# Hydrogen Blended Natural Gas Fuelled A Process Heating Application

[1*]Onur Salcı, [2]Semiha Öztuna, [3]Mustafa İlbaş,
[1] Termo Isı Sistemleri Tic. ve San. A.Ş., R&D Department, Tekirdağ, 59850, Türkiye,
[2] Trakya University, Engineering Faculty, Mechanical Engineering Department,Institute of Natural and Applied Sciences, Edirne, 22030, Türkiye
[3] Gazi University, Engineering Faculty, Mechanical Engineering Department, Graduate School of Natural and Applied Sciences, Ankara, 06500, Türkiye

* E-mails: onur.salci@ecostar.com.tr , semihae@trakya.edu.tr , ilbas@gazi.edu.tr

**Abstract**
$H_2$ (Hydrogen) is an alternative eco-friendly fuel in process burners by blending it with NG (natural gas) in different ratios. In the present study, $H_2$ blended fuel effect to combustion performance of a process burner were investigated. 100% NG, 30%, 40% and 50% $H_2$ blended NG fuels were used. Heat input of the burner is 120 kW. Equivalence ratio is kept constant as 0,77. Experimental studies were validated by Fluent codes. Partially premixed combustion model was used in combustion cases. Resulting by up to 50 %$H_2$ blended NG combustion by volume, $O_2$ (oxygen) remained constant with low fluctuations, $CO_2$ (carbon dioxide) decreased by up to 21%, $H_2O$ (water vapor) increased by up to 16%, CO (carbon monoxide) decreased by up to 82%, $CH_4$ (methane) decreased by up to 79,6% and nitric oxide (NO) increased by up to 26,5%.

**Keywords:**Hydrogen, Hydrogen Blended Fuel, Process Heating, Decarbonization

## I. Introduction

COP28, signaling a transition towards a carbon-free future by moving away from fossil fuels, will play a significant role in meeting global energy needs and decarbonizing industries as part of the transition to human-centered net zero energy, with renewable and low-carbon hydrogen based technologies (COP28 Declaration of Intent - Hydrogen, n.d.).

Passing to low carbon technologies in current industrial processes, accelerating the use of renewable energy alone is not sufficient. Using of eco-friendly renewable fuels blending and adapting with fossil fuels should be expanded. Lower greenhouse gas emissions and pollutants can be achieved by blending different proportions of $H_2$ into NG fuelled burner that require heat power in the continuous operation.

The effects of hydrogen blended in different ratios with NG on combustion and diffusion flame structure have been investigated by Öztuna and Büyükakın (2020) in a non-premixed, pressure-swirl burner and back pressured water-cooled boiler system. As the blending rate of hydrogen in combustion increased, the flame has become less dense and flow velocities of the flame have increased. The effect of $CO_2$ on combustion efficiency of $CH_4$ and $H_2$ have been investigated by Ilbas and Candan (2023b) using a small swirl burner and furnace combustion system. At higher $CO_2$ dilution rates, combustion instability has decreased. The gas emissions resulting from turbulent reactive flow using composite fuels of $H_2$ and $CH_4$ at different blending ratios have been investigated by Ilbas and Yılmaz (2011) in a model burner. As the blending rate of $H_2$ in the fuel increases, combustion efficiency has increased, and CO emissions have decreased. The effect of flame behavior and combustion performance resulting from the combustion of NG mixed with 30 % $H_2$ by volume in different gas stove geometries have been investigated by Sorgulu et al. (2024b). $H_2$ blending rate in combustion increases, shorter flame length, altered flame color to bluish and improved combustion efficiency has been occurred. Experiments involving different ratios of $H_2$ blended with NG in identical gas stoves have been conducted by Öztürk et al. (2023). Despite decreased in $CO_2$ and CO emissions, fluctuation in $NO_x$ emissions has been measured.

## II. Experimental Set-up and Procedure

Experiments of the study have been conducted in the R&D laboratory of Ecostar, located in Tekirdağ, Türkiye, using a combustion experimental system with blending of NG and $H_2$. The combustion experimental system includes NG, $H_2$, a gas blending unit, and pressurized air lines. Leakage and safety controls were performed before each experiment. The experimental system provides a maximum heat input of 120 kW with a blending of 50 % $H_2$ gas and 50 % NG.

