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FLAME TEMPERATURE ANALYSIS IN THE OXYCUT PROCESS USING ACETYLENE GAS: A NUMERICAL STUDY

ANÁLISE DE TEMPERATURA DE CHAMA NO PROCESSO OXICORTE USANDO GÁS ACETILENO: UM ESTUDO NUMÉRICO

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ABSTRACT

To cut metals, the oxycut process uses a preheating flame, usually composed of oxygen and a combustible gas, in addition to a flame-independent jet of oxygen. In the present work, the partially premixed combustion model of a finite volume-based software was applied to analyze the flame temperature in a cutting tip of acetylene. At the torch inlet boundary, the flow rates of oxygen and acetylene were adjusted to sweep a wide range of fuel-oxygen ratio. The results pointed a peak surrounding the stoichiometric ratio, at 3106 °C for the literature and 2650.93 °C for the numerical model, contrasting a deviation of 14.65%. The maximum temperature occurs at 52.38% of oxygen volume for the literature and 50.03% for the model, a difference of 2.35 percentage points only. It is concluded that the results of the numerical approach attained the ends of the research.

RESUMO

Para corte de metais, o processo oxicorte usa uma chama de pré-aquecimento, normalmente composta por oxigênio e um gás combustível, além de um jato de oxigênio independente da chama. No presente trabalho, o modelo de combustão de pré-mistura parcial de um software de volumes finitos foi aplicado, com o objetivo de analisar a temperatura de chama em um bico de maçarico de acetileno de corte. Na entrada da tocha, as vazões de oxigênio e acetileno foram ajustadas para varrer uma grande extensão da razão oxigênio-combustível. Os resultados apontaram um pico nas proximidades da proporção estequiométrica: 3106°C para a literatura e 2650,93°C para o modelo numérico, uma diferença de 14,65%. A temperatura máxima de chama ocorre a uma proporção volumétrica de 52,38% de oxigênio para a literatura e 50,03% para o modelo, uma diferença de 2,35 pontos percentuais apenas. Conclui-se que os resultados da abordagem numérica atingiram os objetivos da pesquisa.

1. INTRODUCTION

Oxycut is a thermal and chemical cutting process, frequently performed to cut carbon and low alloy steel, faster and cheaper than any mechanical mean (Machado, 1996). Oxycut main advantages are its relatively simple configuration, directly associated to expenses, alongside with the chemical source of most of the amount of energy required by the process: a reaction between oxygen and a combustible gas.

The oxyfuel gas cutting uses a pure jet of oxygen to oxidate the base metal and to remove the mixture of oxides and the material to be cut from the fissured region (Marques et al., 2011). The preheated surface at the ignition temperature, combined with the oxygen jet, produce the catastrophic oxidation of all the part's thickness (Machado, 1996). Cut quality is connected to, among many properties, the gases flow rates (Marques et al., 2011), as well as the temperature reached by the process (Marques et al., 2011; Ramalho, 2008).

Although studies such as the one developed by Carlos (2008) evidence the attractiveness of Liquefied Petroleum Gas (LPG) for oxyfuel gas cutting, acetylene is still the most widely fuel gas employed. However, the investigation of acetylene oxidation is beyond welding and cutting applications, because it also takes place during the combustion of larger hydrocarbon fuels and plays a major role in the growth of soot particles in fuel rich flames (Murray et al., 1992).

Amongst many researchers, such as Perry et al. (2016), Tian and Lindstedt (2018), Staffelbach et al. (2009) and Drake and Haworth (2007), it is a general agreement, in combustion devices, the naturality of the presence of heterogeneity in the composition. These devices are gas turbine chambers, direct-injection engines, industrial burners and others. The concept of partially premixed flames has been employed, in combustion simulations, by many researchers. It involves different devices and applications, such as a direct injection natural gas engine (Li et al., 2019), precision test burners and Bunsen burner systems (Chen et al., 2014), and others.

The partially premixed combustion model combines the non-premixed and the premixed combustion models. Yu et al. (2019) report in their work the importance of the study of probability density functions, PDF, in the solution of turbulent reacting flows, due to the modeling of the averaged chemical source term. The chemical source term appears in a closed form in PDF transport equations, thus this problem can be solved. However, there is a necessity of accelerating the computational process. The Lagrangian Monte-Carlo particle method is then used to solve the transported-PDF equation (Haworth, 2010).

See and Ihme (2015) allege that large-eddy simulation (LES) has provided considerably improved predictions of turbulent reactive flows. Their work was carried out in a gas turbine model combustor. Wu and Ihme (2016) studied the use of low-dimensional manifold combustion models for LES of turbulent reactive flows. The work identified sources of uncertainties. The authors also state that evaluating uncertainties in the absence of measurements or reference results is crucial for reliable and predictive simulations.

