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STRUCTURAL ASSESSMENT AND REDISIGN OF THE WATER CHAMBER IN A DOMESTIC GASIFICATION BOILER

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1. Introduction

Residential heating boilers burn fuels to heat water, which flows through a network of pipes and radiators to warm the house [1]. One type of residential heating boiler characterized by its high efficiency is the gasification boiler. Gasification boilers operate with an efficiency of around 85% [2] compared to a classic wood boiler with an efficiency of around 63% [3]. The gasification boilers use a controlled amount of oxygen and precisely defined temperatures to transform the solid biomass into gas, which is later combusted to generate the needed heat [4]. The technology behind gasification boilers is called biomass gasification – a thermochemical conversion of organic feedstock under high-temperature conditions, through which biomass is converted to syngas. Syngas composition varies, but it is mainly composed of CO, H_2, N_2, CO_2, and some hydrocarbons (CH_4, C_2H_4, C_2H_6, etc.) [5].

A variety of papers have investigated gasification boilers and attempted to optimize their operation and design. The IEA Bioenergy annual report [6] analyzed the product spectrum (organics, char, gas, water) from fast pyrolysis of aspen poplar wood, depending on process temperature. It was shown that with an increase in temperature, the yield of gas also increases. Similar research was done by Raibhole and Sapali [7], namely, they investigated how the flow rate of oxygen influenced the syngas composition. They concluded that the optimal mass flow of oxygen is around 8 kilograms per hour, when the participation of H_2 in syngas is the highest. Karmarković et al. [8] investigated the combustion chamber of the gasification boiler to find its optimal design. Drosatos et al. [9] described the computational fluid dynamics simulation of syngas combustion and the heat transfer in a domestic wood gasification boiler to further optimize its operation. Hopan et al. [10] investigated emissions from 111 measurements on solid fuel household boilers, among which was a hefty number of gasification boilers. One of the conclusions was that emissions-wise, a significant improvement was observed when the gasification boiler was operated by a trained operator.

Overall, regardless of the type of boiler, the heated water is kept in the boiler water wall, hereinafter referred to as the “water chamber” (Fig. 1). To the authors’ knowledge, the pressure of 3 bars is considered as critical pressure of the water in the water chamber, which triggers the activation of the safety valve. This paper investigates how the critical pressure of the water of 3 bars will influence the water chamber with a wall thickness of 5 millimeters, and the possibility of mitigating the displacements without increasing the thickness of the wall.

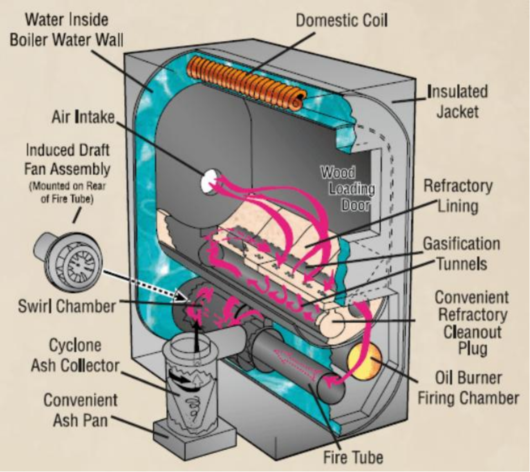

Fig. 1. Section view of a gasification boiler [11]

2. Materials and methods

The three-dimensional model of the water chamber (Fig. 2) and the static analysis were done in the "CATIA V5R21" software. There is a variety of studies that used CATIA for modeling and analysis. For example, Mohamad et al. [12] did a design and static structural analysis of a race car chassis using CATIA, Pinca-Bretotean and Chete [13] did a static analysis of a rolling chassis, Anggono and Riyadi did a finite element analysis of a truck frame [14], Hernandes et al. [15] examined the structural optimization using CATIA finite element analysis and optimization.

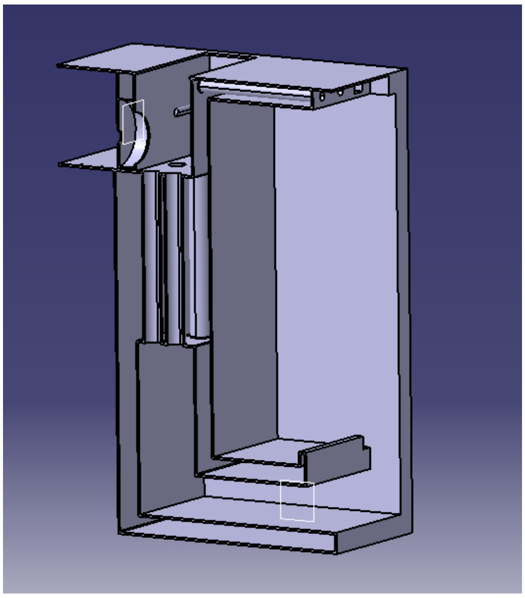

Fig. 2. Three-dimensional model of the water chamber

To give a better insight into the analyzed water chamber, the characteristics of the domestic gasification boiler are shown in Table 1.

Table 1. Characteristics of the analyzed domestic gasification boiler

Power	*20 kW*
Boiler dimensions	*H: 1412 mm, W: 984 mm, L: 841 mm*
Gasification chamber dimensions	*H: 600 mm, W: 500 mm, L: 500 mm*
Gasification chamber volume	*150 l*
Diameter of the flue pipe	*80 mm*
Water flow rate	*0.238 l/s*

The rendered model of the analyzed boiler is given in Fig. 3.

Fig. 3. Rendered model of the analyzed boiler

3. Results

The first iteration of the static analysis of the original water chamber under given pressure resulted in a transitional displacement magnitude of 10.28 millimeters (Fig. 4).

