Numerical research of thermal stress in a gas burner with a cylindrical mantle in relation to its construction

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Abstract. Over the last few years there has been a great interest in research into the improvement of gas condensing boilers with pre-mixing. Many researchers are concerned with the improvement of the construction of these boilers, whose individual parts directly affect some parameters such as combustion efficiency, burning intensity, flame stability and NOx emissions. The outer mantle of a cylindrical burner stands out among the parts of the structure as the said parameters depend on it This paper analyses the outer cylinder of the premixed burner in relation to thermal stress. Numerical FEM analysis was performed based on experimental measurements and CFD input data. The tests were carried out in different gas and different materials. The results obtained show different thermal stresses which are dependent on the different gas and materials on the outer cylindrical mantle. This indicates the necessity to optimize materials and patterns applied to the outer cylindrical mantle of the burner, which will be the subject of further research.

1. Introduction

In this paper, we tried to contribute to the development of new flexible premix-burners with a large modulation of power 1:3, produced from specially optimized materials, with reduced emission of harmful combustion products, intended for condensing boilers in heating systems. This construction is subjected to the study of thermal stresses, both in the stationary mode of operation and in non-stationary ones. Increasing the flexibility of gas burners refers to the aspect of fuel, or the ability to use a variety of gaseous fuels such as natural gas, liquefied petroleum gases, biogas, natural gas of low thermal power. The construction requirements refer to finding the optimal material and optimal geometry of a high degree of perforation burners.

Many researchers are concerned with the improvement of the construction of these boilers, whose individual parts directly affect some parameters such as combustion efficiency, burning intensity, flame stability and NOx emissions. Weibo Chen and Guixiong Liu [1] studied the temperature of combustion, flow, CO distribution and NOx emissions of 10MW gas burners at different primary and secondary air ratios numerically using the Fluent software. Schiro and others [2] emphasize that the composition of gaseous fuels is expected to differ significantly in the coming years due to several factors, such as injection of biogas and hydrogen on the gas network. They note that each gas device has its own characteristic response to the changed input quality, so any future requirement for increased tolerance to gas composition and heat value will require customized activity to optimize the design of the burner. Pil Hyong Lee and Sang Soon Hwang [3] studied a thin premix flame on the surface of a cylindrical burner. They focus on the emission characteristics of this flame and the effects of flow distribution on the stability of the surface flame in the cylindrical porous or perforated mantle of the burner. For the production of a flat cylindrical flame it has been found that it is very important to choose the appropriate hole arrangement - the pattern and construction of the flame mount that prevents the flame from escaping at the edge of the cylindrical burner. Mohammad Hossein S. M. and others [4], investigate geometric parameters related to thermal efficiency and emission of burner pollution with large number of holes, flat flame openings. They conclude that the shape and number of main holes and the distribution network can be studied as a separate topic. Seungro Lee and others [5] in their study experimentally tested a cylindrical burner with a large number of openings, a hole for its use in a condensing gas boiler. Jithin Edacheri Veetil and others [6] worked on a numerical study of the structure of laminar-coated flames on perforated plate burners. They performed three-dimensional numerical simulations on different geometries of perforated plates, under different operating conditions.

As we see, many scientists are concerned with the construction of condensation premix burners.

The outer mantle of a cylindrical burner stands out among the parts of the structure as the said parameters depend on it. This paper analyses the outer cylinder of the premixed burner in relation to thermal stress.

2. Model cylindrical burner

The gas combustion process simulates with the help of numerical simulation of CFD software and software for simulating chemical kinetics, and the results of these simulations are compared with experimental prototype measurements. In this paper, the results of these investigations will be taken as input data and we will not describe them here. They helped us to get the heat field on the outer mantle, confirmed by experimental prototype measurement. Testing of the gas burner model was carried out with specific test installations and a test model of a boiler with a gas burner. On Figure 2.1 and Figure 2.2 can see how look the outer burner mantle after testing, and on Figure 2.2 can see how look complete test installation.