The experiments utilized an Ecostar FPB 200 (FPB 200 - Ecostar, n.d.) process gas burner. This type of burner is primarily used in industry for process heating, heat treatment, melting, drying, and various applications. In the experiments, the burner was used with dual-stage, direct ignition, and ionization features (Salcı, O., 2023).

The control of the burner, fuel and air lines, and emission variations were provided by the PLC (Programmable Logic Controller) operating the combustion experiment system. The schematic view of the combustion experiment system is given in **Fig.1**. Fuel types in experiments are 100% NG, 70% NG and 30% $H_2$, 60% NG and 40% $H_2$, and 50% NG and 50% $H_2$, respectively. NG was supplied by Çordaş Çorlu NG Distribution Co. and the compositional values of NG used in the experiments are given in **Tab 1**. $H_2$ was supplied by Habaş Industrial and Medical Gases Production Industry Inc. as pressurized cylinder tanks (Salcı, O., 2023).

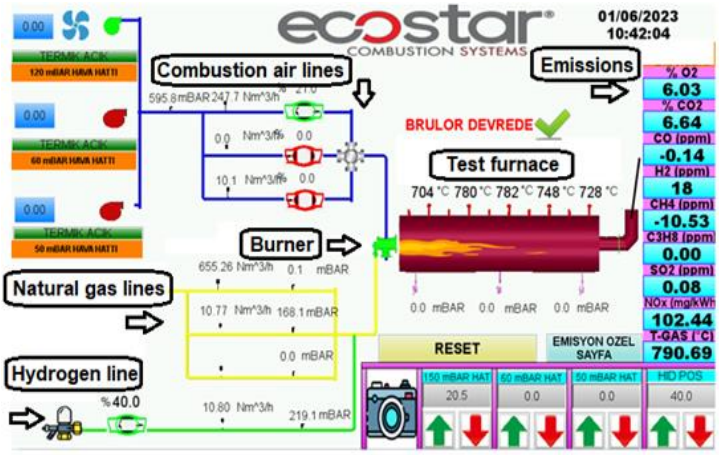



Fig. 1: The schematic view of the combustion experiment system (Salcı, O., 2023).

Tab 1. Natural gas compositions (Salcı, O., 2023).

| Content | $CH_4$ | $C_2H_6$ | $C_3H_8$ | $C_4H_{10}$ | $C_5H_{12}$ | $C_6H_{14}$ | $N_2$ | $CO_2$ |
|---|---|---|---|---|---|---|---|---|
| Mole % | *96.068* | *2.198* | *0.654* | *0.194* | *0.0131* | *0.01* | *0.668* | *0.0177* |

Four different combustion experiments were conducted in the test furnace to measure flue gas emissions and temperature variations.The experiments were conducted again at atmosphere ambient conditions to observe of $H_2$ effects on flame. Heat input of 120 kW was applied in the combustion experiments with constant $\varphi$ (equivalence ratio) of 0.77. The fuel and combustion air flow rates required for combustion are given in Tab 2.

Tab 2. Fuel and combustion air flow rates depending on blended fuel composition and constant $\varphi = 0.77$

| Blended Fuel Composition | Heat Input (kW) | $\dot{V}_{fuel,NG}$ ($Nm^3/h$) | $\dot{V}_{fuel,H2}$ ($Nm^3/h$) | $\dot{V}_{air}$ ($Nm^3/h$) |
|---|---|---|---|---|
| **100 % NG + 0 % $H_2$** | *120* | *12.5* | *0* | *195.1* |
| **70 % NG + 30 % $H_2$** | *120* | *14.1* | *6.1* | *192.2* |
| **60 % NG + 40 % $H_2$** | *120* | *13.2* | *8.8* | *189.3* |
| **50 % NG + 50 % $H_2$** | *120* | *12.1* | *12.1* | *187.4* |

The furnace internal pressures measured from different points are -0.1 mbar constantly. Main flue suction line created vacuum condition in furnace during combustion experiments and any pressure rises didn't occur. $O_2$, $CO_2$, CO, $CH_4$, NO, and temperature were measured with MRU MGA Prime gas analyzer after all values were stabilized.

