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COMPUTER AIDED OPTIMIZATION OF A NOZZLE IN AROUND-THE-PUMP FIRE SUPPRESSION FOAM PROPORTIONING SYSTEM

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Abstract: *The paper presents the results of numerical analysis oriented at the optimum design of the Venturi nozzle applied in the around-the-pump proportioning systems of fire suppression foam. The dimensions of the system are limited by the available space in the fire engine on one hand and the effective operation on the other hand. The computational fluid dynamics research tool was used within the confines of carried out analysis. Numerous designs were investigated in term of mass flow rate of the foam compound. The obtained results allowed to improve the efficiency of the system by 9.5 % in comparison to the baseline design.*

Keywords: Computational fluid dynamic, Nozzle, Fire suppression, Foam proportioning.

1. Introduction

The around-the-pump proportioning systems of fire suppression foam provide a simple and effective means to introduce a foam concentrate at the desired percentage to the water being discharged in a fire pump system (Conroy et al., 2015; Zhao et al., 2016). They are widely applied due to numerous reasons. First of all, they are very robust and cost-effective because no additional foam compound pump is required. Moreover they are suitable for very large foam compound outputs and are easy to operate. Therefore they are commonly installed as an auxiliary device in modern fire engines. The principle of its operation is based on a well-known and widely applied Venturi nozzle (Gupta et al., 2016; Long et al., 2016; Mi et al., 2012), which is located in the drive water line which creates suction for the foam compound as depicted in Fig. 1. In this way, very high foam compound outputs can be generated. A fire truck may have a dual proportioning system with one tank having a Class B foam concentrate for flammable liquid fires and a second tank having Class A foam concentrate for structural fire attack or other ordinary combustible fire materials.

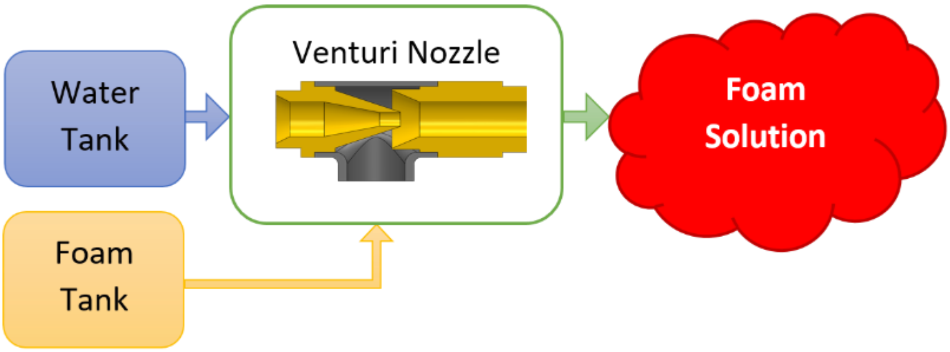

Fig. 1: Schematic diagram of around-the-pump fire suppression foam proportioning systems.

In practical applications the dimensions of the system are limited by the available space in the fire engine on one hand and the effective operation on the other hand. Therefore the optimum design of the Venturi nozzle is crucial in terms of proper operation of the system quantified by the ratio of mass flow rate of the foam compound to the mass flow rate of foam solution.

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2. Methods

Computational Fluid Dynamics (CFD) has been selected as a research tool in order to specify the design of the nozzle because it is commonly and successfully applied in numerous branches of industry such as aerospace, automotive (Jamrozik et al., 2013), civil engineering (Gnatowska, 2015; Gnatowska, Sosnowski et al., 2017), power engineering (Krzywanski et al., 2014; Sosnowski et al., 2017), medicine and others. CFD has also been applied in the analysis of Venturi nozzles (Kuldeep et al., 2016; Manzano et al., 2016; Tukimin et al., 2016). This technique allows to perform very robust analysis of various configurations in a time-effective manner.

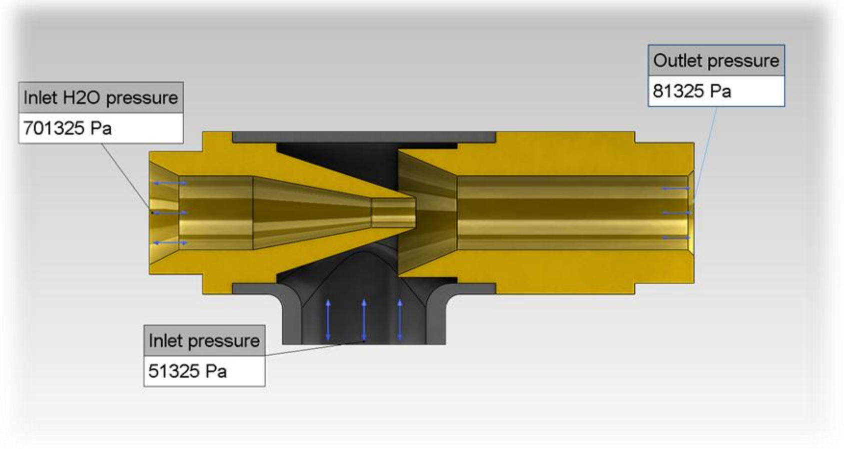

Fig. 2: The boundary conditions of the analyzed computational domain.

