gas that is exiting the gasification chamber and enters the water heater. Then the flow behavior of the flue gas and heat transfer in the water heater can be described. That divides the experiment in two parts: calculation of the gasification chamber and calculation of the water heater. For both calculations were used multiple methods to determine the state and behavior of the flue gas. The entire calculation process is not mentioned in this article. Only the main means and methods are briefly explained. The entire calculation can be found here [2].

The process of calculation is summarized in picture Fig. 5. Blue values have been obtained by experiments and measurements. Required and chosen values are in green and red values represent calculation outputs.

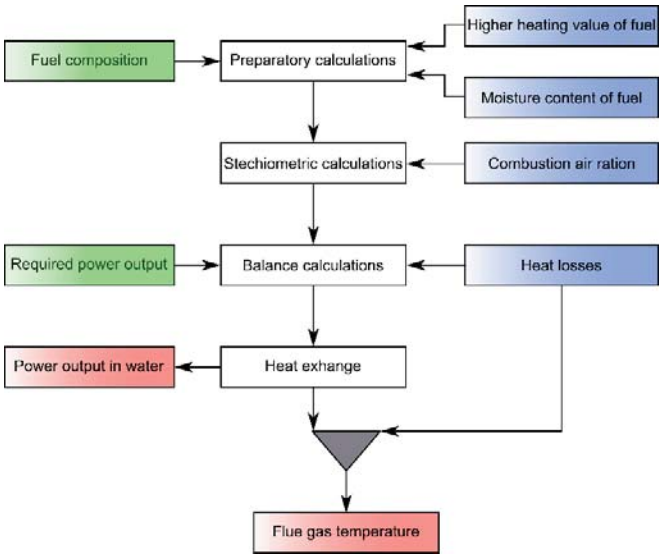


Fig. 5 Calculation Overview

TABLE I
Overview of Main Values

Name	Value	Description
Power output	110 kW	Required
Moisture content	35 %	Measurement
Higher heating value	13 400 kJ/kg	Measurement
Excess air ratio	2,26	Calculation
Combustion air temperature	199.5 °C	Measurement
Ambient temperature	25 °C	Measurement
Outlet flue gas temperature	178.83 °C	Measurement
Overall effectivity	77.4 %	Calculation

Table I shows the main values and how they have been obtained.

B. Calculation of the Combustion Chamber

The calculation of combustion chambers consists only from determination of the state of the flue gas when it exits the chamber. A standard calculation approach was used [3]. The properties of the fuel were measured to find out its higher heating value, moisture and composition. The fuel consumption at 110 kW heat output was found experimentally. Then a complete stoichiometric calculations presuming complete combustion were made to determine the amount of flue gas [4]. To find the state of the flue gas, the temperatures in the combustion chamber were experimentally taken and thus were determined the temperature, composition and velocity of the flue gas. To enhance the results, a thermo camera and surface temperature readings were made to determine the heat losses of the chamber. Convective and radiative heat transfers from the combustion chamber in the surrounding environment were calculated by dividing the examined surface in smaller areas and averaging their temperatures in their respective average temperature.

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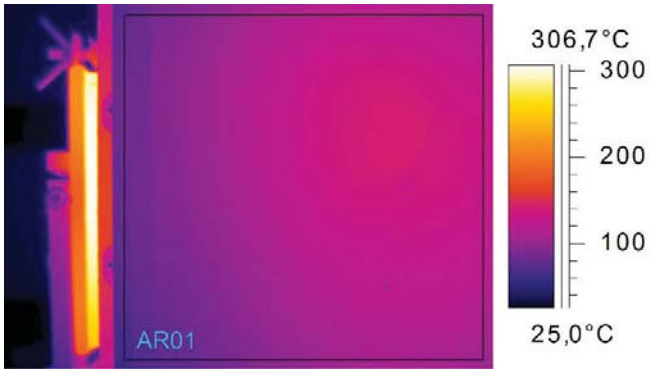


