TO THE PROBLEM OF FREE GAS FLOW MODELING IN THE ENERGY EFFICIENT STOVE FOR PRIVATE HOUSE AND OFFICE

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The novelty of the well-known in the world heat generators built on a principle of "free gas movement" lies in the organization of fuel combustion in the bell. The paper is devoted to study the processes of the heat and mass transfer inside the combustors with detail measurements of the temperatures, flow rates, etc. in different parts of the system to optimize its parameters and to build the strong theoretical backgrounds with mathematical modeling and simulation.

The computer simulation code is developed and tested for the investigation of any particular case and for the optimal stove construction by the stated request (functionality, productivity, fuel type, etc.). The computer code allows getting the drawings for the masonry that is going to build the stove in each particular case. The heat generators with a system of a free gas movement invented by Igor V. Kuznetsov (http://www.stove.ru) have shown the highest effectiveness in the world (up to 90%). Many of them having diverse functionality and construction were built and successfully implemented for private houses and small offices in USA, Canada, and Europe.

Presently such type of energy efficient ecologically clean stoves is demanded in the EU countries including Norway, Finland, Sweden, Denmark, etc. Customers request an optimal construction in each particular case and ask for basics about the thermal hydraulic processes in a free gas movement system and about the constructing and building the stoves, as well as about their use. The paper answers some of the questions and describes the basic features of the new effective stoves. The problem of the free gas movement modeling in the stoves is considered in the paper as the one of the most important for optimization of the stoves, for increase of the stove effectiveness and for their computer design.

Keywords: stove, modelling, free gas movement, ecologically clean, effective.

1. Introduction

Multistory heating stoves with a single firebox were designed by V.E. Grum-Grzhimailo and I.S. Podgorodnikov, V.P. Protopopov, I.I. Kovalevsky, N.F. Volkov and other authors [1-10]. All their designs follow schemes of the multistory stove heating systems from the book [1]. The "System of Free Gas

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Movement" was born in Russia at the beginning of the 20th century (1905-1912). Prof. V.E. Grum-Grzhimailo elaborated the basic theory of the stove construction and of the thermal hydraulic processes in the stoves [1].

His pupil I.S. Podgorodnikov followed the ideas of the teacher and successfully continued this work [3-8]. Many different types of the stoves were elaborated and adopted for diverse purposes and demands and theoretically substantiated. The free gas movement principle was further developed and explained with examples of the specific stove constructions.

Since the middle of 1960th, I.V. Kuznetsov has continued the work on further improvement of the system [9, 10]. He defined some basic principles that were not reflected in the previous work. In particular, basics for design of the stoves, functioning on the principle of "free gas movement" were formulated. More than 4000 stoves where designed and built by him and his team of masons since that time. He holds several patents on improvements in stove design and continues his work on the System. His team is currently serving Russia and Europe building several hundreds of different stoves a year.

In channel-free-bell-type furnaces the convective system consists of bells connected in series. When hot gases move through the bell, they go up and are accumulated in the bell where they uniformly warm up the walls or the heat exchanger that is provided in the bell. Cold gases being heavier go down and pass through the lower part of the bell into another bell or pipe exerting no influence on the heat exchanger.

Heat generators are built in accordance with the formula “The stove’s lower level and the firebox are combined to form a single space creating a lower bell”. The gist of the formula is as follows. It concerns fuel combustion in the firebox placed in the bell and optimum use of the extracted heat energy. The conception is aimed at receiving the maximum amount of a heat from the fuel combustion and its maximal use; the design of a heat generator shall meet functional requirements and ensure maximum heat transfer.

Hot air moves in the bell due to a natural convection and does not require external energy. Going through the lower zone of the bell hot air accumulates its heat, which is transferred to the bell’s walls and to the heat exchanger placed inside the bell. The surplus of heat (cooled air) will be exhausted.

2. The problem of a free gas flow modelling in the heat generators

The novelty of heat generators lies in the organization of fuel combustion in the bell. The firebox of heat generator is placed in the bell and is combined with it to form a common space. This formula foresees an obligatory availability of dry joint. The dry joint is a vertical crevice of 2-3 cm width connecting the firebox and the bell. The firebox can be different as far as the design is concerned as well as the principle of fuel combustion. This can be the principle of top combustion and the principle of bottom combustion, the principle of back burning, the principle of gas generation, etc.