SolidWorks Flow Simulation was used as a CFD tool that solves the Navier-Stokes equations, which are formulations of mass, momentum and energy conservation laws. In addition it employs transport equations for the turbulent kinetic energy and its dissipation rate, using the k-ε model. The adaptive Cartesian mesh was applied in order to capture gradients in the flow field. Pressure boundary conditions were selected with turbulence intensity equal 2 % and turbulence length equal $0.55e^{-3}$ m. The analysis assume the inlet pressure of water (Inlet H_2O) at the level of 701 325 Pa (ambient pressure + 600 kPa), the inlet pressure of foam compound (Inlet) equal 51 325 Pa (ambient pressure – 50 kPa) and outlet pressure (Outlet) equal 81 325 Pa (ambient pressure – 20 kPa) – Fig. 2. Such values were measured by the manufacturer of the system used during research as a baseline design. The outside dimensions of the nozzle must not be changed in relevance to the baseline design in order to fit the optimized nozzle into the installation without modifying the existing systems already installed in the fire engines. Some simplifications have been introduced to the inner part of the baseline geometry in order to eliminate the low quality elements of computational mesh and in consequence improve the convergence of the numerical model.

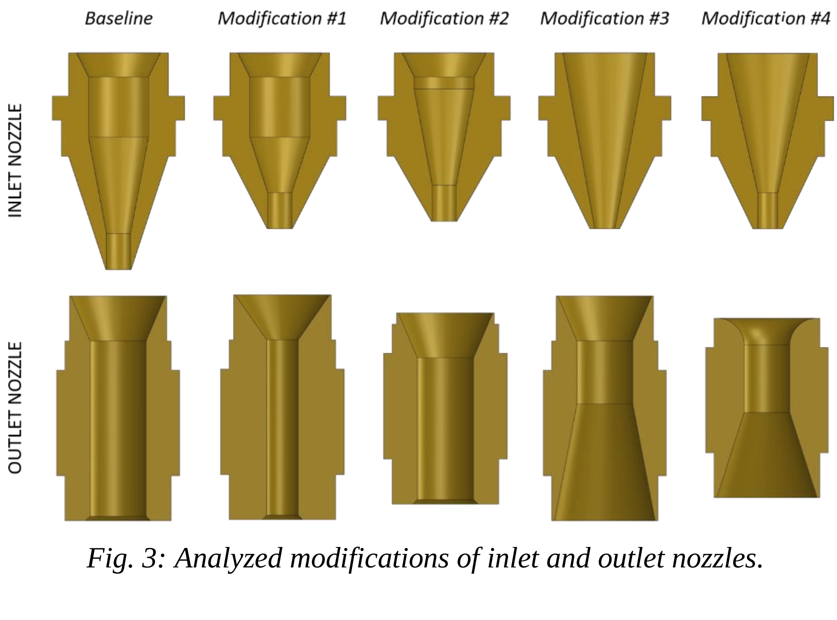

Fig. 3: Analyzed modifications of inlet and outlet nozzles.

Four modifications of inlet nozzle and four modifications of outlet nozzle (Fig. 3) were analyzed in eleven different configurations shown in Tab. 1. The results were compared to the baseline model.

Tab. 1: Analyzed configurations.

CONFIGURATION NUMBER	INLET NOZZLE	OUTLET NOZZLE
Baseline Configuration	Baseline	Baseline
Configuration #1	Modification #1	Baseline
Configuration #2	Modification #2	Baseline
Configuration #3	Modification #3	Baseline
Configuration #4	Modification #4	Baseline
Configuration #5	Baseline	Modification #1
Configuration #6	Baseline	Modification #2
Configuration #7	Baseline	Modification #3
Configuration #8	Baseline	Modification #4
Configuration #9	Modification #1	Modification #2
Configuration #10	Modification #1	Modification #4
Configuration #11	Modification #2	Modification #4

3. Results

Mass Flow Rate (MFR) was selected as a key indicator of the nozzle effectiveness in firefighting applications therefore maximizing the MFR was the main goal of the design modifications. The MFR provides information on the ratio of foam compound to the inlet water and simultaneously indicates the pressure drop in the whole system (lower overall MFR). As can be seen in Fig. 4, six investigated configurations are characterized by higher overall mass flow rate in comparison to the baseline configuration. It is worth mentioning that the water content in all but one (#3) configurations does not differ significantly. Therefore the main contribution to the increased MFR results from higher foam compound content in the foam solution at the outlet of the system.

