

## COB09-1185 - DESIGN OF AN INFRARED BURNER OPERATING WITH GLYCERINE/LPG – PART I

**Dantas, Marcello Araújo; marcello\_1984@hotmail.com**  
**Farias, Sandro Ricardo Alves; sandro.farias2@gmail.com**  
Federal University of Rio Grande do Norte, Brazil

**Fontes, Francisco de Assis Oliveira; francisfontes@uol.com.br**  
Federal University of Rio Grande do Norte, Brazil

**Barbosa, Cleiton Rubens Formiga; cleiton@ufrnet.br**  
Federal University of Rio Grande do Norte, Brazil

**Silva, Djalma Ribeiro da; djalma@ccet.ufrn.br**  
Federal University of Rio Grande do Norte, Brazil

***Abstract.** One of major concerns of thermal engineering in industrial production of heat is related to the conventional combustion processes due to the levels of gas emissions released into the atmosphere. Currently the glycerine co-produced on the plants of biodiesel is discarded into the environment through the process of burning. The glycerine burned directly from a conventional gas produces species critical to human health and the environment. As an action to reduce this problem, it is proposed the development of infrared burner, where the main exchange of heat is by radiation and the hot gases emitted pass through a ceramic capillary bed with enough time to complete oxidation of fuel, thereby avoiding the formation of dangerous gaseous species. This paper proposes initially investigate the thermodynamic behavior and the effects on the burning of glycerin with LPG in order to obtain an adequate evidence to establish the parameters for design of a burner infrared to be built, capable of inhibiting the formation of acrolein mainly among other pollutants like NO<sub>x</sub>, particulates and CO. Has been made, therefore, the balances of mass and energy in order to provide the excess air used in combustion and the supply of heat, beyond the parameters of operation (pressure, adiabatic and work temperatures and the consumption of fuels). The preliminary thermodynamic analysis aimed to establish reference and a methodology to assess the efficiency of infrared burner operating with the dual fuel glycerine / LPG. The analysis of the process is in accordance with the rules and regulations of environmental control bodies. The results will be used to design and implement a prototype to able demonstrate and validate the results.*

***Keywords:** thermodynamic; infrared burner; mass and energetic balances*

### 1. INTRODUCTION

In many combustion processes, should be observed the formation of many harmful intermediate products during chemical reaction (Van Wyllem, Borgnakke & Sonntag, 2003). Regardless of the energy used, there are many possibilities to reduce the environmental impact generated by the burning of fuels, all related to measures of energy conservation, such as: control of combustion and draft (the products of combustion monitoring and regulation of pressure the equipment), pre-heating of the mixture (providing fuel economy), atomization of the fuel (to reduce it into small droplets so as to increase the specific surface area up close to the gas phase to be an efficient mixing with oxygen and obtain a good combustion, perfect air-fuel ratio provided a good mix between them, increasing the area of contact between the fuel and air to improve the efficiency of combustion.

The use of glycerin as dual fuel with liquefied petroleum gas (LPG) can only become possible with the use of high temperatures (say, 1000 ° C) not to produce toxic fumes of acrolein formed between 200 ° C and 300 ° C (Metzger , 2007). This organic compound can be delivered in the combustion process and is caused by the incomplete combustion of glycerol. The origin of this compound can be part of the fuel which could not be burned completely and went with the other products of combustion, or compounds formed from radicals of hydrocarbons not completely oxidized. (Joseph, 2004)

Even as Metzger (2007), the glycerol has the potential to produce energy. However, the direct use of crude glycerin as a fuel has some drawbacks to be burned, such as having a low calorific value (between 2800 and 3500 Kcal / Kg) as compared to LPG which is 11,100 Kcal / kg on average, high viscosity when at room temperature, which makes the spray more difficult to achieve, presence of salts that can cause problems of corrosion in the burner and injectors in the combustion chamber, these salts can also inhibit the burning of a flame inhibitors act as.

Regarding LPG, it is composed of a mixture of paraffinic hydrocarbons (propane, n-butane and iso-butane) and olefins (propene, n-butene and iso-butene), in various proportions. May also occur the presence of traces of ethane, ethylene, butadiene and iso-pentane-1, 3. The LPG consists of hydrocarbons that are produced early in the process of distillation of petroleum, and also during the processing of natural gas. Depending on the origin and processes of treatment they have undergone, may present significant variations of the elements in their composition.