Any fuel can be used for combustion. Combustion of fuel in the Russian stove represents the simplest case of fuel combustion in the bell. Such stoves for private houses have Performance factor up to 0.9 and can be multifunctional: heater, boiler, smoking (for meat, fish), etc. The stoves are built and successfully used in the different countries around the world, e.g. the one shown in Figure 1 was successfully built and is presently used in one private house of Sweden:

Fig. 1. Multifunctional stove built by the principle of "free gas movement" (Kuznetsov).

To meet the specific requirements of each customer and make the construction and design computerized, one needs the following further steps: to study the processes of the heat and mass transfer inside the combustors with detail measurements of the temperatures, flow rates, etc. in different parts of the system to optimize its parameters and build strong theoretical backgrounds with mathematical model. Computer simulation code will allow easily and promptly investigate any particular case and advice the optimal stove construction by the statement (functionality, productivity, fuel type, etc.).

The heat generators with a system of a free gas movement invented by I.V. Kuznetsov have shown the highest effectiveness in the world (up to 90%) up-to-date. Many of them having diverse functionality and construction were built and successfully implemented for private houses and small offices in USA, Canada, and Europe. Presently such type of energy efficient ecologically clean stoves is requested by a number of the EU countries people.

Customers requested advices by an optimal construction in each particular case and asked for the classes where they could learn basics about the thermal hydraulic processes in a free gas movement system and about the constructing and building of the stoves, as well as their use. Despite the stoves are highly efficient, ecologically clean and simple in use, they are as such ones if they are computed, optimized and then built by the optimal construction in each and every specific case according to the requirements of the customer.

Size of the stove, its functional elements (heater, smoker if needed, cooking part and so on), productivity, type of the fuel, etc. differ for different cases, and this is why even experienced masonry have problems to build the stove without preliminary consultation with the inventor. Therefore the main objective of the paper is to study the conception of this kind stoves and the maximum amount of a heat extraction from the fuel combustion. The other objectives are:

- design a heat generator meeting functional requirements, which ensures maximum heat transfer;
- develop the mathematical model for free gas movement system;
- numerical simulation of the processes inside the stove and optimization the energy efficiency;
- analysis of the data obtained with a computer model.

The created theory for design and construction of the residential masonry heaters based on “principle of free gas movement” has been partially proven successful by the hundreds of different masonry heaters designed and built under supervision of I.V. Kuznetsov all around the Europe. But there is much to do in the future for further validation of the model against experimental data. The following types of the stoves were constructed and built:

- numerous heaters with heated benches or even a “heated bed”
- two- and three-story stoves for multistory buildings that work on one chimney flue. These stoves may have various functions, including open fireplaces, hot water coils, bake ovens and other in any combinations
- multifunctional stoves with built-in hot water heating system (coils or tanks) that is used as a back-up and preheating system in the heating systems.

3. Substitutive equations of the model

The mass and momentum conservation equations for a gas flow are considered together with the energy conservation equations for a gas inside the stove and inside the room heated, as well as for the stove walls and in general for the building walls are implemented. In the Cartesian coordinate system (x,y,z) the equations are represented:

$$\nabla \cdot \vec{V}_1 = 0, \qquad \frac{\partial \vec{V}_1}{\partial t} + (\vec{V}_1 \cdot \nabla)\vec{V}_1 = -\frac{1}{\rho_1}\nabla p_1 + \nu_1 \Delta \vec{V}_1 + \rho_1 g \beta_T \Delta T_1, \qquad (1)$$

$$\rho_1 c_{v1}\left(\frac{\partial T_1}{\partial t} + \vec{V}_1 \cdot \nabla T_1\right) = \nabla\left(\lambda_1 \nabla T_1\right), \quad \rho_s c_s \frac{\partial T_s}{\partial t} = \nabla\left(\lambda_s \nabla T_s\right), \qquad (2)$$

where ∇, Δ are the Hamilton and Laplace operators, $\vec{V}_1, p_1$ - velocity vector and pressure of a gas flow, T is a temperature, ρ, c, λ - density, heat capacity and heat conductivity, correspondingly, β_T - thermal expansion coefficient. Index 1 depicts a gas, and index s corresponds to the material of a stove walls.