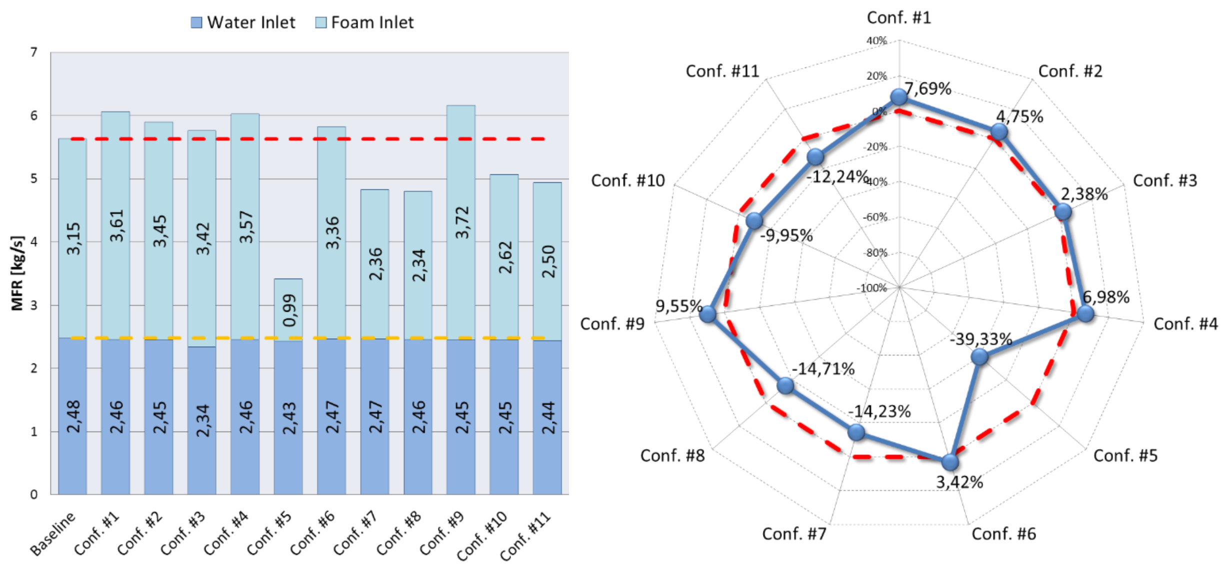

Fig. 4: The mass flow rate of the investigated configurations (left) and the relative difference of mass flow rate on the outlet in relation to the baseline configuration marked with the red line (right).

Configuration #9 was selected for further investigations as it is characterized by the highest MFR and highest foam compound content in the foam solution. Pressure and velocity distribution for both above mentioned configurations are depicted in Fig. 5.

4. Discussion

The original baseline as well as eleven modified configurations of the nozzle shape were analyzed using computational fluid dynamics in order to improve the efficiency of the around-the-pump proportioning systems of fire suppression foam. The research allowed to improve the efficiency of the original design by 9.5 % due to changing the inner shape of the inlet and outlet nozzle of the proportioning system without modifying the outer dimensions of the assembly. The obtained results were confirmed by the field tests performed by the manufacturer of the system. Therefore the applicability of CFD as a research tool was confirmed and allowed to optimize the baseline design in a very robust and effective way.

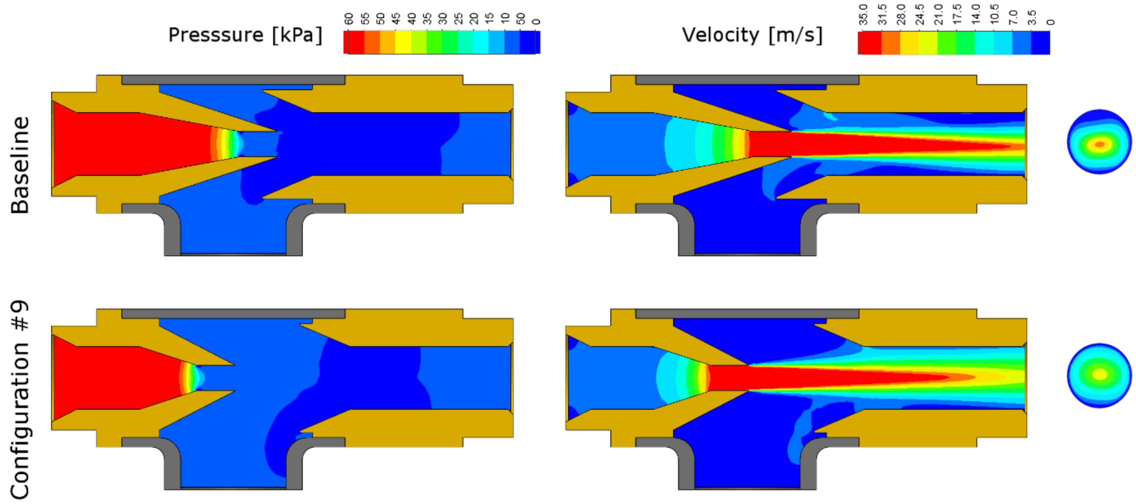

Fig. 5: Pressure and velocity distribution for the baseline and #9 configuration.

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