On the other hand, several researchers have studied the use of the SST k-ω (Shear Stress Transport) turbulence model in fluid flow applications. Azad et al. (2016) claims the efficiency of this model for turbulence complex flow and variable density field. Their work also found that this model could be a powerful tool to predict combustion phenomena under low temperature combustion strategies.

Costa Rocha (2014) calibrated a model for a small-scale horizontal axis wind turbine. In contrast, Riahi et al. (2020) stated in their paper the use of the SST k-ω for a turbulent combustion with hybrid enrichment by hydrogen and oxygen. In their work, a turbulent diffusion flame from a coaxial burner is analyzed by investigating the impact of hydrogen amount variation on the flame structure, on the temperature distribution and on the emissions of atmospheric pollutants.

According to Williams and Smith (1970), the combustion of acetylene is of a considerable chemical and industrial interest. Furthermore, the importance of the flame temperature study in the oxycut process using acetylene gas is prominent. The objective of the research is to study and analyze the flame temperature created by an oxycut tip. The process is simulated through a numerical model, for a wide range of oxyacetylene ratio. Ansys® Fluent Release 16.0 is applied to compute the model, using the partially premixed combustion and the SST k-ω models, and the results are compared to those provided by the literature.

2. TYPES OF FLAMES

Not every combustion phenomenon produces flames. On the other hand, flames can be classified as premixed or non-premixed. The difference between the flames lies in the reagent mixing molecular states (Turns, 2013; Kuo, 2005).

Figure 1 illustrates the configuration of acetylene combustion for welding or gas cutting processes. As well as to other fuel gases, it occurs in two stages: the primary and secondary combustion zones, according to Wainer (2004). In this figure, within the primary combustion zone, there is a narrow region where chemical reactions occur and propagate through the mixture air-fuel. This narrow region is the so-called flame (Turns, 2013).

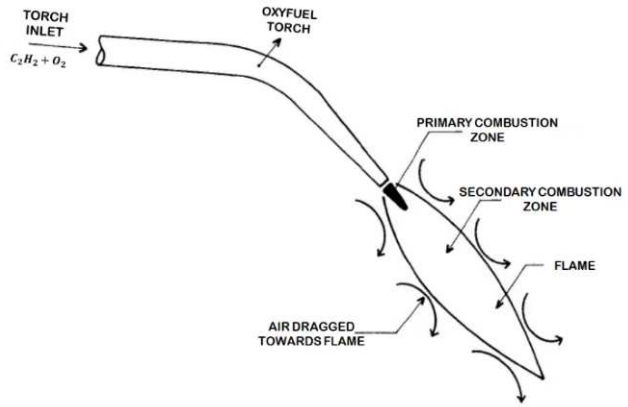

Figure 1 – Configuration of oxyacetylene flame torch. Adapted from Wainer (2004).

As reported by Zhang (2020), the acetylene, C_2H_2, as in Figure 1, is a commonly employed gas in aerospace technology, power systems, chemical industry and other fields. It is also frequently exploited in the industry, where the work was focused, for high temperature cutting and metal welding, due to its rich combustion temperature: Approximately 3200°C.

Within this same concept, other researchers, such as Lokachari et al. (2018), Ramalho (2008) and Williams and Smith (1970), emphasize the high temperature of acetylene compared to other hydrocarbons. Many studies are then established in acetylene oxidation, therefore, one of the main application sources in welding and gas cutting.

The relevance of the research of acetylene and its high flame temperature in combustion is related to its molecular structure. According to Williams and Smith (1970), because of its triple bond that results in high enthalpy of formation, the combustion of acetylene produces flame temperatures higher than those usually achieved by another hydrocarbon fuel. As stated by the authors, acetylene is a linear molecule and its structure is best described in terms of sp hybridization. However, the authors report the instability of this hydrocarbon, due to its short bond lengths and high bond strengths, but the enthalpy of formation is also high, which results in an unstable nature.

The flames are classified in welding and gas cutting applications according to the oxygen and fuel consumption rates. They are frequently called carburizing flame, when there is an excess of acetylene, neutral, if the amounts of oxygen and acetylene are similar, or oxidizing, when there is oxygen in excess.

3. PARTIALLY PREMIXED COMBUSTION MODEL

Several researchers, such as Gicquel et al. (2012) and Veynante and Vervisch (2002), discuss the purpose of combustion regimes. According to them, these regimes are introduced to represent physical processes that dominate turbulent flames and to choose closure models, such as flamelet, thickened flame and distributed reaction. Aggarwal (2009) describes the structure of partially premixed flames as hybrid flames possessing the characteristics of both premixed and non-premixed flames.

