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Research paper

Research of Operation Factors of the of Bullerjan Stove in the Program Environmentfor 3D Simulation

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Abstract

The article is devoted to the calculation of the thermal power of the Bullerjan stove according to a preconstructed model, which is realized in the 3D modeling environment of SolidWorks 2016. The thermophysical characteristics of the processes passing through the heat pipes of the Bullerjan stove were studied in detail. In the course of the work, the values of airflow velocity and temperature distribution, the temperature distribution of a solid, the surface of the heat pipe, that in the end allowed us to obtain the values of the heat output of the oven. The obtained data made it possible to determine the value of the heat output of the oven on the mode of smoldering wood and on the mode of flaming burning. The thermal power of a Bullerjan stove and in particular, its flow simulation module for modeling the flow of liquids and gases were obtained.

Keywords: *Bullerjan stove, domestic oven, heat transfer, thermal power, 3D modeling*.

1. Introduction

Any of the heats the air and the efficiency of its heating will depend on the size of the oven itself - the bigger it is, the faster the air will heat, because there will be more heat transfer area. Outside, the oven Bullerjan is similar to the usual "burzhuyka", but compared to the latter it has great opportunities in heating air, realizing heat exchange in three ways - radiation, convection and heat transfer. In this not too complicated design, Bullerjan is combined at once with three devices - the oven itself, the heater and the gas generator.
The air temperature directly at the very exit from the air pipes during the combustion of the oven reaches as much as 110-120 ° C. Smoldering wood fuel in the first (lower) combustion chamber forms a special generator gas - it is combustible and is capable of providing additional thermal energy during its combustion. True, for its formation it is necessary to burn exceptionally dry firewood and for the complete combustion necessary conditions that Bullerjan can provide only partially (for the complete combustion of such generator gases, air supply under pressure, and also a special catalyst and a much higher temperature, than Bullerjan develops).
The "Bullerjan" stove operates in two modes. The first one is the ignition, during which normal working temperature is achieved inside of the oven, and the air in the heated room quickly warms up, reaching the optimum level. The second mode is the gasification, when the oven switches about half an hour from the time of the beginning of the kindling and after the rapid heating of your cold room. To transfer to the gasification mode, the Bullerjan firebox is filled with firewood "to the point of failure", closes the doors and sets the angle of opening of the dampers in order to reduce the amount of air entering the furnace. As a result, wood fuel will not burn with an open flame, but will smolder, while the air temperature at the outlet of the air pipes will be reduced to 55-60 ° C. One full firing of wood in the oven Bullerjan is enough for 10-12 hours of heating [1].
Different manufacturers indicate the power of the oven depending on their geometric dimensions while significantly overestimating not only it, but also the efficiency. The aim of the paper is to calculate the thermal power of a "Bullerjan" stove from a preconstructed model in the 3D modeling environment of SolidWorks 2016 and in particular its flow simulation module for modeling the flow of liquids and gases.
Flow simulation is software that is fully integrated into SolidWorks for the calculation of liquid and gas flows inside and outside the SolidWorks model, and calculates heat transfer from, to, and between these models by convection, radiation and thermal conductivity using the technology of the computational hydrodynamics (CFD).

2. Analysis and Modelling

The parametric model of the oven is shown in Fig. 1 and is an oval barrel-shaped steel case, a two-tier furnace, from and through which are vertically held fourteen air tubes, bent in the middle to the center of the furnace itself. Outside there are oven doors, a regulator of giving of the air and a smoke flap, the usual pallet for removal of ashes is absent. The original design of the Bullerjan stove can also solve the problem of air pressurization for heating, avoiding the use of electric fans - convection provides only the difference in temperature at the entry and exit points of the air from the pipes passing through the furnace oven.