Fig. 6 Combustion Chamber – Top Side

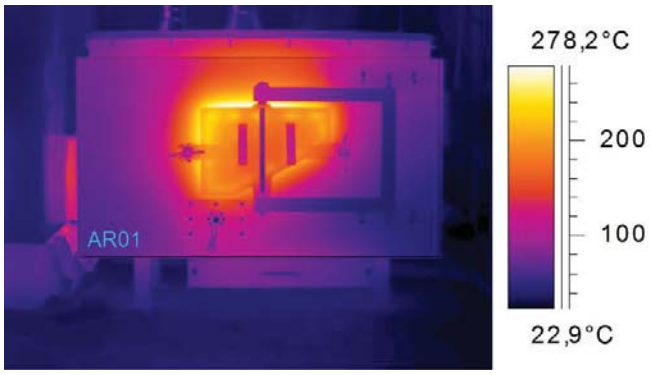


Fig. 7 Combustion Chamber – Left Side

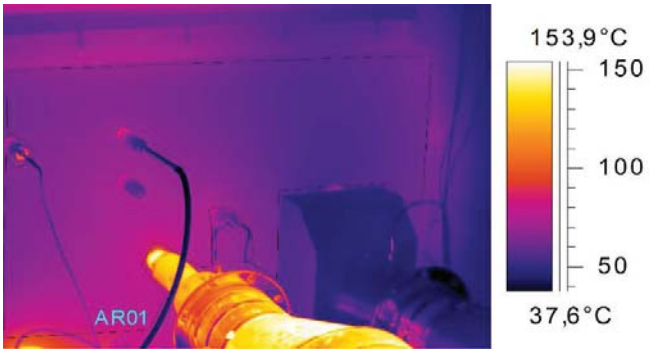


Fig. 8 Combustion Chamber – Right (Air Preheater) Side

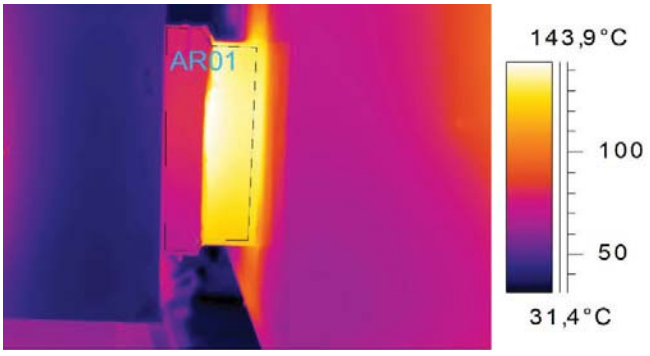


Fig. 9 Combustion Chamber – Nozzle

C. Calculation of the Water Heater

With the state of the flue gas now known, it is possible to describe the heat transfer in the water heater [5]. To determine this, it is necessary to also know the heat losses of the water heater and the flow characteristics of the flue gas. As in the case of the combustion chamber, a thermo camera was used to find the heat losses by radiation and convection.

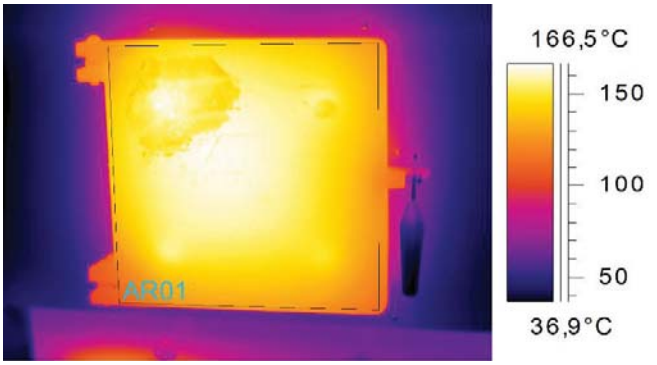


Fig. 10 Water Heater – Front Side Inspection Door

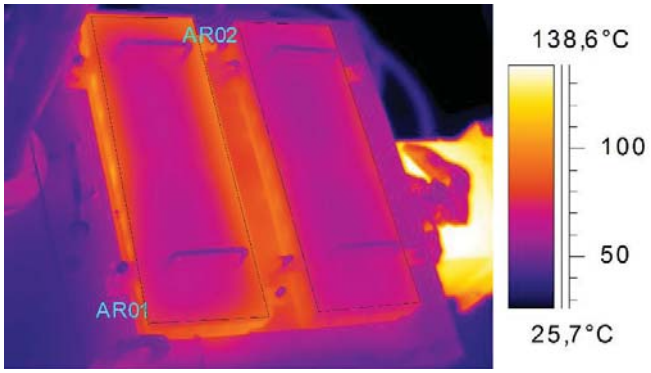


Fig. 11 Water Heater – Top Side Inspection Doors

Calculation of the flow characteristics that are essential to determine the heat transfer required a Finite Element Method. The programing was made in Star-CD software. The water heater was figuratively divided in several sections (see Fig. 3) and they were calculated sequentially downstream of the flue gas. For each section must have been found out mean flue gas velocity, that depends on temperature (initial) and for that velocity a heat transfer rate was calculated. From the heat transfer rate was calculated temperature that was compared with the initial one. One can get a better picture of this process from Fig. 12.

To have a fast convergence the initial temperature was experimentally taken. The resulting temperatures were also compared with the experimental temperatures. When all sections were calculated, the heat transfer of the water heater and the temperature of the exiting flue gas were obtained.

IV. Conclusion

With the obtained results and experimental measurements it is possible to evaluate the results. Only the calculated measured temperatures of the flue gas can be compared

directly. The temperature at the exit of the combustion chamber was: 959.4°C measured and 1062.6°C calculated. The temperatures of the flue gas at the exit from the water heater were: 178.8°C measured and 239.7°C calculated.