The partially premixed combustion model allies the non-premixed, which can be reasonably simplified to a mixture problem, to the premixed combustion model, a powerful tool capable of studying the speed of the flame. The transport equations are solved for arbitrary scalars (ϕ) as described in Equation 1 in the solver.

$$\int_V \frac{\partial \rho \phi}{\delta t} dV + \oint \rho \phi \vec{v} \cdot d\vec{A} = \oint \Gamma_\phi \nabla \phi \cdot d\vec{A} + \int_V S_\phi dV \quad (1)$$

Where: ρ = density, $\vec{v}$ = velocity vector, $\vec{A}$ = surface area vector, Γ_ϕ = diffusion coefficient for ϕ, $\nabla\phi$ = gradient of ϕ and S_ϕ = source of ϕ per unit volume. These scalars may be quantities such as the mean mixture fraction (f) and progress variable (c). The mean mixture fraction is related to the equivalence ratio (ϕ^*) and the stoichiometric mixture fraction (f_{ST}) as in Equation 2 (Peters, 2010; Turns, 2013).

$$\phi^* = \frac{f}{1-f} \cdot \frac{(1-f_{ST})}{f_{ST}} \quad (2)$$

According to Turns (2013), the mean mixture fraction is vital when non-premixed flames are evaluated, where carburizing and oxydizing flows are initially separated. This scalar is adopted to generate a chemical species conservation equation, which do not possess a source term. This form simplifies the solution of reacting flows when applied locally in infinitesimal control volumes.

There is a relation between the equivalence ratio and the conserved scalar f in Equation 2. The mean mixture fraction can thus be used to define the flame borders. This conserved scalar can be preserved throughout all the flow field, according to a governing equation with no source terms.

The progress variable describes the evolution of a reaction from unburnt state to burnt. This variable is defined as 0 for reactants ahead of the flame, 1 for products behind it and fluctuating between 0 and 1 within the flame brush given its transport through the domain (Ansys Fluent Theory Guide 16.0, n.d.). Probability Density Functions (PDF) have been used to reproduce partially premixed flames, where a combination of conserved and reacting scalars parametrizes the thermochemical field (Tian and Lindstedt, 2008). The PDF, frequently written as $p(f)$, reflects a portion of time that the fluid spends in the proximity of a state f. Scalars such as temperature and density-weighted mean species mass fractions ($\bar{\phi}$) are calculated in the software as in Equation 3, which can save computational time compared to approaches that solve species transport equations.

$$\bar{\phi} = \bar{c} \int_0^1 \phi_b(f) p(f) df + (1 - \bar{c}) \int_0^1 \phi_u(f) p(f) df \quad (3)$$

Where the scalars $\phi(f)$ are polinomial fits experimentally obtained and the subscripts b and u represent burnt and unburnt. The equation for reduced temperature can be simplified to the form of Equation 4, where T_u is the temperature of the unburnt mixture and T_{ad} is the highest adiabatic burnt temperature.

$$T = (1 - c)T_u + cT_{ad} \quad (4)$$

The temperature calculated by the model is then a function of the mean mixture fraction, determined by the software's PDF approach. T_{ad} is a variable supplied by the software's library. ANSYS® Fluent presents this variable as a function of the mean mixture fraction in Figure 2, where the PDF table is generated for pure acetylene and oxygen as fuel and oxidizer, respectively. The figure shows the temperature, which can barely reach 2726.85 °C (3000 K) at stoichiometric vicinities for acetylene in the conditions presented by the present work.

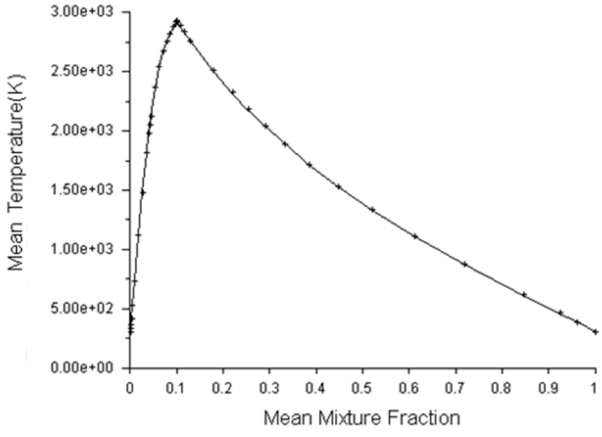

Figure 2 – Relation between temperature and mean mixture fraction in ANSYS® Fluent PDF approach.