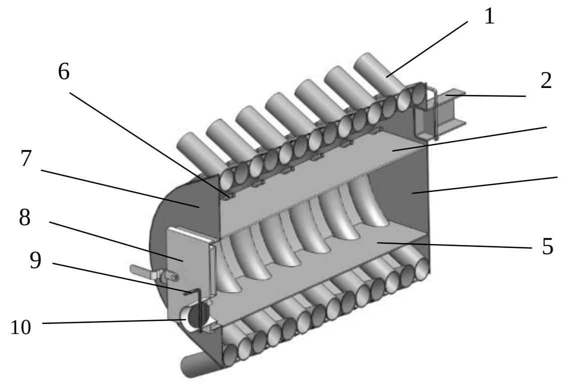

Fig. 1: "Bullerjan" stove:1. Heat pipe; 2. Chimney branch with regulator; 3. The secondary chamber; 4. Back wall; 5. Primary chamber; 6. Injector; 7. Front wall; 8. Loading door; 9. Handle of the power regulator; 10. Ash-pit.

The process of heat transfer in the case of free convection (free motion) of a liquid is very widespread both in engineering and in everyday life. Free fluid movement is considered to be due to the difference between the densities of heated and cold particles. For example, when the air contacts the heated body, the air heats up, becomes lighter and rises. If the body is colder than air, then, on the contrary, from contact with it, the air cools, becomes heavier and falls down. In these cases, the movement of air occurs without external stimulation because of the heat exchange process itself.

In the case of the heat emission in a confined space, the heating and cooling processes of the liquid take place close to each other and they cannot be separated; in this case, the whole process should be considered as a whole. Due to the limited space and the presence of ascending and descending currents, the conditions of movement become more complicated. They depend on the shape and geometric dimensions, the kind of fluid and the temperature head [2].

Combustion of wood it is a self-accelerating exothermic chemical reaction with oxygen, which is able to support itself due to backward coupling spread in space. But to initiate this reaction, an initial impulse of external thermal energy is needed. The transition from the slow process of decomposition of wood material to the combustion mode corresponds to the condition that the rate of heat evolution as a result of a chemical reaction becomes greater than the rate of heat losses from the reaction zone.

Phenomenological picture of the beginning and development of the process of fiery wood burning can be represented as follows.

Under the influence of an external heat flow directed to the surface of the wood due to thermal conductivity, radiation and (or) convection, the material heats up. In a dry state, the wood is characterized by low gas permeability and has a structure with predominantly closed pores; therefore, volumetric interaction with air oxygen is difficult. When a sufficiently high temperature is reached on the surface of the wood, pyrolysis begins with the formation of volatile vapor and gases, as well as non-volatile decomposition products in the condensed state. Gases and vapors of combustible products are emitted and they mixed with air in the boundary layer with the surface.

When the content of this mixture begins to exceed the lower concentration limit of ignition of combustible substances, their ignition occurs. This process can be spontaneous or initiated by an additional small ignition source localized in the boundary layer. Such a "pilot" source can be a small flame of a gas burner, an electric spark or a red-hot wire. After ignition, the heat flow directed to the surface of the wood is a combination of external and reverse heat flows from the generated flame.

The ability to support the combustion process due to the flow of heat from its own flame (qfl) to the neighboring layer of original wood, even in the absence of the original external heating (qe), is the basis for the development of combustion and flame spread along the surface of the wood. When burning, the source of energy is the release of heat as a result of the chemical reaction of fuel oxidation, the main property of which is expressed by the exponential dependence of its velocity on temperature. The rate of heat release during combustion Q″ (kW / m2) per unit surface area is:

$$Q'' = \eta \cdot m'' \cdot \Delta Hc, \quad (1)$$

where η - coefficient of combustion completeness;
m″ - the mass burnup rate per unit surface area, g / (m2 • s);
ΔHc – he low heat of complete combustion of fuel, kJ / g.

