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Flame characteristics analysis of a methane gas' premixed combustion on a ring attached-bunsen burner using ansys fluent

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Abstract. Many studies have had been done relating to the Bunsen burner. However there are only a handful of studies which focus on the implementation of a foreign component integrated to a Bunsen burner. Therefore, the effect of such component to the Bunsen burner still need to be investigated further. The study proposes a further analysis on the effects of a ring, primarily its temperature, on the Bunsen burner to the flame characteristic of methane gas. Flame's temperature, flame's height, and laminar flame speed are the 3 key properties observed. The study is done using a computer based numerical simulation software Ansys, implementing a 2D Fluent steady state analysis. The variations are the value of the ring's temperature, which are 400 K, 600 K, and 800 K. The result of the study suggests that for the same equivalence ratio value, the higher the temperature of the ring attached to the burner, resulting in a higher flame's temperature and laminar flame speed value. Proven by the fact that the 800 K temperature variation has the highest value of both flame's temperature and laminar flame speed for the same value in equivalence ratio compared to all of the variations. However, a higher ring's temperature value resulting in a lower or reduced flame's height formed for the same equivalence ratio. Also proven by the fact that the 800 K temperature variation also has the lowest flame's height value compared to all the variations at any given equivalence ratios.

1. Introduction

Many studies have had been done relating to the Bunsen burner, be it to observe the flame's characteristics on a different gas fuel or mixture [5,8,10], comparing the characteristic to another combustion apparatus such as a slot burner [1,2] or analyzing how a different mixture addition affects the flame's stability [4]. However, there's only a handful of them focusing on the integration of foreign component, how it directly or indirectly affects the resulting flame of the apparatus. Flame's temperature, flame's height and laminar flame speed are the 3 parameters to be observed. With these differing parameters, aside from many other different factors which need to be accounted as well will surely affect the resulting flame on the Bunsen burner. One of that component factor is a ring.

One Study suggest that the diameter of the ring integrated to the Bunsen burner directly affect the flame resulted on the apparatus. With a bigger ring diameter used, the greater it will affect the flame's characteristics. Flame's temperature, laminar flame speed are reduced in proportion to an increase of the ring's diameter. The result is consistent at several equivalence ratio values. However, the opposite happened to the flame's height. A bigger diameter resulted with a higher number value of it at any given equivalence ratio values. Due to the nature of the ring which adds an additional heat transfer effect [6].

The distance at which the ring implemented to the apparatus is also directly affect the resulted flame characteristics. With A further increase of the gap between the ring to the tip of the apparatus resulting an increase value for flame's temperature and laminar flame speed. And it is also consistent at any equivalence ratio values. The flame's height falls to the same behavior as well similar to the previous study above. The value of the flame's height increased with a further decreased of the gap between the ring and the tip of the burner. The flame's temperature and laminar flame speed are inversely proportional to the flame's height [2,4].

Another factor which needs to be accounted, further analyze as well and the primary focus of this study is the initial temperature of the ring. Its due to the ring is giving the system an additional heat transfer effect as stated above. Therefore, different values of temperature will directly affect the resulting flame's characteristics on the Bunsen burner as well compared with a Bunsen burner without a ring attached into it.

The aim of the study is to observe and determine how the ring and its initial temperature will affect resulting flame's characteristics of the Bunsen burner using a numerical based analysis simulation software, Ansys.

2. Methods

The design of the Bunsen model is demonstrated as Figure 1 below. The burner is attached with a 25 mm radius, and 3 mm wide ring. The distance of the ring from the tip of the burner is 5 mm. Aluminum and copper materials are used in this model, to the burner and ring respectively.