The PDF approach in combustion modeling is a tempting method to avoid problems in the mean reaction rate modeling, (Warnatz et al., 2006). Through this concept, at the spatial location $\vec{r}$, the representation of a density between ρ and $\rho +$

$d\rho$, a temperature between T and $T + dT$ and other parameters, such as the local composition, corresponded by mass fractions between Y_i and $Y_i + dY_i$, are then given in terms of a statistical function. The shape of this function behaves, at some points, similarly to a Gaussian distribution. In Figure 2, there is a peak at approximately 2650°C in the vicinities of stoichiometric proportion in the mixture of C_2H_2 and O_2.

The regions where the oxygen volume percentage is under 50% are described as cumulative probability of these values. As long as the curve goes to the right, that is, this concentration increases, the respective temperature decreases until 1, where the chemical reaction ceases.

The progress variable, c, may also be written, according to Veynante and Vervisch (2002), as a reduced mass fraction, as in Equation 5.

$$c = \frac{Y_F - Y_F^u}{Y_F^b - Y_F^u} \quad (5)$$

Where Y_F, Y_F^u and Y_F^b are, respectively, the local unburnt gas and burnt gas fuel mass fractions. The burnt gas fuel mass fraction, Y_F^b, is non-zero for a rich, i.e. with fuel in excess.

In Computational Fluid Dynamics (CFD) researches, studies are carried out to ensure the accuracy of the results, so a posterior refinement of the mesh would generate useless additional computational cost. In these studies, one parameter has key function: the dimensionless y^+, calculated in the software by Equation 6, where y is the distance from the wall and u_τ is the so-called friction velocity. Ansys Fluent's User's Guide recommend the use of $y^+ \approx 1$.

$$y^+ \equiv \frac{\rho u_\tau y}{\mu} \quad (6)$$

The turbulence intensity (I) is defined as the ratio of the root-mean-square of velocity fluctuations and the mean flow velocity (Turns, 2013). According to the software's help system, this variable can be estimated, for fully developed pipe flows, as in Equation 7, and values below 1% are then defined for low turbulence and turbulence intensities greater than 10% are considered high. Re_{Dh} is the Reynolds number based on D_h.

$$I = 0.16 Re_{D_h}^{-1/8} \quad (7)$$

The turbulence intensity is set up as a boundary condition in CFD models. The Damköler number (Da), defined as the ratio between mixing and chemical time scales, τ_{mixing} and $\tau_{chemical}$ in Equation 8, measures the reaction rate in terms of the interaction between turbulence and chemistry (Rehage and Kind, 2021).

$$Da = \frac{\tau_{mixing}}{\tau_{chemical}} \quad (8)$$

Several applications are found for Da in the literature. Some authors, such as Marchisio and Barresi (2003), use it to interpret results. Others, such as Marchisio et al. (2006), Gillian and Kirwan (2008) and Johnson and Prud'homme (2003), develop rules derived from Da analysis. Others, such as Gradl et al. (2006) and Metzger and Kind (2016), use Da to suggest a transformation point when it comes to the influence of the mixing and chemical issues on the reaction.

4. MATERIALS AND METHODS

The present work simulates the combustion of an oxyacetylene flame and was developed in three stages. The first one is Computer Aided Design (CAD) modelling of the parts assisted by SolidWorks®. The behavior of the flame temperature is then evaluated, varying the mixture fraction on a CFD solver (ANSYS® Fluent Release 16.0) and the results are compared to those provided by the traditional literature, with the support of MatLab® to postprocess data. The development was carried out profiting resources provided by Federal University of Viçosa - UFV, with the support of the university's department of production and mechanical engineering during all the extent of the project.

4.1 Model Description

The cutting tip chosen is a Torch model 3502 series, tip number 1, as shown in Figure 3. White Martins Gases Industrials Ltda supplied it for research purposes. The tip is made of a copper and brass alloy, and the manufacturer recommends its use to cut plates from 10 to 15 mm thick. Acetylene is the recommended fuel gas.

However, aiming the reduction of computational cost, the model contemplates the outer zone of the cutting tip, so only one of its six flame outlets is modeled. By modeling the outer zone, the present work considers the mass conservation while gases are blended within the mixture chamber. The model was also reduced to a 2D domain with cylindrical symmetry, with the same end.

Figure 3 – Cutting tip Torch 3502 series number 1.

Figure 4 exhibits the 140 x 28 mm domain designed, in silver, where model inlet, outlet, axis and walls are exposed. To favor convergence, the top edge is simplified to a wall 140 mm long. The inlet edge is 0.35 mm long, half of the Torch tip's flame outlet, which is the hydraulic diameter (D_h) of 0.7 mm. The model outlet edge is designed 28 mm long, in order to reduce influence of the top edge wall in the flow. Boundary conditions are in red.