The moisture content in the wood samples affects the heat dissipation dynamics. With an increase in the moisture content, ignition slows down, the maximum heat dissipation rate ($СТВ_{макс}$) decreases both at the first and at the second stage of the process. The time to reach peak values of heat release $\tau_{макс}$. Снижается общее тепловыделение за определенный период ($ОТВ_{\tau}$). Under the influence of external heat flows, which begins at a temperature of 110 ° C, further heating is accompanied by the removal of free and bound moisture from the wood. This process is completed at a temperature of 180 ° C, after which the decomposition of the least heat-resistant components begins with the emission of CO_2 and H_2O. At a temperature of ~250°C pyrolysis of wood takes place with the release of gaseous products: CO, CH_2, H_2, CO_2, H_2O. The released gas mixture is combustible and is capable of igniting from the ignition source. At higher temperatures, the process of thermal decomposition of wood is accelerated. The main mass of combustible gases containing up to 25% hydrogen and up to 40% combustible hydrocarbons is released in the temperature range from 350 to 450 ° C [3].

Table 1: Influence of a variety of samples of coniferous and leafy wood species, as well as the density of the external heat flow on the characteristics of heat release [3]

Sample			q_e, кВт/м²	$\tau_в$, с	$\tau_{1макс}$, с	$СТВ_{1макс}$, кВт/м²	$\tau_{2макс}$, с	$СТВ_{2макс}$, кВт/м²	$ОТВ_{2мин}$, кВт·мин/м²
wood species	ρ, кг/м³	W, %							
			20	10	40	94,8	279	202,1	142,5
Spruce	422	6,4	35	< 10	23	131,2	195	233,2	218,2
			52	< 10	<20	141,8	159	256,1	270,2
			20	10	43	98,2	354	159,3	128,8
Pine	448	6,0	35	< 10	20	129,0	276	203,5	180,6
			52	< 10	<20	137,0	247	247,3	202,0
			20	23,3	63	104,9	284	321,9	149,3
Birch	567	5,5	35	10	53	157,7	215	400,5	279,9
			52	< 10	33	190,8	184	459,6	377,2
			20	20	67	100,9	362	227,7	127,1
Oak	638	4,3	35	10	33	131,3	281	245,1	198,0
			52	< 10	27	161,6	246	312,0	261,6

Using the research in [3], it is possible to determine how much heat is released when a certain amount of wood is burned.

Since the task is to determine the thermal capacity of the oven, that is, the study of heat exchange processes, rather than combustion processes, the following assumptions are introduced:

- The combustion material (wood) is represented as a volumetric heat source of cylindrical shape;
- The volume of wood is 35% of the total oven furnace volume;
- In order to save computer resources, the calculation is carried out for a single heat pipe;
- The volumetric heat source is segmented in percentage terms relative to the heat pipe area participating in the heat exchange process.

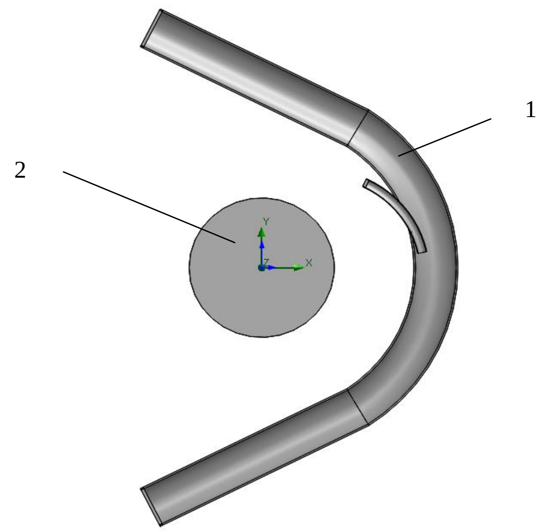

Fig. 2: Parametric model of a heat pipe with a volumetric heat source: 1. Heat pipe; 2. Segmented heat source

