Similarity Numbers in the Study of a Flame Formed by Two Gas Injection Burners

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***Abstract*— This publication investigates the interaction between two gas injection burners. Previous studies conducted under isothermal conditions indicated the potential for forming a jet geometry with practical applications. These preliminary investigations revealed favorable flow characteristics that suggested the feasibility of a useful jet configuration. Subsequent experiments performed under combustion conditions demonstrated the formation of a flame with a sheet-like structure. This flame geometry implies an increased surface area of the resulting composite flame, bringing it closer to that of a planar flame. A detailed analysis is necessary to explore the feasibility of achieving a flame shape that closely resembles a flat configuration. From the perspectives of hydrodynamics and aerodynamics, it is well known that generating a planar jet poses significant challenges. However, such a flow structure can be realized through the controlled interaction of two or more free turbulent jets.**

***Keywords* Dimensional analysis, criterial equation similarity numbers, flame formed, injection torch.**

I. Introduction

One of the approaches for conducting research of this type is the use of the method of generalized variables. This method allows for determining the extent to which various design and operational parameters influence the performance of the combustion device[1], [2]. The complexity of the method resides in the selection of physical quantities that affect the final outcome. The chosen physical quantities must be independent and not exert mutual influence.The objective is to determine the relative significance of their effect on the target variable under investigation. These independent variables may have thermal, aerodynamic, or purely geometric significance. It is inherently difficult to account for all relevant variables in advance, and there is a risk of developing a criterion-based relationship with an error exceeding the limits commonly accepted in engineering practice. The set of independent variables must include all quantities that could logically influence the variable of interest.

According to the theory of similarity, a system of differential equations describing a physical process can be represented in the form of a dimensionless (criterial) equation. This criterial equation is a mathematical expression that relates the dependent (target) variable to the independent variables through similarity criteria, also known as dimensionless similarity numbers. Essentially, it reflects the relationship embedded in the differential equations governing the process under investigation. The determination of the exponents and the proportionality coefficient in the criterial equation is based on experimental data, with the results typically presented in the form of a power-law function.

Dimensional physical quantities can be grouped into dimensionless similarity numbers, often referred to as criteria or complexes. The number of these criteria is smaller than the number of original dimensional variables from which they are derived. These similarity numbers represent new generalized variables of the process, and their introduction into the governing equations reduces the total number of independent variables, thereby simplifying the analysis of the physical process. These complexes capture the influence not only of individual physical parameters but also of their combined effects, which aids in the investigation of interdependencies within the studied process. Several authors have experimentally investigated the interaction between injection burners. Using a device and combustion process arrangement similar to the one considered in this publication [3],[4],[5],[6]. Research efforts have primarily concentrated on flame impingement, flame propagation characteristics, and the efficiency of fuel–oxidizer mixing. [7],[8],[9][10],[11],[12],.

The following figures illustrate the burner configuration schemes, along with key design dimensions.

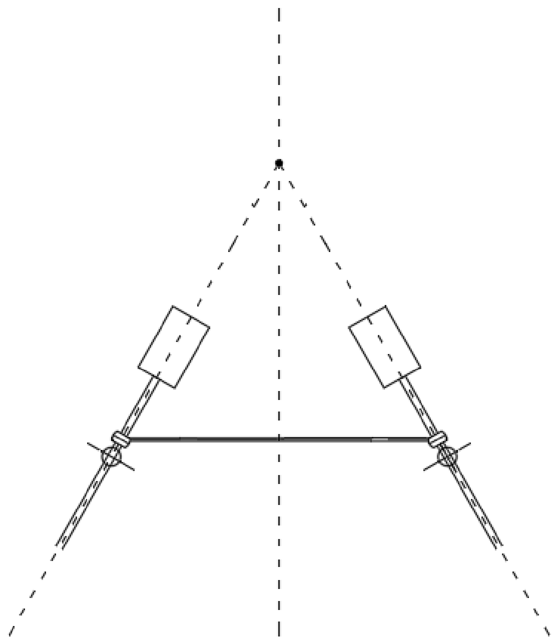

Fig. 1. Design arrangement of the Two Burners

Figure 1 illustrates the spatial configuration of the burners. They are mounted horizontally, and the supporting structure allows for adjustment of the angle between them