The boundary conditions prescribed for the model inlet and outlet edges are given in Table 1. The model was carried out adjusting flow rates of oxygen and acetylene at boundaries to sweep a wide range of fuel-oxygen ratio, from 4 to 82% oxygen volume percentage in steady state.

Table 1 – Boundary conditions for model inlet and outlet borders.

	Inlet	Outlet
Boundary Type	Velocity-inlet	Outflow
Progress Variable	0.5	n/a
Turbulence Intensity	5.7%	n/a
Hydraulic Diameter	0.0007 m	n/a
Velocity Magnitude	69.5 m/s	n/a
Gauge Pressure	264780 Pa	n/a

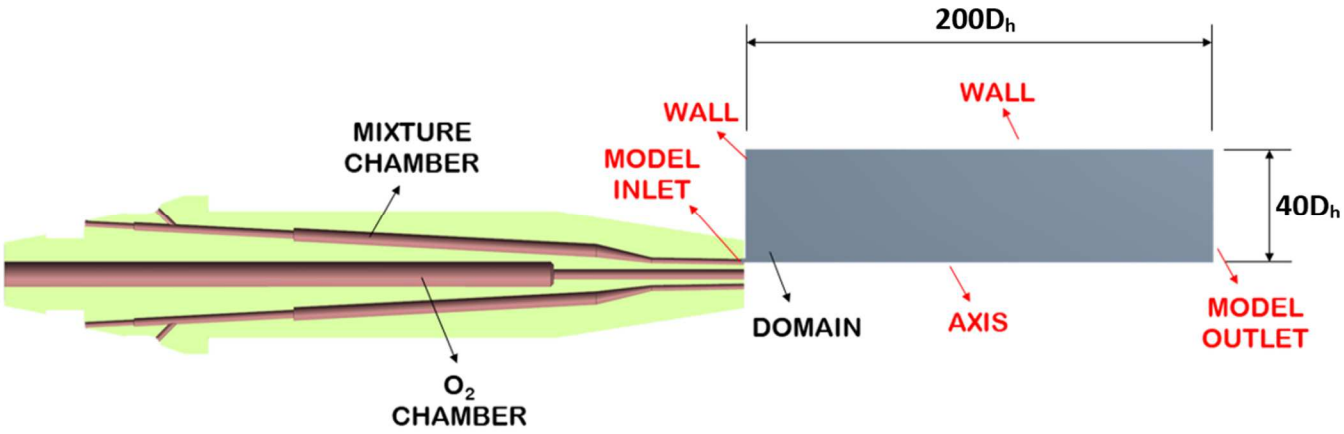

Figure 4 – Cutting tip and model scheme.

The SST k-ω turbulence model is employed with standard parameters, an approach based on zones that unites the qualities of two of the most widely used turbulence models in CFD: the k-ε and k-ω standard models. The flow rate and pressure chosen at the inlet boundary are values frequently applied in cutting applications. Considering the flow is fully developed when the mixture is about to reach the tip's mixture chamber outlet, which is virtually reproduced by the model inlet, and also considering there is chemical equilibrium at this point, the hydraulic diameter and velocity magnitude are applied in Equation 7 in order to estimate the turbulence intensity. A factor of 5.7% is then prescribed.

5. RESULTS AND DISCUSSION

5.1 Mesh Independence Test

To ensure the results are not dependent on the grid quality, a mesh independent test is carried out. In the present work, the test was performed at stoichiometric proportion. Six refinement levels are exploited: 1252500, 1637634, 2227112, 2651373, 3200000 and 3500000 cells. These grids are represented by the numbers 1 to 6, respectively.

A reference grid, which in this case was the grid number 1, is used to calculate a reference value of the Outlet Average Velocity. The Outlet Average Velocity is calculated based on the law of mass conservation, so continuity equations are applied by the software. Once a velocity of 0.0204002 m/s is found, the average size of elements in the domain is decreased, so the new mesh has a greater quality. The file is run again with the grid number 2 and a new value, of 0.0203439, is found. The percentual deviation on the Outlet Average Velocity (%D) between the current mesh, grid number 2, and the previous one, grid number 1, is -0.2856%. This procedure is repeated until the deviation in the velocity is judged ineffective when compared to the additional computational time it would demand. The relation between all the mesh refinements and the change in the velocity is given in Table 2.

Table 2 – Relation between Outlet Average Velocity and mesh refinement.