The calculation is carried out for two processes of burning wood: smoldering and flaming.
In the calculation parameters of the physical model, both the thermal conductivity in solids and the radiant heat exchange were included. This allows solving the problems of the conjugate heat exchange, i.e. consider convection in conjunction with thermal conductivity in solids and radiant heat exchange.
In this task, heat transfer from a volumetric source of heat through the walls of the model to a fluid carrier and heat exchange inside the bodies are investigated. In the conditions the heat emission from the outer walls of the model to the fluid is specified on the wall, which is located outside the model and is not indicated in the project. The value of the heat emission coefficient is set at 15 $W/m^2/K$.
Then atmospheric pressure equal to 101325 Pa at the inlet to the heat pipe and the air outlet velocity equal to 1 m / s are assumed as boundary conditions or initial data for calculation.
And also the heat dissipation capacity of the volumetric heat source for the process of smoldering wood (pine) is 7700 W and 12147 W for the flame process.
The temperature and velocity of the fluid medium, the temperature of the solid, as well as the density of heat flow are established as a global goal.

3. Results

The results of the calculations are shown in Figures 3, 4, 5, 6, 7, 8, 9, 10 and in Table. 2, 3.

The process of smoldering wood

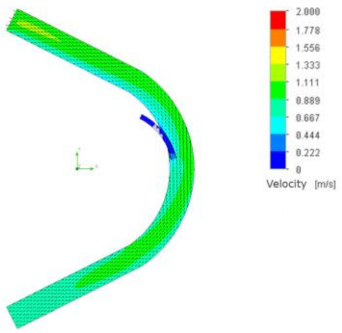

Fig. 3: The flow rate distribution

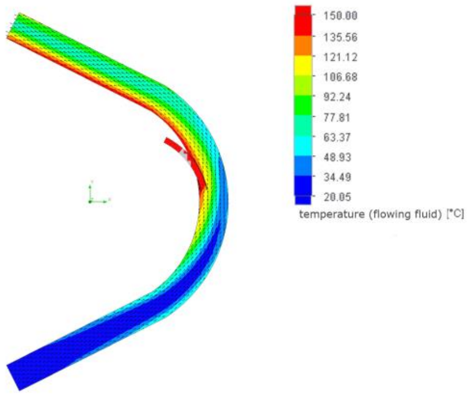

Fig. 4: The distribution of airflow temperature

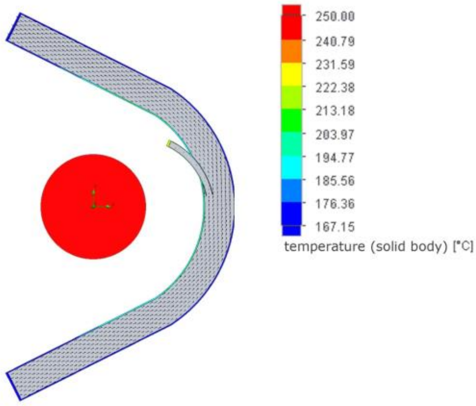

Fig. 5: The distribution of the temperature of a solid in the cross section

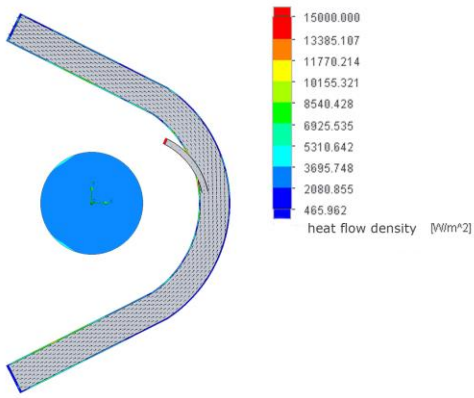

Fig. 6: The distribution of heat flow density over the pipe surface

Table 2: The calculating results of the surface parameters of a heat pipe on a smoldering mode

Local parameter	Minimum	Maximum	Average	Average expense
Pressure [Pa]	101323,7094	101324,8531	101324,2944	101324,2944
Velocity [m/s]	0	1,024652238	0,020677203	0,91001329
Coefficient of heat emission [W/m^2/K]	5,46332E-07	117,2379249	5,789738504	
Surface density of heat flow [W/m^2]	-5381,959052	20759,26806	207,0528564	
Temperature (fluid carrier) [°C]	20,05	213,9982325	170,7340278	58,12510938
Temperature (solid body) [°C]	122,1259215	378,7972701	203,5591928	

