A NUMERICAL INVESTIGATION ON THE THERMAL CHARACTERISTICS OF A MULTI-HOLE BURNER FED WITH H_2-ENRICHED MIXTURES

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Abstract
This paper presents a numerical investigation of the thermal behavior of a premixed multi-hole burner operating with a hydrogen-enriched fuel (CH_4-H_2 mixture) using CFD. A 3D model of a laboratory-scale perforated burner was developed using the Species Transport model coupled with a conjugate heat transfer approach. The study focuses on the burner plate temperature field under reacting conditions, with particular attention to the effects of boundary conditions and fuel blends. Burner power and equivalence ratio were kept constant, while different H_2–CH_4 blends were examined. Numerical predictions were compared with experimental data from the literature. The maximum temperature on the burner plate surface has been calculated to be approximately 982 K, and the minimum temperature 731 K for PH_2 = 60%. The results provide insight into local thermal loading and surface temperature distribution, supporting the design of safer, more reliable, and fuel-flexible premixed burner systems.

Keywords: H_2-enriched combustion, multihole burner, CHT, CFD, plate temperature

Introduction
The ongoing decarbonization of residential and small-scale industrial heating systems has renewed interest in premixed perforated burners, which are key components of compact combustion devices such as domestic condensing boilers and small-scale industrial burners [1–7]. These burners offer several practical advantages, including compact flame stabilization, high heat-release intensity, and relatively low pollutant emissions under lean premixed conditions. Nevertheless, their behavior is governed by complex interactions such as combustion characteristics are changed [5,6,8]. In recent years, hydrogen-enriched gaseous fuels

have attracted attention as a promising route for reducing the carbon footprint of gas-fired heating technologies. However, the introduction of hydrogen also poses major combustion challenges. Because of its higher laminar burning velocity, wider flammability limits, smaller quenching distance, and stronger diffusive effects, hydrogen can significantly alter combustion parameters. Experimental and numerical studies have shown that hydrogen addition may improve combustion, but it works in a narrower safe operating window [1,4,8]. At the same time, the literature shows that combustion in perforated and multi-hole burners cannot be explained solely by global parameters such as laminar burning velocity. Local flame-wall interaction, burner temperature, conjugate heat transfer, reactant preheating, and hole arrangement have a strong influence on flame shape, stabilization, and pollutant formation [2–4,6,9]. In boiler systems, moreover, the interaction between burner and heat exchanger has been shown to play an important role in determining emissions and overall combustion characteristics [2,3,6]. Recent studies have further demonstrated that realistic geometric effects can substantially modify flashback dynamics and burner thermal response [4,7,9].

Despite this growing body of work, previous studies have mainly focused on flashback limits, blow-off behavior, pollutant emissions, and the effects of inlet conditions, whereas comparatively limited attention has been devoted to the temperature-specific thermal characteristics of the burner body itself under direct flame interaction [2–6]. In particular, the local thermal response of a flame-contacting multi-hole burner remains insufficiently clarified, even though it is directly related to material durability, thermal feedback to the incoming mixture, and long-term burner reliability [1,4,8].

In this context, the present study numerically investigates the thermal characteristics of a multi-hole burner with particular emphasis on its surface temperature behavior under reacting conditions. The novelty of this work lies in shifting the focus from conventional flame stability and combustion parameters to the burner's own thermal response, thereby providing a clearer understanding of local temperature distribution and thermal loading in flame-contacting premixed burner configurations. Such an approach is expected to support the development of safer, thermally robust, and more fuel-flexible burner designs for next-generation heating systems.

Methodology, Modeling, and CFD Numerical Setup

In this study, the steady-state combustion of a perforated, laboratory-type, flat burner [8] was investigated to determine the thermal characteristics of the burner plate. The Species Transport (ST) Model was incorporated into the 3D-CFD analysis [2,10,11]. The influence of combustion parameters on the thermal characteristics of the burner plate is investigated using a conjugate heat transfer (CHT) approach [2]. The numerical model is primarily developed for premixed combustion of hydrogen-enriched conventional natural gas. 3D numerical simulations of a multi-slit burner were conducted using ANSYS Fluent 2024 R2 [12]. Table 1 shows the numerical setup parameters of the study. The computational domain is shown in Fig. 1.

Table 1. Parameters of the study

Boundary conditions and properties	**Unit**	**Value and condition**
Inlet	kg/s	Mass flow inlet
Outlet	-	Pressure outlet
Inner walls (Upstream, Burner, Downstream)	-	Symmetry
Outer walls (Upstream, Burner, Downstream)	-	Adiabatic, non-adiabatic, pressure outlet/inlet
Burner side walls (Outer, inner)	-	Convection, non-adiabatic
Burner dimensions and thickness (L_b x L_b x t)	mm	59 x 59 x 0.6
Burner material	-	18SR (EN1.4742) St. Steel
H_2-enriched fuel blend (PH_2 = 60%, Φ = 0.8)	vol%	H_2 (%83.3) – CH_4 (%16.7)
H_2-enriched fuel blend (PH_2 = 97%, Φ = 0.68)	vol%	H_2 (%99) – CH_4 (%1)

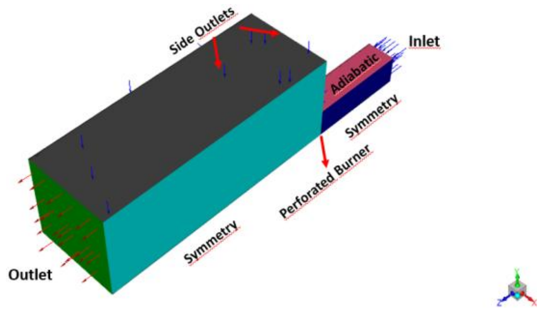

Figure 1. Computational domain of the numerical analyses with BCs

Results and Discussion

This study investigates the temperature distribution of the burner plate under different boundary conditions, and hydrogen–methane blend ratios (H_2–CH_4). Fig. 2 demonstrates validation of the numerical results with experimental data and the temperature distribution of the plate.

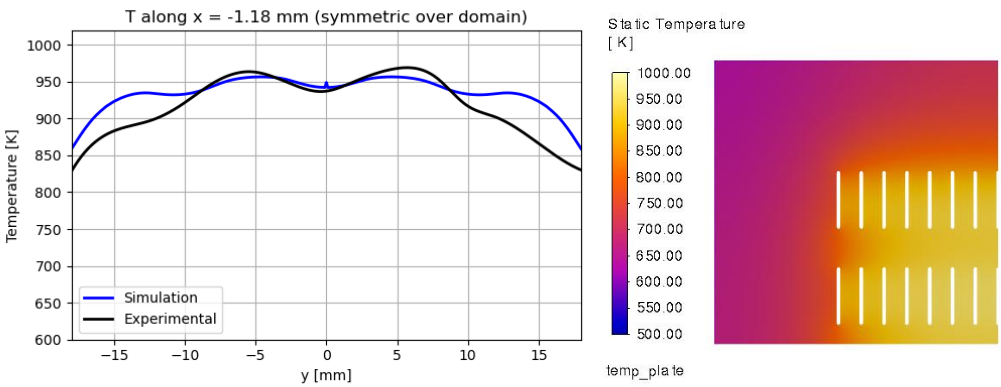

Figure 2. a) Validation of the results and b) temperature distribution of the plate

Burner power and equivalence ratio are treated as constant parameters. The numerical findings are then compared with experimental results available in the literature [8] to evaluate the influence of these varying conditions. This validation shows that the numerical model can be applied to multi-holed burners with various fuels and their mixtures.

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