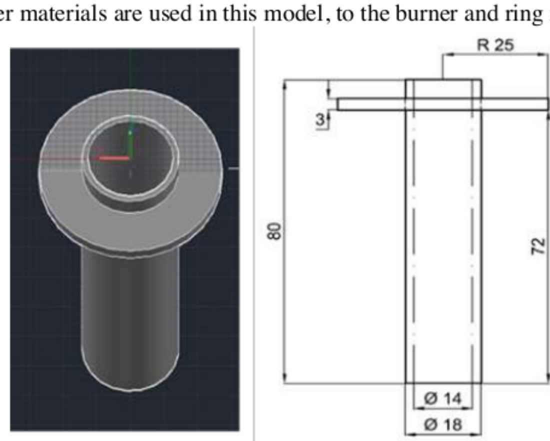

Figure 1. Dimensions of The Bunsen Burner

The study was performed using a computer based numerical analysis software, Ansys. The Fluent was selected as the solver for the experiment. Automatic sizing method was selected for the meshing process for the design as the 2D is less complex and sophisticated than 3D. With a high smoothing option, proximity accuracy was set to 0.5, inflation option was set to smooth transition to obtain a better accuracy. The total number of Nodes and Elements generated from the meshing step are 1723 and 1343 respectively. The calculation model for this study includes energy equations, K-epsilon viscosity standard wall function and eddy dissipation species transport model on volumetric reaction. The system was assumed at Steady-state condition.

The data obtained from the simulation is a temperature distribution of the flame. Which then the height and the angle of it are measured with an AutoCad software. The obtained flame's angle then further calculated using the equation (1) below to obtain the laminar flame speed.

$$s_L = v_U \times \alpha \tag{1}$$

3. Result and Discussion

3.1. Flame's Temperature

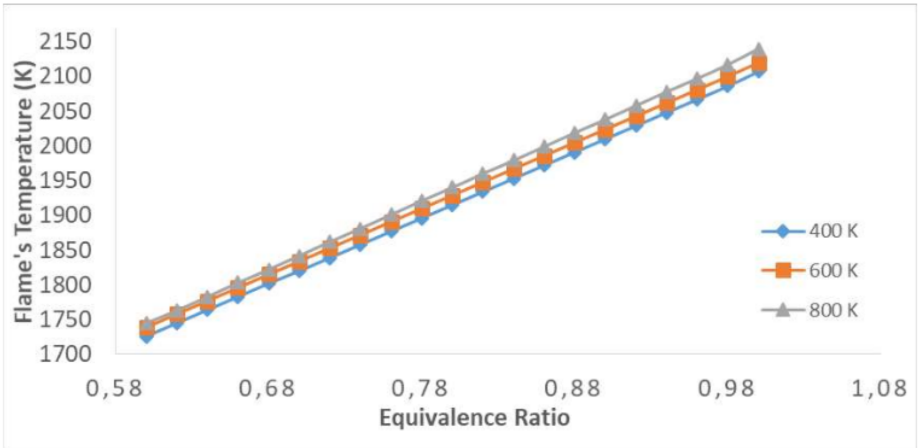

Figure 2. Flame's Temperature at various Equivalence Ratio

Figure 2 demonstrates the correlation between flame's temperature and equivalence ratio. As shown, the closer it gets to equivalence ratio of 1, the higher the flame's temperature value will be. A higher value in ring's temperature, the higher the flame's temperature will be, with the 800 K ring's temperature variant having the highest flame's temperature value in all of equivalence ratios. Specifically, the 800 K variant at equivalence ratio of 1 has the highest value for flame's temperature at 2140 K, meanwhile the 400 K variant at equivalence ratio of 0,6 has the lowest value at 1726 K.

At equivalence ratio of 1, the combustion process occurred at a complete or near complete state. A complete or near complete combustion state occurs when there is an equilibrium amount of mass flow rate between the fuel and the air, when such conditions satisfied, any losses occurred in the process will be at its minimum value. Therefore, the flame are able to sustain its energy. One of the losses occurred during the combustion process can be in the form of energy absorption of the flame to initiate any chemical reactions around it. At equivalence ratio of 1, nearly all of the reactants are burnt completely so then the leftovers substances, the primary cause for energy loss or absorption of the flame to initiate stated chemical reactions will be minimum as well.

Meanwhile, at equivalence ratio below 1, the combustion process occurs at a fuel lean state, a state in which the mass flow rate of the air is greater than the fuel. When such state occurs, the combustion process will produce many excess substances which did not form and react with the fuel. As a consequence, these excess free air molecules then proceed to absorb and utilize the flame's energy to decompose its molecule into a simpler form. Hence the flame's energy and temperature drop.