The process of flaming wood burning

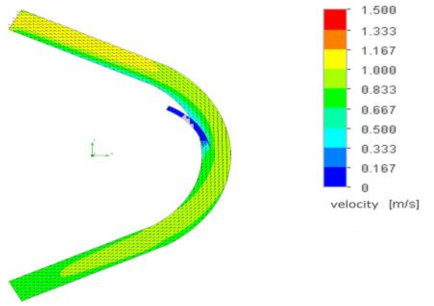

Fig. 7: The distribution of flow velocity

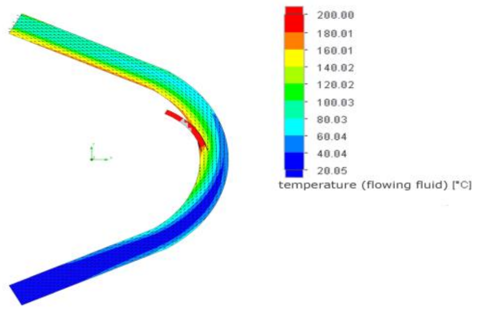

Fig. 8: The distribution of air flow temperature

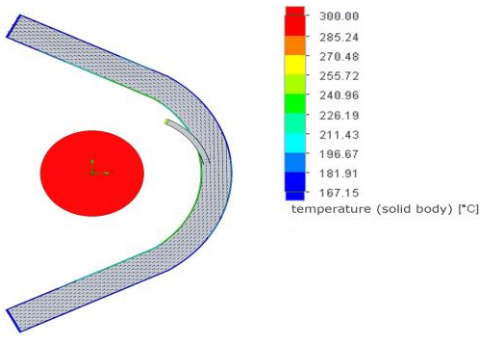

Fig. 9: The distribution of the temperature of a solid body in the cross section

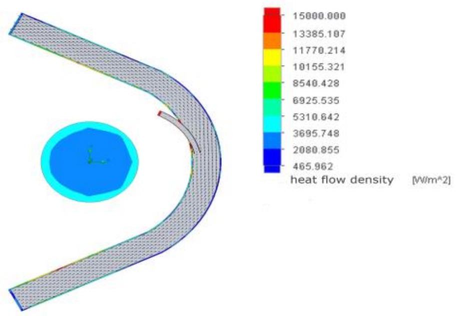

Fig. 10: The distribution of heat flow density over the pipe surface

Table 3: The calculating results of the surface parameters of the heat pipe in the mode of flaming combustion of wood

Local parameter	Minimum	Maximum	Average	Average expense
Pressure [Pa]	101323,7084	101324,8232	101324,3044	101324,307
Velocity [m/s]	0	1,025152337	0,020437312	0,899341273
Coefficient of heat emission [W/m^2/K]	3,78422E-07	111,6866805	5,7971479	
Surface density of heat flow [W/m^2]	-6303,166857	23302,02952	229,4582246	
Temperature (fluid carrier) [°C]	20,05	248,9286027	187,1723363	63,34970333
Temperature (solid body) [°C]	135,7460009	440,2111238	226,4916632	

The obtained data made it possible to determine the value of the heat output of the oven on the mode of smoldering wood and on the mode of flaming burning at a level of 5 kW and 6 kW, respectively.

4. Conclusion

As a result of the calculations, the thermophysical characteristics of the processes passing through the heat pipes of the "bullerjan" stove were studied in detail.

Numerical modeling has made it possible to evaluate the influence of certain environmental factors on the results of experimental researches of various phenomena in low-velocity flows. Using the capabilities of Flow simulation allowed us to solve the problem of developing a new oven with a maximum close to the real values of the power parameter quickly.

This method allows carrying out calculations at different values of the heat source power, due to which it is possible to vary the choice of construction materials to achieve the optimum efficiency coefficient.

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