## III. Analysis

CFD model mesh properties are polyhedral cell types 2,896,126 cells, 505,174 nodes, and maximum skewness is 0.79 .

At the furnace flue exit, atmospheric pressure have been defined. Inner walls of the furnace are firebrick material and average temperature is 1000 K and emissivity value is 0.33 (Bergman et al., 2011). Adiabatic wall boundary condition has been defined for other furnace and burner surfaces. Heat input of the burner was set to 120 kW constantly.

The measured average combustion air temperature was 298 K, and fuel temperature was 293 K. Hydraulic diameters are 0.0272 m for fuel, 0.091 m for air, and 0.22 m for flue gas.

NG consists of approximately 96% $CH_4$ by volume given in Tab 2. Therefore, $CH_4$ was used instead of NG in numerical analyses. Boundary conditions of fuel and air inlets are given in Tab 3.

Tab 3. Boundary conditions of fuel and air inlets (Çengel and Cimbala, 2004),(ANSYS Fluent 2023R2, 2023)

| Blended Fuel Composition | $\dot{m}_{air}$ (kg/s) | $\dot{m}_{fuel}$ (kg/s) | $\rho_{fuel}$ ($kg/m^3$,) | Hu ($kcal/Nm^3$) | Air/Fuel ($m^3/m^3$) | $I_{fuel}$ (%) | $I_{air}$ (%) |
|---|---|---|---|---|---|---|---|
| **100 % $CH_4$** | *0.04984* | *0.00228* | *0.683* | *8570* | *12.38* | *4.75* | *4.3* |
| **70 % $CH_4$ + 30 % $H_2$** | *0.04890* | *0.00213* | *0.504* | *6770* | *9.59* | *4.62* | *4.3* |
| **60 % $CH_4$ + 40 % $H_2$** | *0.04846* | *0.00206* | *0.444* | *6170* | *8.66* | *4.56* | *4.3* |
| **50 % $CH_4$ + 50 % $H_2$** | *0.04793* | *0.00198* | *0.384* | *5570* | *7.74* | *4.51* | *4.3* |

PPC (partially premixed combustion) model was used for all combustion cases. PPC model solves a transport equation for the mean mixture fractions and reaction progress variables to determine the position of the flame front (ANSYS Fluent 2023R2,2023). f (mean mixture fraction) equation is given Eq (1).

$$f = \frac{Z_i - Z_{i,oxidizer}}{Z_{i,fuel} - Z_{i,oxidizer}} \quad (1)$$

In Eq.(1) $Z_i$ is the elemental mass fraction for element, i (ANSYS Fluent 2023R2,2023). $Z_{i,fuel}$ and $Z_{i,oxidizer}$ defines gas fuel and combusiton air.

Chemical equilibrium model and PDF (probably density function) were solved for diffusion flames. Density weighted mean scalars (such as temperature and species fractions) defines as $\bar{\Phi}$, are calculated from the probablity density function (PDF) equation of mean reaction progress (c) , and local mixture fraction (f) is given Eq(2) (ANSYS Fluent 2023R2,2023).

$$\bar{\Phi} = \int_0^1 \int_0^1 \Phi \ (f,c) p(f,c) df dc \quad (2)$$

DO (discrete ordinates) model was used for radiation modelling. In the present study, the flow characteristics of fuel and air are determined as turbulent flow for all cases (Tab 3.). Realizable k - ε turbulence model has been used. After all variables converged, $NO_x$ post processing have been done.

**IV. Results and discussions**

The comparison of numerical calculations and experimental measurements in the present study is given in Tab 4. Experimental and numerical results conducted $\varphi$=0.77 and four different fuel blending ratios, differences of $O_2$, $CO_2$, CO, $CH_4$, NO, and $T_{flue\ gas}$ have been examined. $H_2O$ emissions in the flue gas composition were not measured by gas analyser and were only estimated based on CFD calculations. $O_2$ emissions remained constant with small fluctuations due to the increased proportion of hydrogen gas in fuel blends, as a result of constant $\varphi$=0.77 combustion. $CO_2$ emissions decreased by 21% as the volumetric percentage of $H_2$ in fuel blend increased to 50%. As the proportion of $H_2$ in the fuel content increased up to 50%, there was a 16% increase in H2O emissions.