The 800 K variant is the highest in regards to flame temperature followed by 600 K and then 400 K variant subsequently in all equivalence ratio. This is due to the higher the ring's temperature, the energy transfer will go towards from the ring to the wall of the burner, from there the wall then will transfer some of that energy subsequently to the unburned reactants, making its temperature to rise. A higher temperature of reactants always correlated with a higher flame temperature. The result is quite similar with the finding of previous study [2].

3.2 Flame's Height and Laminar Flame Speed

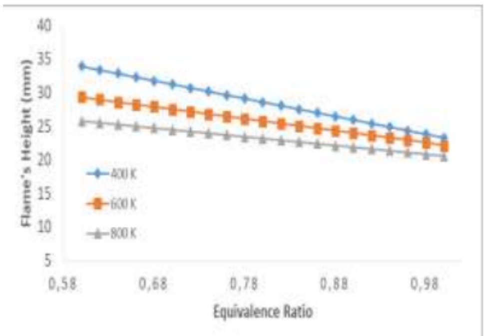

Figure 3. Flame's Height at various Equivalence Ratio

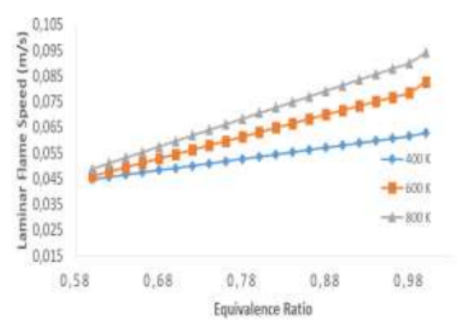

Figure 4. Laminar Flame Speed at various Equivalence Ratio

A higher value in ring's temperature, the lower the flame's height will be, with the 400 K ring's temperature variant having the highest flame's height. Specifically, the 400 K variant at equivalence ratio of 0,6 has the highest value for flame's height at 33,896 mm, meanwhile the 800 K variant at equivalence ratio of 1 has the lowest value at 20,58 mm. The value of the flame's height as demonstrated in Figure 3, gradually decreases as the equivalence ratio get closer to 1. Similar behaviour exhibits also in previous study [3]. This is due to the lower the ring's temperature the energy transfer will go towards the opposite direction to that of a higher temperature ring. As a consequence, the energy moves towards the ring, lessening the reactant's temperature and energy. A lower reactant's temperature is always correlated with a higher flame height and is inversely proportional to the flame temperature.

Laminar flame speed, contrary to the flame's height, as it gets to equivalence ratio of 1, the higher the value will be. A higher value in ring's temperature resulting a higher laminar flame speed, with the 800 K ring's temperature variant having the highest laminar flame speed in all of equivalence ratio values. Specifically, the 800 K variant at equivalence ratio of 1 has the highest value for laminar flame speed at 0,0943 m/s, meanwhile the 400 K variant at equivalence ratio of 0,6 has the lowest value at 0,0448 m/s. Due to at equivalence ratio of 1, the combustion process occurred at a complete or near complete state. Thus, resulting a higher flame's temperature value. The higher the flame's temperature, the higher the laminar flame speed as well. The 2 are proportional with one another. Referencing to equation (1), it is clear that the laminar flame speed heavily depends on the angle of the flame. A taller flame will have a small angle on the tip, meanwhile a smaller flame it's the opposite. Hence why the taller flame has relatively small laminar flame speed compared to its smaller counterparts.

4. Conclusion

The integration of a ring on a Bunsen burner directly affects flame characteristics produced. The initial temperature of it directly affects the resulting flame characteristics as well. A higher ring's temperature resulting a higher value of flame's temperature and laminar flame speed. Proven by the fact that the 800 K having the highest value for both flame's temperature and laminar flame speed of all ring's temperature variants at any given equivalence ratio. On the other hand, for the flame's height is the opposite, a higher ring's temperature resulting a lower value of flame's height. With 400 K having the highest value for flame's height of all ring's temperature variants at any given equivalence ratio. This is due to at a higher ring's temperature, the energy transfer occurs from the ring towards the system, while at lower ring's temperature, the opposite direction of energy transfer occurs.

Flame's temperature and laminar flame speed both gradually increase as equivalence ratio gets closer to the value of 1. The inverse happens for the flame's height, it gradually decreases as equivalence ratio gets closer to the value of 1. This is due to flame's temperature and laminar flame speed are inversely proportional with the flame's height.

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