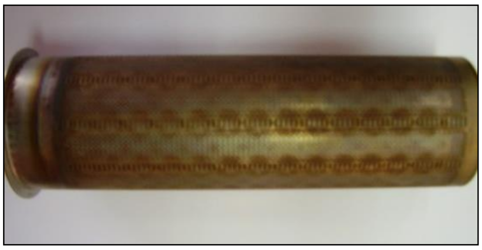


Figure 2.1. Appearance of the outer burner mantle after testing

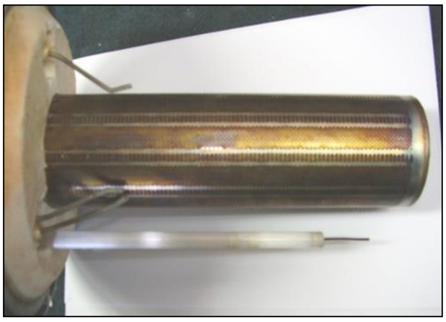
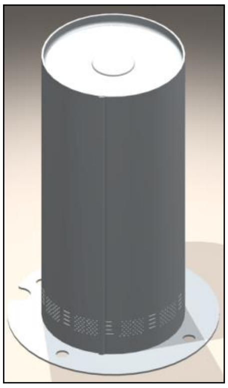


Figure 2.2. Burner with thermo-steam

Figure 2.3. Prototype boiler and premix gas burner with complete test installation

3. Numerical model of gas burner

Complexity of geometry, requires preliminary analysis of segments of gas burner. Figure 3.1 shows a CAD model showing an outer mantle, a cylinder of over 7000 holes in diameter ϕ 0.8 [mm] and other shapes of the opening from whose layout and the behavior of the loaded gas burner with a thickness of 0.5 [mm] seems to depend significantly. Figure 3.2 shows cross-section of the whole model in which the interior mantle can be seen.



The starting numerical model, the whole burner with both mantles, in the display with only a few rows of openings.

Burner cross section, inner mantel

Outside mantle

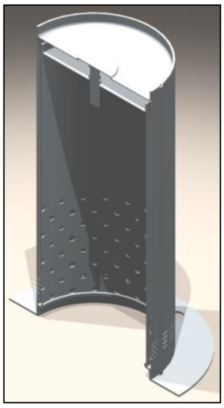


Figure 3.1. CAD model an outer mantle, showing only the first few lines of the holes

Figure 3.2. A cross-section of the model in which the interior mantle can be seen, also showing the first few lines of the opening

A series of different hole types and other types of opening, which are repeated at a slight distance make demanding perforation, pattern, and it is a fair task for CAD, but also for FEA programming systems. In the Figure 3.3 can be seen repeated pattern showing the finite element mesh.

The analysis was made for the stationary and non-stationary regime of operation of different input loads, different materials. As the input load with great changes in the operating mode and high perforation. The CAD model had to be approximated for numerical simulation. For this purpose, the model is reduced and an axisymmetric angular cut is observed, Figure 3.4.

The input load ranges from 5 to 50 kW. The boundary condition is combustion in a "blue flame mode" with low emission of harmful products.

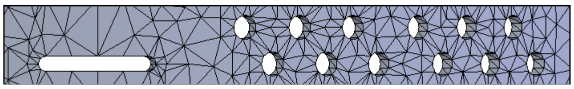


Figure 3.3. Repeated pattern of the burner model showing the final elements network

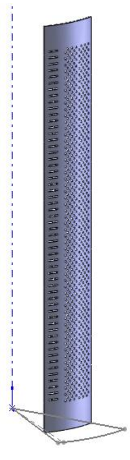


Figure 3.4. Angular cut out of the outer mantle with pattern over the entire height - Reduced model

4. Numerical research of thermal stress

After a carefully designed net of finite elements, a numerical simulation of the thermal stress of the perforated outer burner mantle was initiated. The research was conducted in the territory of Serbia where two types of gas were available, Russian and Serbian natural gas. The numerical simulation is done for different types of materials for burner mantle, and here we will show comparative results for two types of materials, AKsteel18SR and Haynes230. Observed load parameters are mechanical and thermal stress.

The heat field on the outer mantle was obtained after CFD simulation and experimental measurement and is expressed as heat flux.

The input load also included ambient temperature, convective cooling due to the approach of the burner gas to the burner and the radiation of the gray body as a boundary condition. For FEM analysis, the educational version of SolidWorks, Simulation Module was used.

4.1. Analysis of thermal stress for short-term load, for two types of gas, two different materials and the same pattern

We simulate the different power modulation required by the construction. A short-term load is a high heat load of 50 kW burner. It is achieved after 5 s, for Russian gas, Figure 4.1, and the maximum for the Serbian gas was 40 kW, Figure 4.3. The total analyzed period was 15 s.

The results are shown for the analyzed group of materials, the cheaper AKsteel18SR, Figure 4.2, Figure 4.4, Table 1 and more expensive material Haines230.