CO and $CH_4$ greenhouse gas emissions result from incomplete combustion of hydrocarbon-based fuels. As the proportion of these emissions increases, incomplete combustion and unnecessary fuel consumption also increase. Although CO and $CH_4$ greenhouse gas emissions were too low to be measured in the experiments, numerical calculations showed low levels of emissions, which decreased significantly with an increase in $H_2$ gas content. CO emissions decreased by -82%, and $CH_4$ emissions decreased by -79.6% due to the increase in $H_2$ content in the blended fuel.

$NO_x$ pollutant emissions are mostly composed of NO. As the proportion of $H_2$ in the fuel increased, NO emissions increased by 26.5% in the experiments and by 29.8% in the CFD calculations. Since, increase in flame peak temperature as the proportion of $H_2$ gas in combustion increased, $NO_x$ emissions increase. $NO_x$ emission rates can be reduced with $NO_x$ reduction methods applied in current burner technology.

Tab 4. Comparison of experimental and numerical results

| Blended Fuel Composition | $O_2$ (%) | $CO_2$ (%) | $H_2O$ (%) | CO (mass fraction) | $CH_4$ (mass fraction) | NO (ppm) | $T_{fluegas}$ (K) |
|---|---|---|---|---|---|---|---|
| **100 % $CH_4$, EXP** | *4.86* | *9.23* | - | *0* | *0* | *36.4* | *1302.1* |
| **100 % $CH_4$, CFD** | *4.95* | *8.97* | *15.2* | *1.13E-05* | *4.57E-07* | *40.6* | *1330.2* |
| **70 % $CH_4$ + 30 % $H_2$, EXP** | *4.78* | *8.39* | - | *0* | *0* | *48.3* | *1310.9* |
| **70 % $CH_4$ + 30 % $H_2$, CFD** | *4.95* | *8.19* | *16.6* | *2.51E-06* | *1.16E-07* | *44.7* | *1336.4* |
| **60 % $CH_4$ + 40 % $H_2$, EXP** | *4.88* | *8.06* | - | *0* | *0* | *45.8* | *1318.8* |
| **60 % $CH_4$ + 40 % $H_2$, CFD** | *4.83* | *7.88* | *17.4* | *2.12E-06* | *1.07E-07* | *48.4* | *1342.4* |
| **50 % $CH_4$ + 50 % $H_2$, EXP** | *4.81* | *7.39* | - | *0* | *0* | *49.5* | *1347.6* |
| **50 % $CH_4$ + 50 % $H_2$, CFD** | *5.05* | *7.3* | *18.1* | *2.04E-06* | *9.33E-08* | *52.7* | *1351.3* |

Flame center velocities formed on the central axis from the burner and furnace to the chimney exit are shown in Fig 2.. As the proportion of $H_2$ in combustion increased, the flow velocity at the center of the flame increased, resulting in a decrease in flame diameter.

In experimental studies and CFD calculations, flue gas increased relative to the fuel content as the proportion of $H_2$ increased. This can be explained by the increase in flame peak temperature as the proportion of $H_2$ increased in combustion.