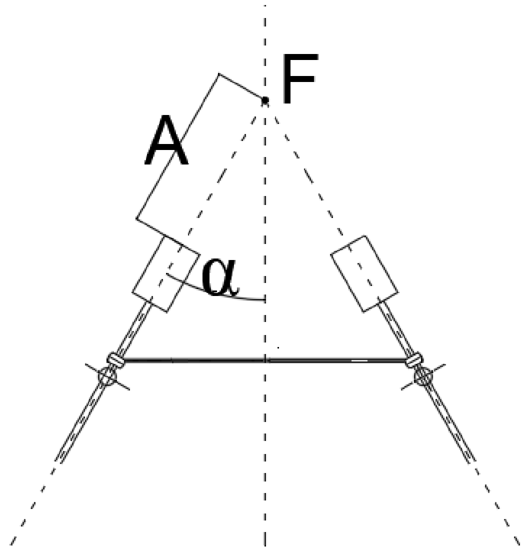

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Fig. 2. Design arrangement of the Two Burners

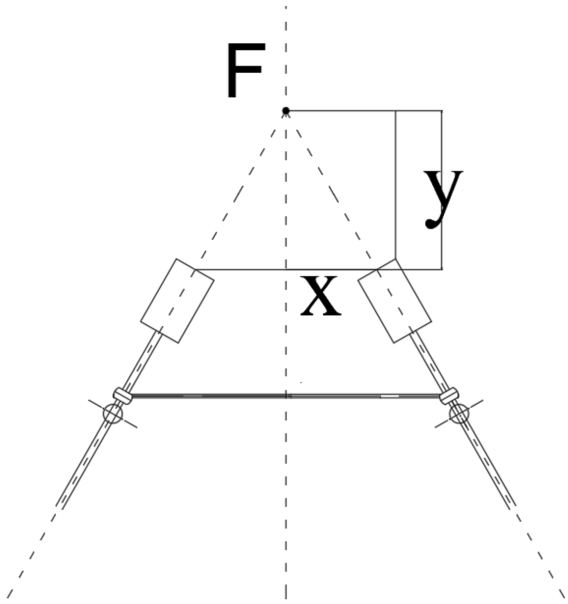

Fig. 3. Design arrangement of the Two Burners

Figures 2 and 3 present primary geometric dimensions that are critical for an accurate and comprehensive characterization of the interaction between the two flame jets. The point denoted as F, referred to as the focus, is defined by the intersection of the projected axes of the two burners. Its position is essential for determining several fundamental geometric parameters. The distance A, along with the dimensions x and y, characterizes the mixing zone formed by the interaction of the two flame jets.

II. Methodology Used and Results

First, it is necessary to define the quantities relevant to the present study. For the specific process, we will consider the useful maximum amount of heat transferred, which has the dimension W. The quantities upon which the maximum amount of heat released depends are described below:

- cross-sectional area of the gas nozzles – m^2;
- A characteristic geometric dimension (e.g., length)-m;
- x-y Characteristic geometric dimension (area)- m2;
- Thermal power of the two burners –W ;
- Radiative heat flux density – W/ m^2 ;
- Velocity Vu m/s;
- Velocity Vv m/s;
- Velocity Vw m/s;
- Kinematic viscosity m^2/s;
- Specific heat capacity J/kg.K.