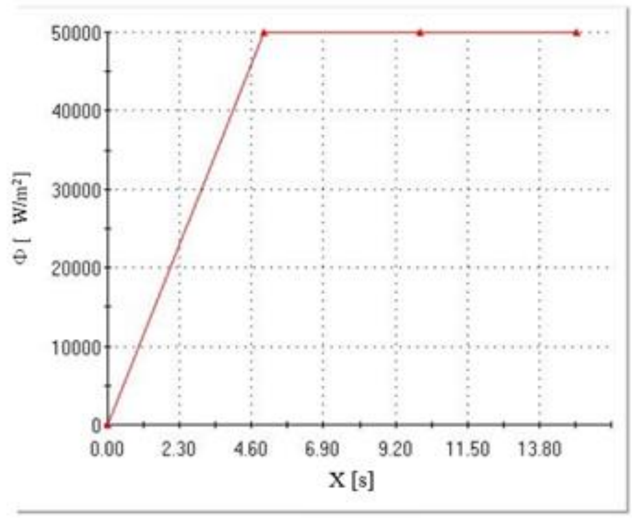


Figure 4.1. Russian gas - heat load of 50 [kW], for 15 [s]

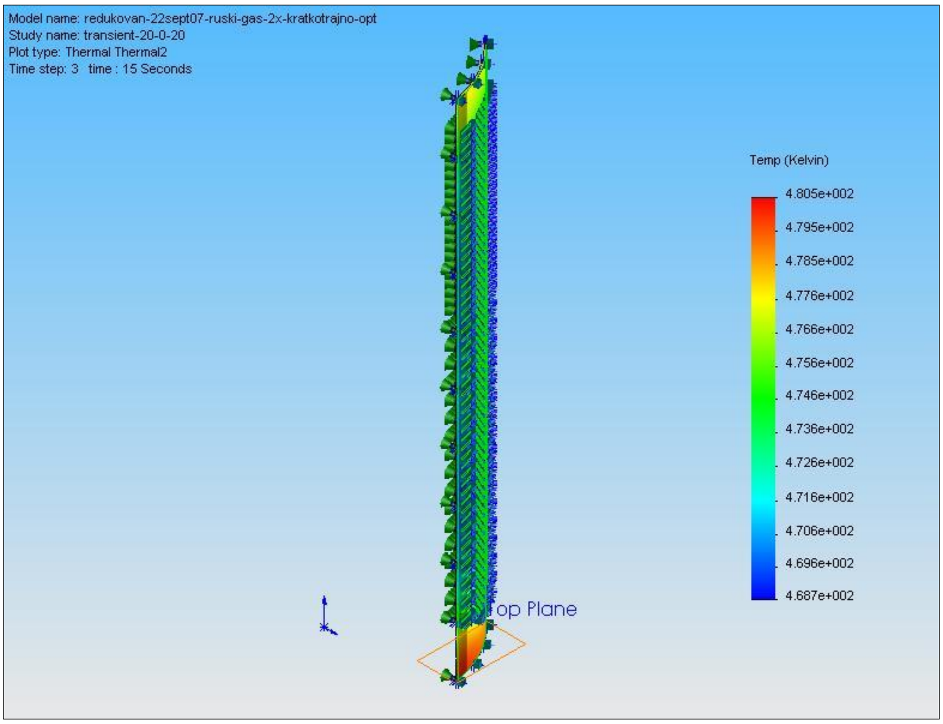


Figure 4.2. Temperature field for heat load of 50 [kW], for 15 [s] and material AKsteel18SR – Russian gas

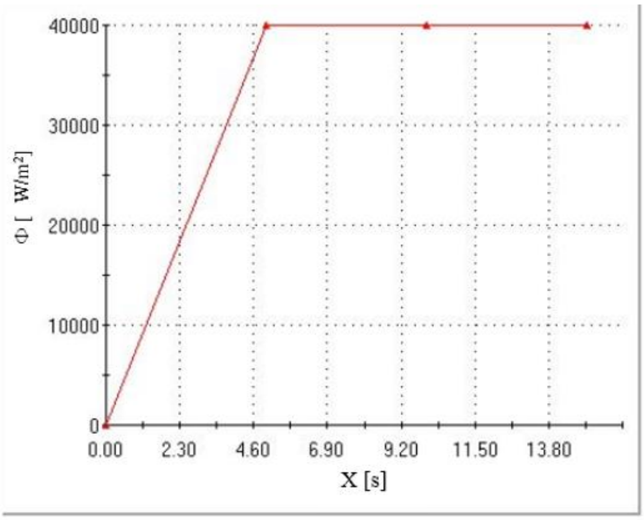


Figure 4.3. Serbian gas - heat load of 40 [kW], for 15 [s]