Grid Number	Number of cells	Outlet Average Velocity (m/s)	%D on Outlet Average Velocity
1	1252500	0.0204002	-
2	1637634	0.0203439	-0.2856
3	2227112	0.0202950	-0.2400
4	2651373	0.0202514	-0.2148
5	3200000	0.0202252	-0.1296
6	3500000	0.0202035	-0.1073

The grid number 5, of 3200000 cells, is thus chosen to proceed the work. The deviation of -0.1073% in the velocity is considered negligeable and the grid number 6 is discarded.

ANSYS® Fluent shows the dimensionless y^+ parameter as an output variable, calculated by Equation 6. According to the software's Theory Guide, the near-wall mesh is fine enough to be able to resolve the viscous sublayer when the first near-wall node is placed at $y^+ \approx 1$. The maximum y^+ found for the chosen grid is 1.2. The scaled residuals are plotted in Figure 5, which indicates convergence of all the equations in 1673 iterations.

The simulations were carried out on a 4 Intel i7-8550U cores, 16 GB RAM. The average computational time was approximately 8 hours per simulation.

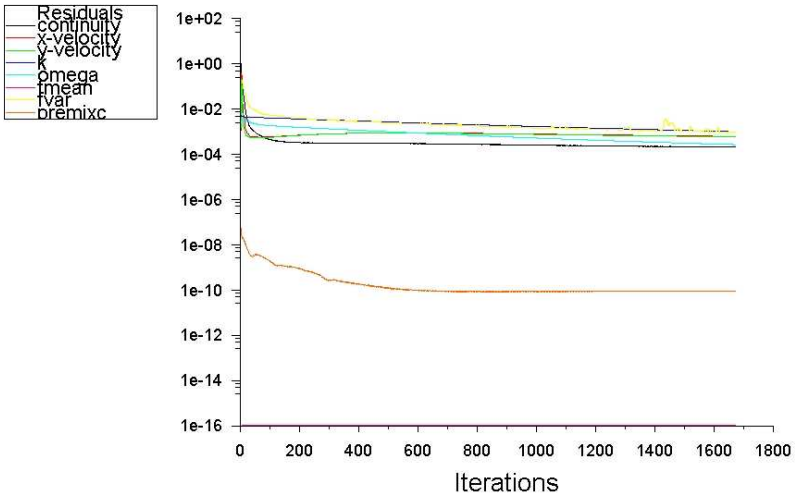

Figure 5 – Scaled residuals: Convergence achieved after 1673 iterations.

5.2 Temperature Correlation

Understanding the temperature achieved by a flame is essential for industrial and scientific applications. However, high temperatures related to oxyacetylene flames hinder experimental procedures, since acetylene is capable of sustaining a self-decomposition flame, while in mixtures with oxygen it readily detonates (Williams and Smith, 1970).

The maximum temperature numerically calculated is plotted, using MatLab®, as a function of the volume percent concentration of oxygen in Figure 6. The trend curve created correlates the numerical results to those supplied by the adapted of Ramalho (2008). The results obtained in the same figure consider a chemical equilibrium of the gas mixture and any heat loss is then negligible. The temperature achieved by other gases oxidation is also plotted. The fact that the acetylene curve, in yellow, is the highest compared to other gases, is directly related to its productivity in welding and cutting applications.