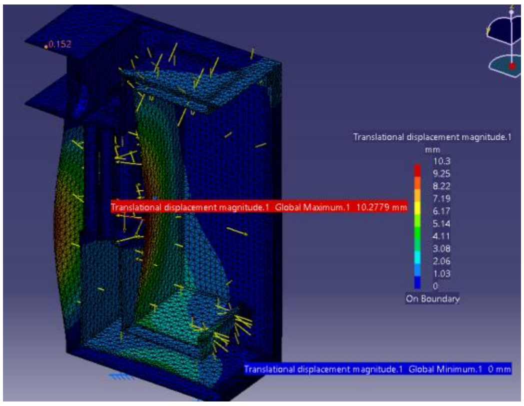

Fig. 4. Static analysis – first iteration

To mitigate these displacements, the chamber design was adapted by adding stiffening rods (Fig. 5). Subsequently, the second iteration of the static analysis revealed relocated, but decreased, displacements with a local maximum of 4.29 millimeters.

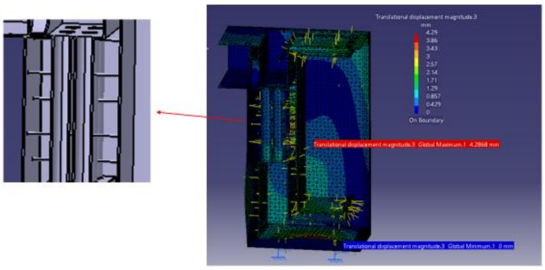

Fig. 5. Static analysis – second iteration

The stiffening rods were added in every following iteration at the place of maximal local displacements. Analogously, the third iteration (Fig. 6) resulted in local maximal displacement of 4.15 mm.

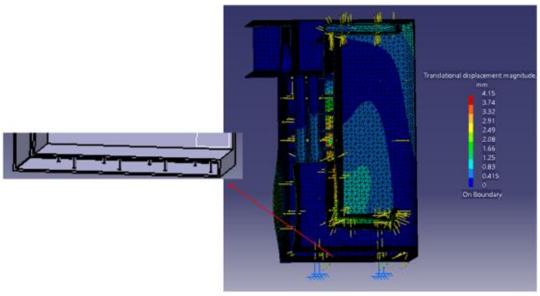

Fig. 6. Static analysis – third iteration

In the fourth iteration, the displacements were relocated with a maximal intensity of 4.29 millimeters (Fig. 7).

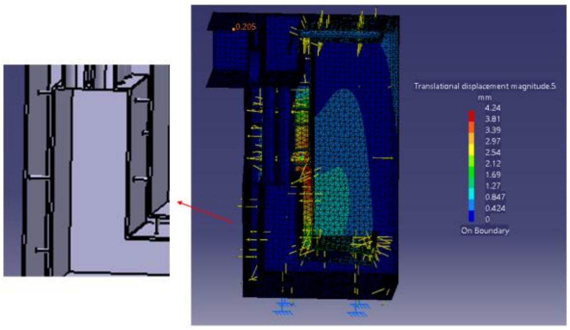

Fig. 7. Static analysis – fourth iteration

The same scenario happened two more times (Fig. 8 and Fig. 9) with transitional displacement magnitudes of 4.29 (fifth iteration) and 1.39 millimeters (sixth iteration).

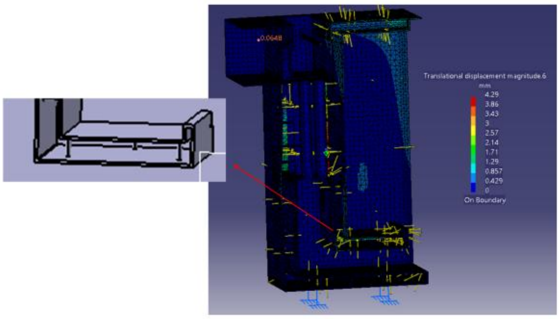

Fig. 8. Static analysis – fifth iteration

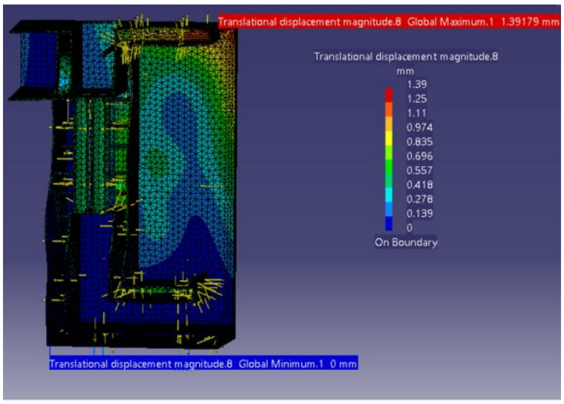

Fig. 9. Static analysis – sixth iteration

After six iterations of static analysis of the water chamber, the non-critical values of displacements were obtained (1.39 millimeters), consequently, defining the final design of the chamber (Fig. 10). Accordingly, it was proven that displacement mitigation of the water chamber is possible using only stiffening rods, i.e., without increasing the wall thickness.

Fig. 10. Final water chamber design

4. Conclusion

The object of the analysis was a water chamber of a domestic gasification boiler. The water chamber was tested at 3 bar water pressure. The first analysis resulted in critical displacements of around 10.3 millimeters, which led to the conclusion that the water chamber needs a redesign.

The redesign was done in six iterations. At every iteration, stiffening rods were added at the place of the highest displacements. The last iteration resulted in a non-critical displacement of 1.39 millimeters. The analysis as a whole showed that the mitigation of the displacements is possible without increasing the wall thickness, i.e., using only stiffening rods.

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