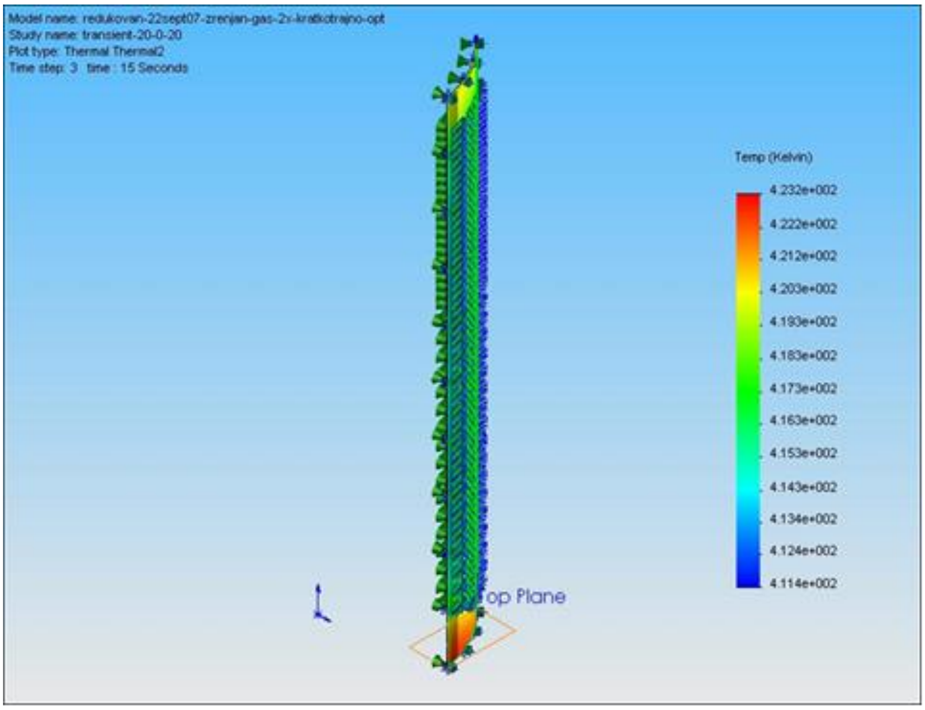


Figure 4.4. Temperature field for heat load of 40 [kW], for 15 [s] and material AKsteel18SR - Serbian gas

Table 1. Results for heat load of 40 [kW], for 15 [s] and two different materials for two gas types

	Materials	Min. load. (K)	Node	Location	Max. load. (K)	Node	Location
Russian Gas	AKsteel18SR	468.657	2607	(28.7215, 46.6061, -20.3498)	480.526	10495	(34.1219, 0, -6.30777)
	Haynes230	431.363	15967	(29.647, 106.735, -18.9761)	448.645	10495	(34.1219, 0, -6.30777)
Serbian Gas	AKsteel18SR	411.379	2607	(28.7215, 46.6061, -20.3498)	423.22	10495	(34.1219, 0, -6.30777)
	Haynes230	379.358	15972	(29.6471, 104.864, -18.976)	396.367	10494	(34.1219, 0, -6.30777)

4.2. Analysis of thermal stress for low load, for two types of gas, two different materials and the same pattern

Another aspect of the real burden of the gas burners for home use "regime switch off-on" means a load of 15 kW for Russian gas and 12 kW for the Serbian gas, initially for a period of 576 s, then off. This implies a breakdown of the load for a period of 576 s, then again "ignition" and continuation of the same load until the end of the analyzed period of 2305 s, Figure 4.5.

The analysis of the results shows significant differences in the behavior of the same material Aksteel18SR depending on the type of gas.

It was noted that the numerical model of gas burner with this material achieves considerably lower thermal stresses and significantly lower temperature values in the analyzed location for Serbian gas than in the Russian one, Table 2.

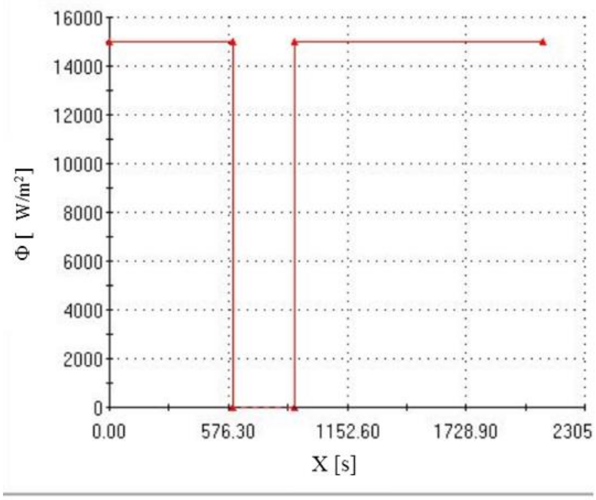


Figure 4.5. Regime “switch off-on" – for low load and Russian gas

Table 2. Results for low load of 15[kW], in period of 576[s], then extinguishing of for a period of 576[s], then ignition and continue with same load of 15[kW] to the end observed period 2305[s]