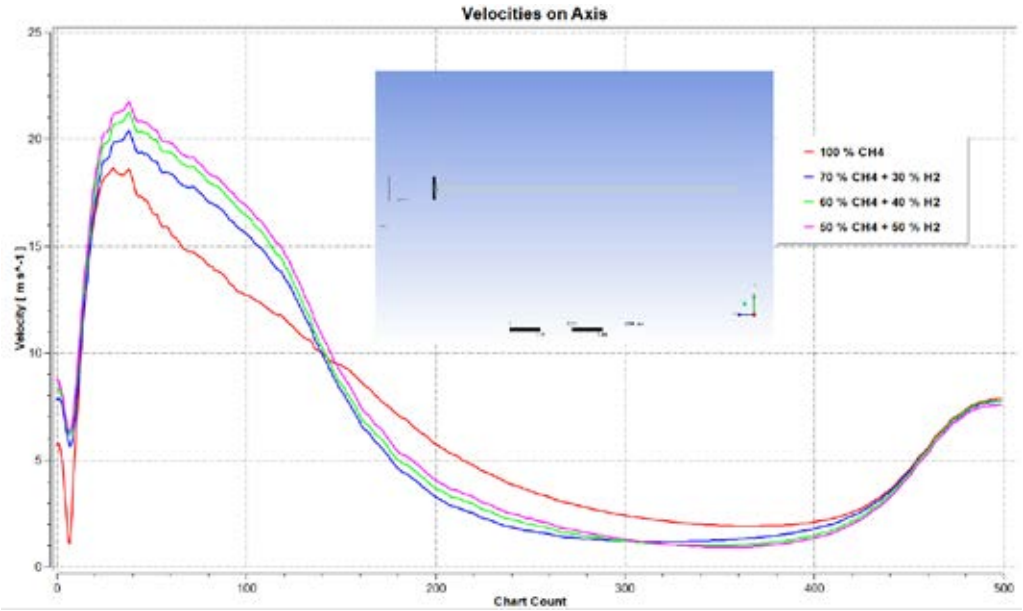



Fig. 2: Combustion flow velocities at burner and furnace axis depending on fuel type

## V. Conclusions

Process burners are commonly used in industry. In the present study, NG fulelled combustion performance of a process burner and NG blended with up to 50% hydrogen by volume have been investigated using experimental and numerical methods. As the proportion of $H_2$ increases, greenhouse gas emissions decrease, leading to eco-friendly combustion. However, flame peak temperature and $NO_x$ pollutants increase with increase of $H_2$ in combustion. $NO_x$ could be reduced by adapting the burner and using traditional NOx reduction methods. Higher flame temperatures and flame front flow velocity with $H_2$ fuel might be useful for process applications requiring rapid heating.

## Acknowledgements

We would like to thank the management of Ecostar and our colleagues, TÜBİTAK, TÜBAP and our families for their supports.

## References

ANSYS Fluent 2023R2, Theory guide. July 2023.

Bergman, T. L., Lavine, A. S., Incropera, F. P., & DeWitt, D. P. (2011). Introduction to heat transfer. John Wiley & Sons.

Çengel, Y. A., & Cimbala, J. M. (2004). Fluid Mechanics: Fundamentals and Applications. http://ci.nii.ac.jp/ncid/BB04830554

COP28 Declaration of Intent - hydrogen. (n.d.). https://www.cop28.com/en/cop28-uae-declaration-on-hydrogen-and-derivatives

FPB 200 - Ecostar. (n.d.). https://www.ecostar.com.tr/en/products/industrial-burners/process/fpb/fpb-200

İlbaş, M., & Candan, G. (2023b). Küçük Bir Girdaplı Yakıcı ve Fırında $CO_2$ Seyreltmesinin Alev Stabilizasyonu ve $NO_X$ Emisyonu Üzerindeki Etkileri. Politeknik Dergisi, 26(2), 603–608. https://doi.org/10.2339/politeknik.1026159

İlbaş, M., & Yılmaz, İ. (2011). Experimental analysis of the effects of hydrogen addition on methane combustion. International Journal of Energy Research, 36(5), 643–647. https://doi.org/10.1002/er.1822

Öztuna, S., & Büyükakın, M. K. (2020). Effects of hydrogen enrichment of methane on diffusion flame structure and emissions in a back-pressure combustion chamber. International Journal of Hydrogen Energy, 45(10), 5971–5986. https://doi.org/10.1016/j.ijhydene.2019.09.187

Öztürk, M., Sorgulu, F., Javanı, N., & Dinçer, İ. (2023). An experimental study on the environmental impact of hydrogen and NG blend burning. Chemosphere, 329, 138671. https://doi.org/10.1016/j.chemosphere.2023.138671

Salcı, O. (2023). Fırın sisteminde hidrojen gazı katkılı doğal gaz yakıtlı proses brülörü yanma analizleri ve optimizasyonu (Master's thesis, Trakya Üniversitesi Fen Bilimleri Enstitüsü)