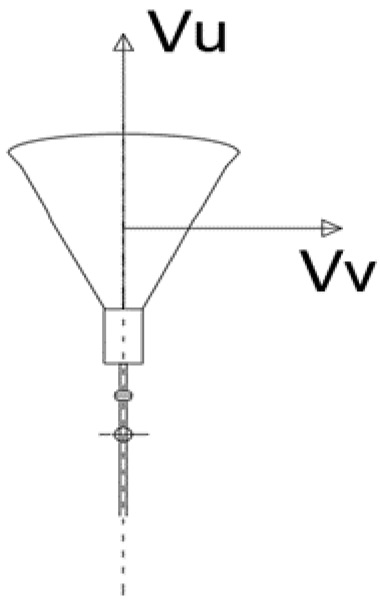

Fig. 4. Velocities in the u and v directions

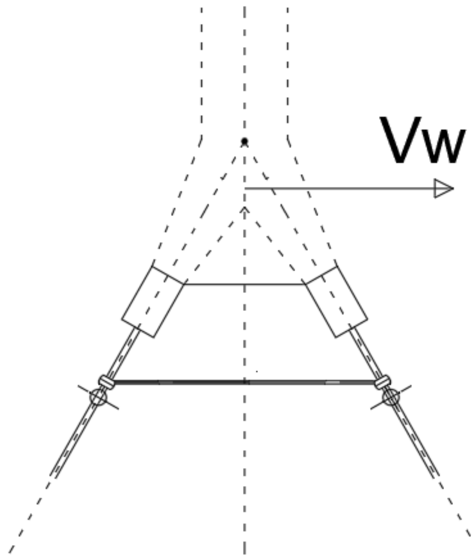

Fig. 5. Velocities in the w direction

Figures 4 and 5 present the coordinate axes along with the velocity components.

After describing the fundamental quantities relevant to the present study, these should be expressed dimensionally through the base quantities. In addition to the base quantities of length, mass, and time (LMT), for the specific case (according to Huntley), when dealing with thermal phenomena, the quantities of heat amount and temperature, denoted by H and Θ, respectively, must be included

The primary quantities considered in this study are:

G - Maximum heat transfer

fn cross-sectional area of the gas nozzles
x*y
A - characteristic geometric dimension (e.g., length)-m;
Q - Thermal power of the two burners –W
Vu - Velosity m/s;
Vw - Velosity m/s;
B - Radiative heat flux density – W/ m2

Based on the listed parameters, the following functional relationship is established:

A= f.(fn(x*y),A,Q,Vu,Vw,B) (1)

It is required to present it in the following format.
A= fna (x*y)b,Ac,Qd,Vue,Vwf,Bg (2)

$$\frac{L^2.M}{T^3}=(L^2)^a * (L^2)^b *(L)^c *\left(\frac{L^2.M}{T^3}\right)^d *\left(\frac{L}{T}\right)^e *\left(\frac{L}{T}\right)^f *\left(\frac{M}{T^3}\right)^g \quad (3)$$

III. Results

In order to simplify the criterial equation and reduce it to one involving only the geometric dimensions of the burners, the physical quantities characterizing the thermal state of the medium are excluded, such as heat load and radiation density. Consequently, the number of determining physical variables is reduced to seven, and the criterial equation takes the form:

$$\frac{L^2.M}{T^3}=(L^2)^a * (L^2)^b *(L)^c *\left(\frac{L^2.M}{T^3}\right)^d *\left(\frac{L}{T}\right)^e *\left(\frac{L}{T}\right)^f *\left(\frac{M}{T^3}\right)^g \quad (4)$$

with the following dimensional constraints:

- Length: 2=2a+2b+c+2d+e+f
- Mass: 1=d+g
- Time: −3=−3d−l−f−3g

We select the free parameters a, b, c, and e, which are then used to express f, d, and g.

f=2-2a-2b-c-2d-e

g=1-d

-3=-3d-e-f-3g

At the end of the transformation, we arrive at:

g=1-d

2a+2b+c=2

f=2-2a-2b-c-2d-e

There are seven unknowns and three equations, so four of the unknowns are chosen as parameters:

a=a, b=b, c=c, e=e

Therefore, the criterial equation becomes:

$$A=Q.\ \left(\frac{f_a.B}{Q}\right)a\ .\ \left(\frac{F.B}{Q}\right)b.\ \left(l\left(\frac{B}{Q}\right)^{\frac{1}{2}}\right)c\ .\ \left(\frac{W_t}{W_a}\right)e \quad (5)$$

IV. Conclusion

The primary factors influencing the physical processes in this type of burner are the characteristic geometric dimensions: the length A and the product x·y. The resulting partial similarity criteria reflect the design and operational characteristics of such a system. Further experimental investigations will provide the necessary data to determine the numerical values of the power exponents.The obtained results can be used to facilitate and accelerate the design of combustion devices of this type.

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