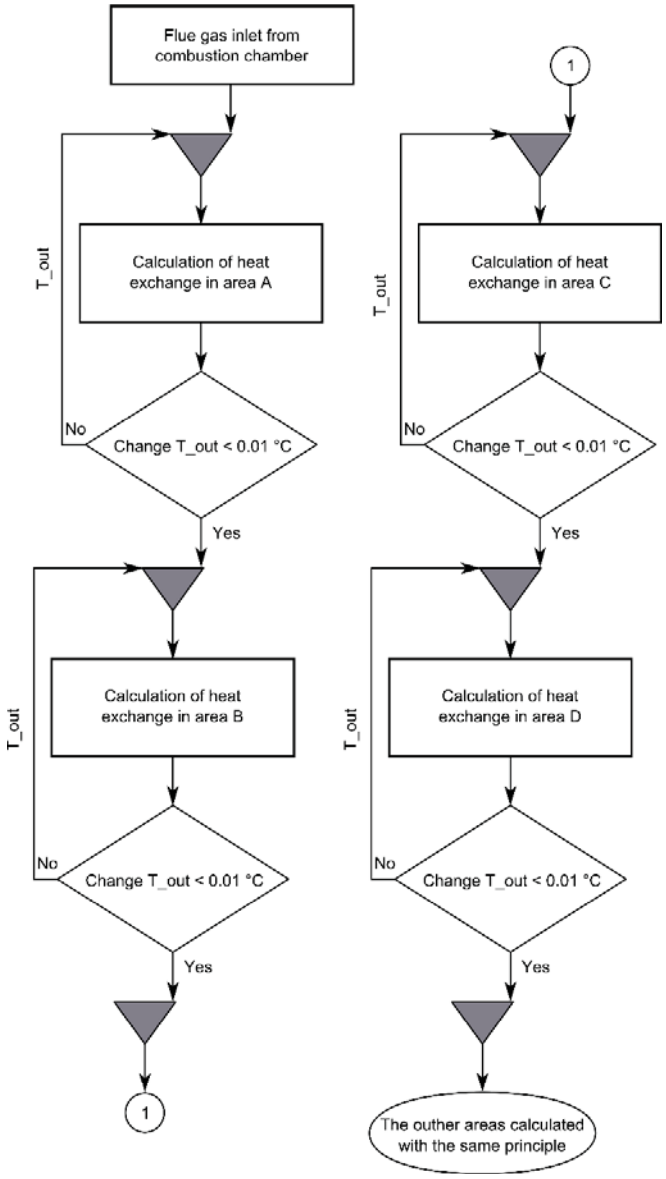


Fig. 12 Flow Chart of Water Heater Calculation

These results show a good correlation between measurement and calculation. That difference can be explained by unfinished combusted processes in the first case and by intake of "false" air and by varying moisture of the fuel in the second case.

The results can be further optimized and used to propose enhancements and improvements for the experimental device.

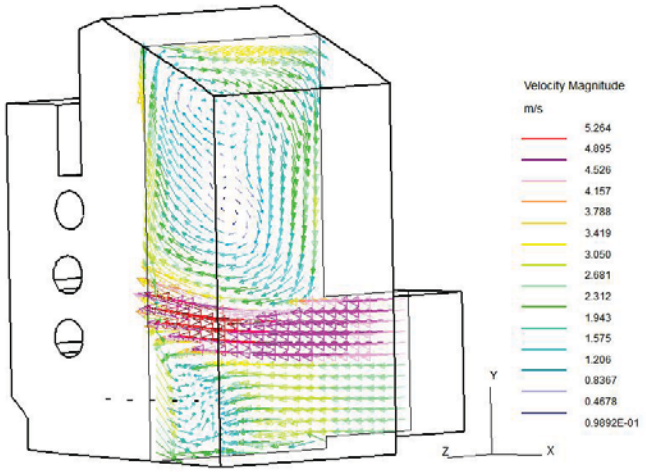


Fig. 13 Water heater sample flow

ACKNOWLEDGMENT

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REFERENCES

[1] M. Spilacek, "Experimental Device for Multi-Stage Combustion of Very Wet Biomass", ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering, 2014, available on-line: (http://annals.fih.upt.ro/pdf-full/2014/ANNALS-2014-1-09.pdf).

[2] J. Kois,"Computational Model of Kwh Boiler" available on-line:https://www.vutbr.cz/www_base/zav_prace_soubor_verejne.php?file_id=86875

[3] T. Dlouhý, "Výpočtykotlů a spalovacíchvýměníků (Calculations of Boilers and Heat Exchangers)", Praha, ČVUT, 2002. ISBN: 80-01-02591-8.

[4] A. Demirbas, "CombustionCharacteristics of DifferentBiomassFuels", Progress in Energy and Combustion Science, 2004, Volume 30, p. 219-230.

[5] F. Incropera et al, "Fundamentals of Heat and Mass Transfer", New York: John Wiley, 2007, ISBN: 04-714-5728-0.

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