Thus, the LPG obtained from natural gas does not contain unsaturated hydrocarbons, while when they are obtained from refinery gas (petroleum) oil that may appear in varying quantities. For the LPG from the oil, the hydrocarbons that appear in larger proportions are composed of three carbon atoms (propane and propylene) and four carbons (butane and butene). Small amounts of ethane and pentane may also occur. Among the main impurities found in LPG, the compounds sulfur oxides are the most undesirable, since they incorporate the corrosion product, the hydrogen sulfide gas being the most aggressive. Therefore, when necessary, submit the product to treatments in special units. (Joseph, 2004)

The main problem of the burners is to atomize the fuel, or reduce it into small droplets so as to increase the specific surface area up close to the gas phase to be an efficient mixing with oxygen and thus, be a good combustion.

To ensure complete combustion is to use an additional quantity of air than the stoichiometric, ensuring that the molecules of dual fuel are the appropriate number of molecules of oxygen for complete combustion. The excess air provides a better mixing between the dual fuel and oxidizer, but must be carefully controlled during the combustion process. In practice, it is known that it is very difficult to get good combustion with air only stoichiometric. If we use only the stoichiometric air, there is a high probability of glycerin dual fuel / LPG not burn completely (with formation of CO instead of CO<sub>2</sub>) and consequently the amount of heat released will be less. (GUO & GHALAMBOR, 2005)

Basically, the optimization of combustion is limited to minimize the excess of combustion air without the presence of significant fractions fuels, being perceived by the increase of CO<sub>2</sub> content and the decrease in content of O<sub>2</sub> in the analysis of products of combustion. Immediate benefits to the environment are obtained, such as: reduction of total emissions of CO<sub>2</sub> and NO<sub>x</sub> due to the minimum excess air. (GUO & GHALAMBOR, 2005)

After this brief discussion of the fuel elements, we should consider the fundamentals of classical thermodynamics. The law of conservation of mass is an important tool to quantify the products generated by combustion from the analysis of flow and how they are dispersed in the environment. In a similar way, the law of conservation of energy is another essential tool for a more accurate assessment of thermodynamic systems, and when combined with other thermodynamic principles, to evaluate its usefulness becomes more predominant.

This paper initially investigate the thermodynamic behavior and the effects on the burning of glycerin with LPG in appropriate proportions, to obtain elements to maximize the performance of dual fuel mixture of this and so set the parameters of a project ejector / infrared burner to be built, capable of inhibiting the formation mainly of acrolein and other pollutants like NO<sub>x</sub>, particulates and CO.

## 2. MATERIAL AND METHODS

The process of analyzing the problem and developing the technical solution for the thermodynamics of this work involves a structure of questions to define the system and identification of relevant interactions with the neighborhood. Based on this premise is defined as the volume control (in the case, the whole ejector / infrared burner) and do analysis of empirical equations for interpreting the conservation of mass, conservation of energy and 2nd law of thermodynamics, in addition to knowledge of properties of the system and how these properties are related.

In this context, you want to know are the states and functions of the dual fuel flows when the product of the ejector / infrared burner. When you know the initial and final states, the application of the first law will be numerically the magnitude of heat exchange and the exchange of work with the neighborhoods of the product. (Smith and Ness, 1980)

According to Van Wylen, Sonntag and Borgnakke (2003), to apply the equation of the first law of thermodynamics in terms of flow, that is the case of this work, we express mathematically the average or instantaneous power that crosses the boundary of the system - such as heat and work - and the rate of change of energy of the system. Considering a time interval  $\delta t$  during which a quantity of heat  $\delta Q$  crosses the boundary of the system and  $\delta W$  is the work done on the system. In this case, it is assumed that the change imposed internal energy  $\Delta U$  is in kinetic energy is  $\Delta EC$  and the potential is  $\Delta EP$ , the application of the first law gives:

$$\Delta Q = \Delta U + \Delta EC + \Delta EP \quad (\text{eq. 1})$$

Dividing the value of  $\delta t$  gives the value of the average rate of energy that was transferred as heat and work, and lifting the energy of the system.

$$\delta Q / \delta t = \Delta U / \delta t + \Delta EC / \delta t + \Delta EP / \delta t + \delta t \quad (\text{eq. 2})$$

Calculating these limits are the values when the interval  $\delta t$  tends to zero, thus we have,

$$\lim_{\delta t \rightarrow 0} \frac{\delta Q}{\delta t} = Q \quad (\text{Taxa de transferência de calor})$$

$$\lim_{\delta t \rightarrow 0} \frac{\delta W}{\delta t} = W \quad (\text{Potência})$$