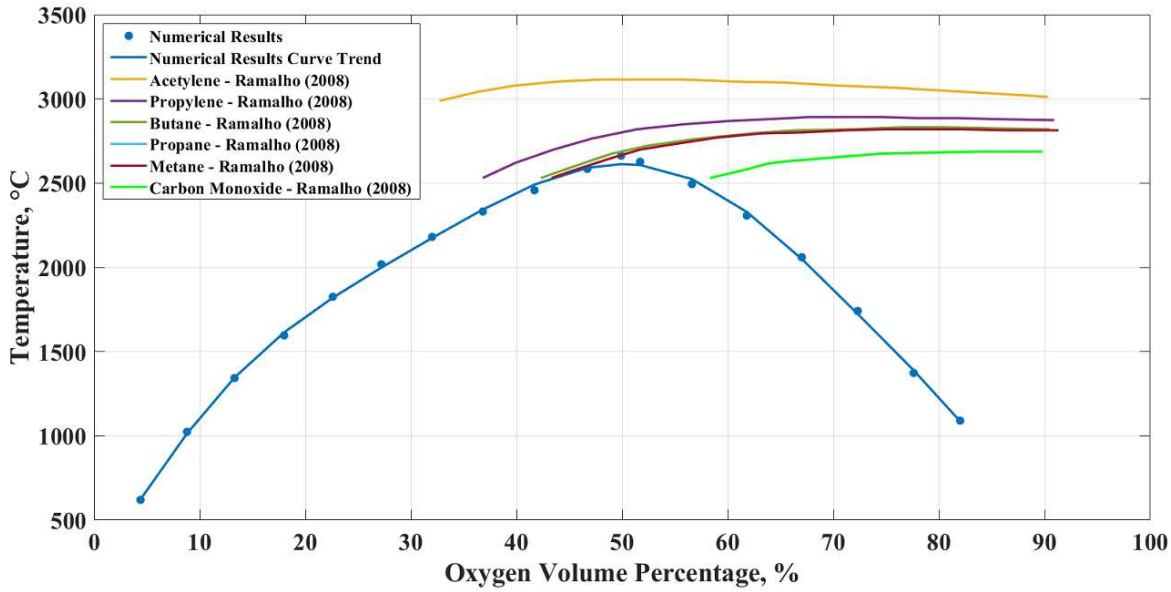

Figure 6 – Temperature correlation: Numerical results and adapted curves from Ramalho (2008).

An initial growth in temperature when increasing the oxygen volume percentage is observed, which indicates the lack of comburent to achieve complete combustion. As long as the oxygen volume percentage increases, it reaches stoichiometric proportion before acquiring a declined shape, which demonstrates complete combustion with oxygen in excess. In this point, there is a significant heat loss motivated by the excess of O_2 molecules that could not perform combustion.

Defining the stoichiometric proportion as a starting point, as long as the fuel-oxygen ratio is either increased or decreased, the number of molecules that do not perform combustion also increases. There is hence a heat loss, which justifies the reduction in temperature. The behavior produced by

the model is thus consistent, which is also observed in the work of Williams and Smith (1970).

A peak near the stoichiometric proportion is noticed at 3106 °C for Ramalho (2008) and 2650.93 °C for the model, a discrepancy of 14.65%. The maximum temperature occurs at 52.38% for Ramalho (2008) and 50.03% of oxygen for the numerical results, a deviation of 2.35 percentage points only. Therefore, for the regions where the flame tends to be neutral, ANSYS® Fluent's partially premixed combustion model best approaches to the curve adopted by Ramalho (2008), which suggests a correlation of the model to welding and cutting applications in these regions. The maximum temperature calculated is though always below those supplied by the literature.

However, the more distant from the peak region, that is, the leaner or richer the flame is, the less accurate the results are comparing to the reference. This means that models, with the conditions presented in this work, do not represent accurately cutting applications if the flame is either overly oxidizing or carburizing. As reported by Williams and Smith (1970), the temperature is a function of log(pressure). Although the pressure chosen at the inlet boundary agrees with oxygen cutting processes in general, according to the tip manufacturer, it is not the goal of the present work to evaluate its influence on the flame temperature.

It is necessary to point out that the correlation is performed for the maximum temperature of the model only, that is, regions where the reaction progress variable, a normalized mass fraction of the reaction products, defines the mixture as burnt. For those regions, the temperature calculated by the model is a function of the mixture fraction only, calculated by the software's PDF approach. The relation between temperature and oxygen volume percentage is plotted in Figure 7, where the mean mixture fraction, in Figure 2, is converted to oxygen volume percentage.

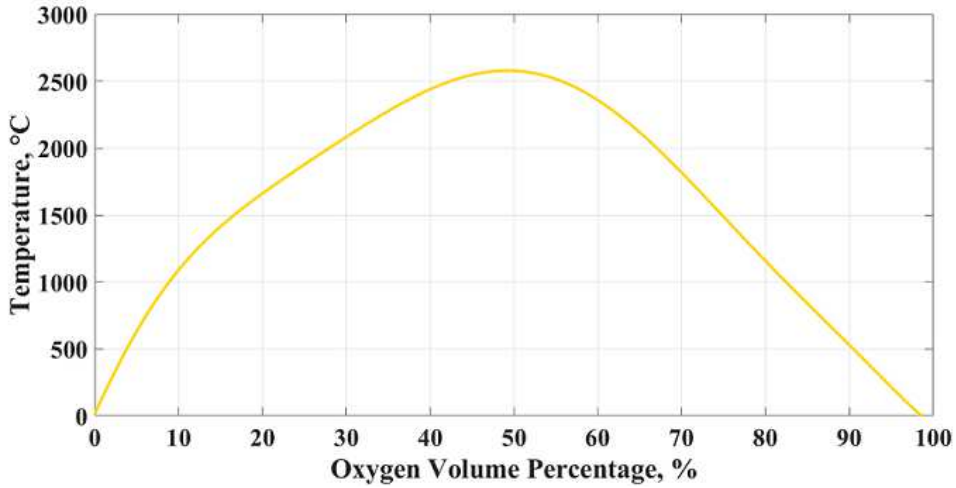

Figure 7 – Relation between temperature and oxygen volume percentage in Ansys® Fluent Release 16.0.