	Material	Min. load (K)	Node	Location	Max. load (K)	Node	Location
Russian Gas	AKsteel18SR	904.549	18052	(33.886, 82.6618,-9.52775)	904.643	10495	(34.1219, 0, -6.30777)
Serbian Gas	AKsteel18SR	811.957	17203	(34.2765, 89.9651, -8.01007)	812.025	10495	(34.1219, 0, -6.30777)

4.3. Analysis of thermal stress for high load, for two types of gas, two different materials and the same pattern

Analysis for high load of 50[kW] - Russian gas, 40[kW] - Serbian gas, Figure 4.6**.** in period of 576[s], then extinguishing of for a period of 576[s], then ignition and continue with same high load to the end observed period 2305[s]. Results are presented for both observed materials in Table 3.

Discrepancies in the behavior of the materials were noticed, so that the burner with the Haines230 material achieved a lower thermal stress than the burner model with the Aksteel18SR material for the same load. The difference in the achieved maximum temperatures at the same location is visible. On the same node of the finite element network, under the same load of difference is 4.3 K for Russian and about 3.8 K for Serbian gas.

It is apparent that the biggest differences in the behavior of two materials at short high loads at the start of the burner when the load increases from 0 to the maximum value observed for each gas.

Then the differences are greatest in the first 15 s of the work under the highest load. This difference is significantly reduced when the maximum load for a longer period to 2300 s, than when it is the load "on, then off."

It should also be noted that for different gases, the same material achieves a difference of up to 92 K during low load.

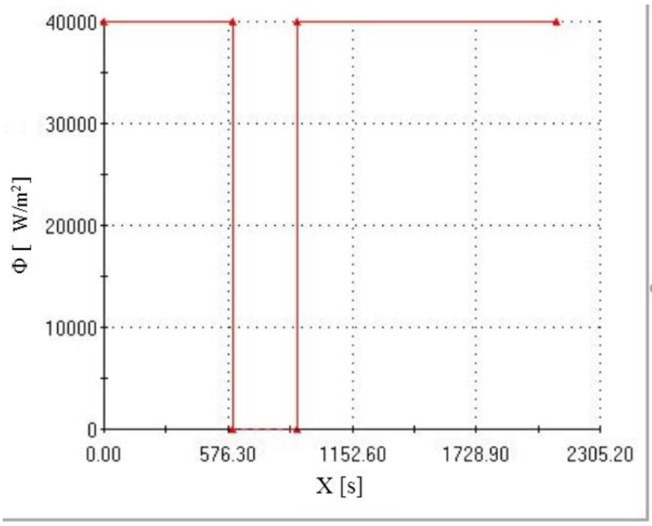


Figure 4.6. Regime “switch off-on" – for high load and Serbian gas

Table 3. Analysis for high load of 50[kW] - Russian gas, 40[kW] - Serbian gas in period of 576[s], then extinguishing of for a period of 576[s], then ignition and continue with same high load to the end observed period 2305[s]

	Materials	Min. load (K)	Node	Location	Max. load (K)	Node	Location
Russian Gas	AKsteel18SR	853.619	10931	(34.1435, 154, -8.55943)	853.701	642	(26.3158, 19.7465, -22.6179)
	Haynes230	849.2	17889	(33.886, 71.3382, -9.52775)	849.352	22159	(24.7163, 6.79412, -24.3555)
Serbian Gas	AKsteel18SR	749.615	17889	(33.886, 71.3382, -9.52775)	749.669	1650	(26.3158, 34.1465, -22.6179)
	Haynes230	745.879	17889	(33.886, 71.3382, -9.52775)	745.982	10495	(34.1219, 0, -6.30777)

5. Conclusion

Here we can see the behavior of a perforated cylinder for burners of loaded with the expected thermal stress in boilers for home heating with great power modulation, which would be applied to different geographical areas, or with different types of gas.

This paper gave a framework model to continue exploring to the solution that will give the best constructive solution independently of the type of gas. The results obtained show different thermal stresses which are dependent on the different gas and materials on the outer cylindrical mantle. This indicates the necessity to optimize materials and also patterns applied to the outer cylindrical mantle of the burner, which will be the subject of further research.

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