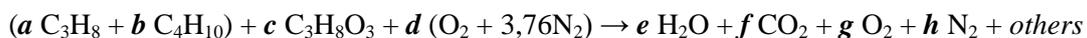
Calculating the limits are in relation to the change in internal energy, kinetic energy and range of variation of potential energy, we obtain:

$$\lim_{\delta t \rightarrow 0} \frac{\Delta U}{\delta t} = \quad \lim_{\delta t \rightarrow 0} \frac{\Delta(EC)}{\delta t} = \frac{d}{dt} \quad \lim_{\delta t \rightarrow 0} \frac{\Delta(EP)}{\delta t} = \frac{d}{dt}$$

Therefore, the equation of the first law in terms of flow is as follows:

$$Q = \frac{dU}{dt} + \frac{d(EC)}{dt} + \frac{d(EP)}{dt} + \quad (\text{eq. 3})$$

According to Van Wylllem, Sonntag and Borgnakke (2003) "the basic principle used to obtain the actual air-fuel ratio from the analysis of the products of combustion is the conservation of mass of each of the elements present in their chemical structures. Thus, we can take stock of carbon, hydrogen, oxygen and nitrogen (and any other element that may be involved in the reaction) in the transformation of reactants into products. Moreover, it is known that there is a defined relationship between the quantities of some elements". Thus, we have:



onde:

- $a \text{ C}_3\text{H}_8$  = number of Mols of propane in the fuel;
- $b \text{ C}_4\text{H}_{10}$  = number of Mols of Butane fuel in the fuel;
- $c \text{ C}_3\text{H}_8\text{O}_3$  = number of Mols of Glycerol in the fuel;
- $d \text{ O}_2 + 3,76\text{N}_2$  = Mols number of theoretical air;
- $e \text{ H}_2\text{O}$  = Mols number of water vapor formed;
- $f \text{ CO}_2$  = Mols number of carbon dioxide formed;
- $g \text{ O}_2$  = Oxygen Mols number formed;
- $h \text{ N}_2$  = Nitrogen Mols number formed;
- others = products of combustion unidentified;

The first step in an analysis of balance of mass is to define the particular region in space that will be analyzed. A substance that enters the region has three possible destinations. Some may leave the region without changes, some may be accumulated within the region and some must be converted into other substances.

According to Pereira (2002) for measuring the instantaneous flow of mass that passes in a given region is given by the following expression:

$$m = \int_A \rho \cdot Vn. \quad (\text{eq. 4})$$

Thus the balance of mass can be written as follows:

$$\frac{d}{dt} \int_A \rho \cdot d.V = \sum_i (\int_A \rho \cdot Vn. dA) - \sum_e (\int_A \rho \cdot Vn. \epsilon \quad (\text{eq. 5})$$

The development of equations of balance of energy for the volume control is done in a manner similar to that done for the balance of mass. Thus the equation for the balance of power for a volume control is:

$$\frac{dEVC}{dT} = Q - W + m_i \left( U_i + \frac{V_i^2}{2} + gZ_i \right) - m_e \left( U_e + \frac{V_e^2}{2} + g \right) \quad (\text{eq. 6})$$

The variation of the energy of the volume control is given by the balance of rates of energy crossing the boundary of the volume control. The mechanisms are: heat and work, as in closed systems energy associated with mass flows that cross borders.

## 2.1. Infrared Burner

The infrared burner provides a heat exchange through the ultra red radiation associated with a substantial volume of heated gases. It is built on a base metal in which a ceramic bed is inserted in that space is where is the reaction of combustion.

The working principle is as follows:

- a) The gases enter the burner at a certain initial temperature, and flow as they are heated due to heat exchange with the solid phase. There is then a balance between the flow of heat through the middle and loaded by the convective flow mixture.
- b) The right is the ignition point of the reagents and the heat generated by chemical reaction is balanced by convection and radiation.
- c) The products of the reaction flow toward the exit surface of the burner, heating the ceramic bed, which, in turn, radiates and transports heat to cooler regions before the flame.
- d) The transfer of heat to be held by the transport of energy in electromagnetic waves emitted by an infrared surface occurs at any temperature.