Similar equations are considered for the gas inside the room, which is heated and inside the rooms' walls if the general problem is solved. The gas flow equations are simplified with account of the low gas compressibility due to low velocities of the gas thermal convection. Thus, flow is incompressible and viscous dissipation in the energy conservation equations is neglected supposed that it is small comparing to the thermal convection and heat conduction.

The combustion process in this model is not taken into account. Instead of that the volumetric heat generation is accounted as a result of the fuel combustion inside the fire box of the stove. Therefore to start the modelling one needs account for the heat generation from the fuel combusted in the fire box. Afterwards the gas flow and temperature evolution inside the stove is computed from the equation array (2), (3). The initial conditions are stated as the room temperature everywhere and absence of the gas flow inside the stove and inside the room too. On the internal walls of the stove the heat exchange between the gas flow and the wall is stated. Similar condition is stated on the external walls of the stove.

4. The objectives for the modelling and the most important tasks

Plan of a proposed research and testing of the stoves built by a "single-" or a "double chamber" ("double bell") design aims to find dependence of stoves' thermal hydraulic characteristics on particular constructive solutions and materials used. The goals of the research were stated as follows:

- find an optimal temperature of the exhaust gases and their optimal mix to achieve the cleanest and the most efficient combustion
- prepare recommendations on the optimal proportions of stoves' elements

- prepare recommendations for the use of “free gas movement” principle in various industrial applications
- test different multifunctional stoves designed and built by this principle
- collect data necessary for designing of various calorific stoves (stoves using a heat carrier to bring the heat to the required areas) and stoves-boilers (fuel: regular firewood and wood pellets).

The proposed research program allows:

1. Build a stove based on a “single-chamber” design incorporating principle of a “top burn”. The stove should be constructed the way it can be easily converted into a contra flow stove. Test both variants on different stages. Test different designs of the firebox to achieve the highest efficiency.
2. Build a stove of a size sufficient for installation of a hot water coil, hot water tank (a permanent “cold zone”) inside a chamber. Test it as in 1. Install different catalysts in the firebox to achieve the cleanest burn.
3. Conduct similar testing building a firebox (or parts of it) from a material with a high thermal conductivity. The goal is to achieve rapid equalizing of the firebox walls’ temperature and temperature of the gas flow to increase temperature of the gases entering the heat-exchanging chambers.
4. Test various firebox designs during different burning cycles including “continuous burn”, “bottom burn”, “backfire”, etc. Test it as in 1. The the same but in a stove with a hot water heating coil/tank, to develop designs for various stoves-boilers using wood pellets as a fuel.
5. To build a stove with a heat accumulating mass with an automatic regulation of the heat output.

The Solidworks code is implemented for the graphical design of the stove, numerical simulations of the thermal hydraulic processes, and optimization of the stove efficiency. Then by the achieved optimal thermal hydraulic parameters the computer design of the stove is made automatically.

5. Solidworks computer modeling of the stove

A computer model of the stove is first made in the Solidworks construction system according to the requirements of the specific customer. All requested elements are included and the desired geometry is prescribed for this preliminary design. This is a first draft design (see Figure 2), which allows starting the modelling of a thermal hydraulic processes in the system.

With the preliminary draft construction of the stove by demand stated the thermal hydraulic processes are modelled and simulated on computer like the one shown in Figure 3, where the temperature distribution and the gas flow field inside the stove are represented. These parameters, as well as the detailed gas flow trajectories allow analyzing all peculiarities of the processes in the stove.