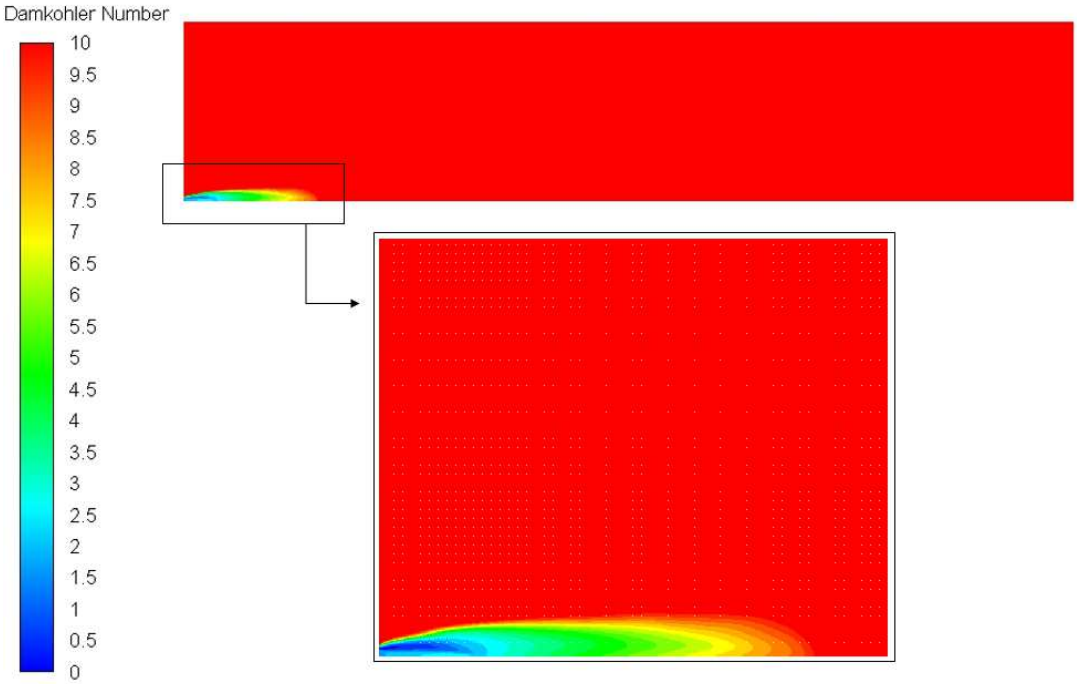

Figure 8 – Contours of the Damköhler number.

It is important to note that it is not possible to reach the same value presented by Ramalho (2008), since the numerical results are limited by the curve in Figure 2, which is always below 2726.85°C (3000K) for any oxygen volume percentage. This limitation is also directly related to the drastic decrease in temperature when displacing the fuel ratio from stoichiometry. Once this trend is observed in Figure 2, the numerical results are limited.

5.3 The Damköhler Number

Since the present work premises there is chemical equilibrium in the domain inlet, the chemical time scale should be greater than the mixing time scale in that region. This means the acetylene and oxygen are intensely mixed within the mixture chambers and the chemistry interactions modeling is important. The contours of the Damköhler number are plotted in Figure 8.

As the analyzed region is distanced from the inlet and consequently the frame brush, the Damköhler number increases. The impact of the turbulence on the reaction itself also increases when distancing from the premixed gases jet, where the primary reaction is more intense.

6. CONCLUSION

The present work studied the flame temperature for the oxycut process, using a computational approach. ANSYS® Fluent's partially premixed combustion and SST k-ω turbulence models were employed, allied to a computational grid of 3200000 cells. The fuel-oxygen ratio was adjusted to sweep a range from 4 to 82% oxygen volume percentage in steady state.

The maximum flame temperature of each model was compared to those provided by Ramalho (2008) and obtained a consistent trend, which for neutral flames best correlated, producing a difference of 2.35 percentage points only at stoichiometric proportions.

As reported by Williams and Smith (1970), the temperature is a function of log(pressure). Although the pressure chosen at the inlet boundary agrees with oxygen cutting, according to the tip manufacturer, it is not the goal of the present work to evaluate its influence on the flame temperature.

However, the model built temperatures not very accurate as the fuel-oxygen ratio was distanced from stoichiometry, since the software's library for the PDF approach is not able to reach temperatures as high as the ones exposed by the references. The trend's shape is nevertheless coherent, although the maximum flame temperature diverges by 14.65% and the divergence increases as long as the fuel-oxygen ratio is distanced from stoichiometry. It is concluded that the objective of the research is attained.

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