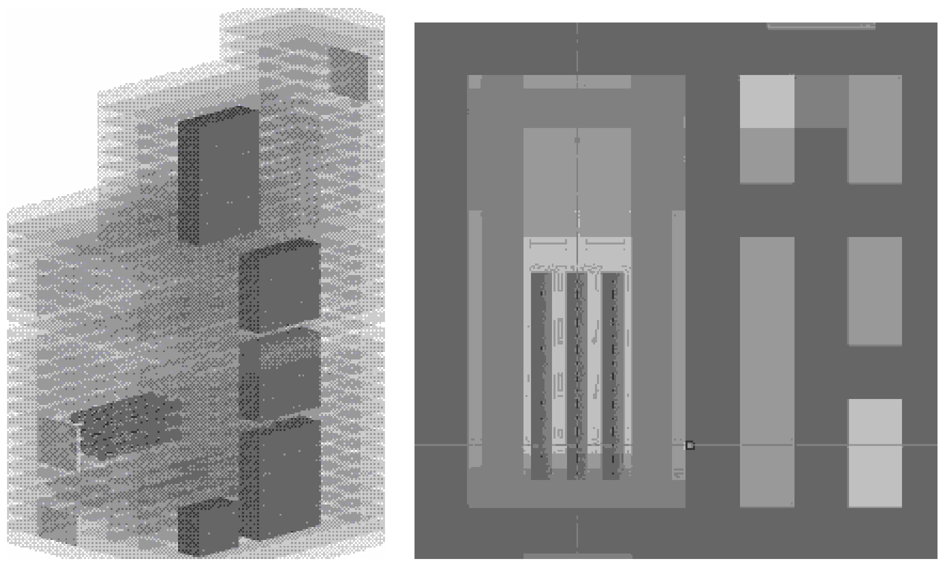

Fig. 2. 3-D model of the stove construction (to the left) and the view from the top (to the right).

Based on the results of such calculations investigator estimates how the gas is moving inside the stove and how the temperature is varying with time. It is important to find the requested temperature distribution so that to achieve the goal of the heating, while from another point of view it is important to know the uniform temperature distribution and the exhaust gas temperature and flow rate.

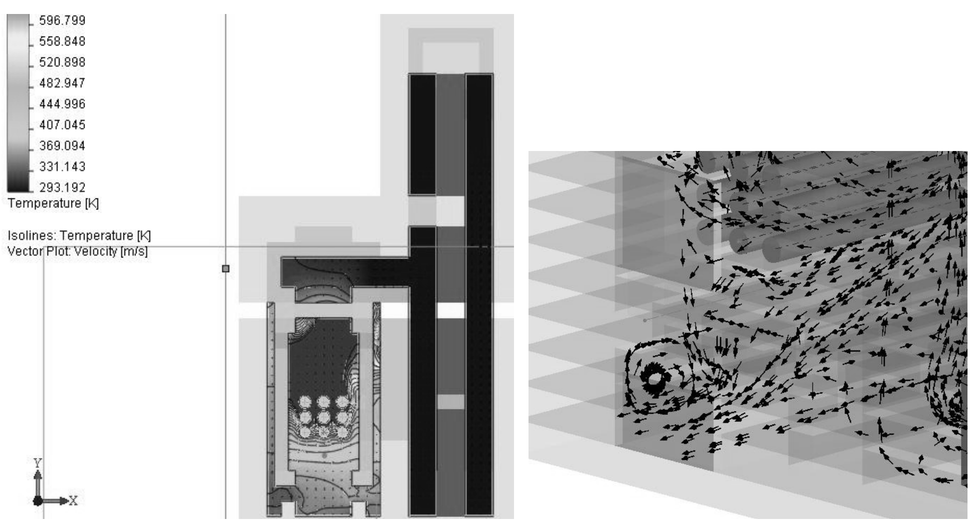

Fig. 3. Parameters of the thermal hydraulic processes and gas flow trajectories (right picture).

Then by the parameters achieved the exhaust gas flow rate and the flow temperature are computed. By these parameters the performance factor of the stove is determined as the ratio of the utilized heat to the whole amount of a heat produced in a fire box. To increase the performance factor or to achieve another goal, e.g. more uniform temperature distribution by the stove walls, one needs to perform simulation using control parameters including variation of the geometric ratios in different places of the stove, configuration of the fire box, intensity of the combustion, etc. Based on this, the new optimal construction and the corresponding stove parameters are sought in the computer simulation. Finally the optimal stove construction found by simulation is designed in the Solidworks platform, which produces the stove detailed drawings for masonry.

6. Conclusions

Basic model of the thermal hydraulic processes for the free gas movement stove and the design computer model are presented and tested. The platform created has shown its applicability for the computer design and optimization of the construction for an ecologically clean and highly efficient stove. The obtained instrumental system is of importance for the prompt stove design according to a specific demand of the customers and it may be used for the projecting and building the stoves with a “free gas flow” system.

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