The radiation does not depend on the material means to transmit heat and the amount of energy carried by the waves is proportional to the fourth power of the temperature of the emitting surface. The infrared radiation does not require any means for transferring heat, and can even travel through the vacuum. (Natural Gas Engineers Handbook, 2005)

According to Santos (2003) "*is the radiant heat energy emitted by the surface that is a given temperature. The energy of the radiation field is carried by electromagnetic waves. For the amount of heat flux transferred by radiation, using the following mathematical expression*":

$$Q = \varepsilon \cdot \sigma \cdot A \cdot T^4 \quad (\text{eq. 7})$$

onde:

Q = Radiated heat flux [W]

$\varepsilon$  = emissivity, the surface property radiative,  $0 \leq \varepsilon \leq 1$

$\sigma$  = constant of Stefan Boltzman, [ $\sigma = 5,67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$ ]

A = surface area of the issuer [ $\text{m}^2$ ]

$T_{\text{sup}}$  = thermodynamic temperature of the surface issuer [K]

The infrared burner of 2250 kcal / h of Jackwal® brand, which is illustrated in Figure 1 below, is made by shaping a steel plate forming a carbon coated metal body (enamel) with a ground layer of molten glass. The carcass has the following dimensions: 7.5 cm wide and 30.5 cm in length. The tiles (three in total) have holes which act as a microburner isolated, and the result of the heat transmitted by burning the whole is the sum of the energy released by each microburners. The burner has a screen of stainless steel AISI 304 on the tiles, which is produced the effect of infrared radiation with the lighting of the burner. (Silva, 2003)

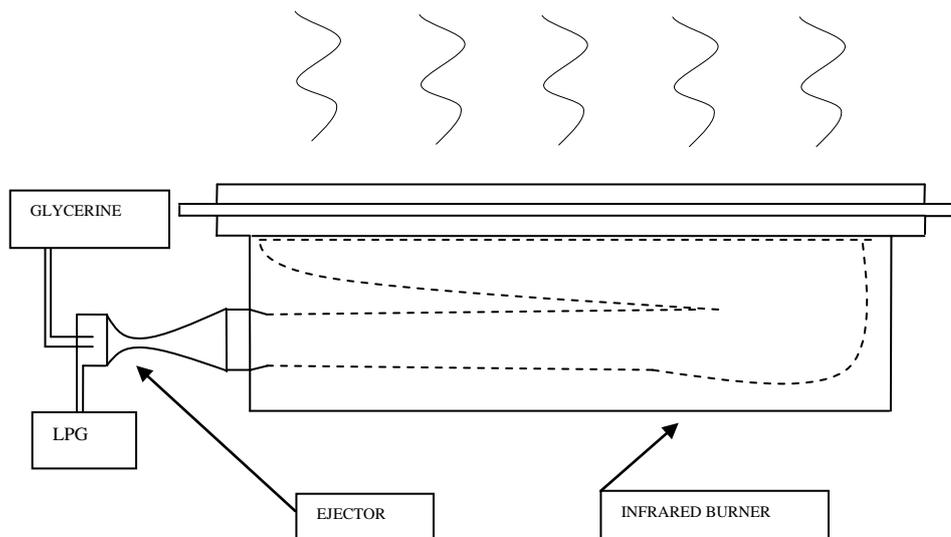


Figure 1. Illustration of the combustor (Eject / Infrared Burner) operating from dual fuel (glycerin / LPG).

According Malico (1999) Infrared combustion involves the stabilization of a flame inside a ceramic matrix. At the entrance to the burner, the solid phase is at a temperature higher than that of gaseous reactants as it is heated by radiation emitted by the ceramic matrix downstream. As a result, after entering the ceramic matrix, the air and fuel pre-mixed are heated by convection as the holes through the ceramic bed.

The reverse occurs in the combustion zone, where the energy of the fuel is converted into heat energy. In this region the temperature of the gas phase is higher than the solid phase, which is thus heated by convection. Therefore, the ceramic matrix can be viewed as a heat exchanger that transfers a fraction of the reagents for chemical energy released by fuel / oxidant.

Due to this feedback mechanism of energy products of combustion to the reagents is possible to burn fuels of lower calorific value, with limits of flammability extended, resulting in higher flame speeds. Other advantages of combustion within ceramic matrices are related to emissions of pollutants, since although the rates of heat transfer can be high, the temperature in the reaction zone are relatively low and very efficient combustion which leads to low emission of NOx and CO. (Malico, 1999)

## 2.2. Ejector

The spraying involves the formation of films and / or ligaments in the vicinity of the atomizer and then droplets. This step is very important, because a good atomization is essential to the process of combustion. The spray is strongly influenced by the geometry and diameter of the atomizer, and the properties of the liquid, the fluid to spray on the same speed as well as the conditions (temperature, humidity, etc.) from the surrounding environment.

According to Ness and Smith (1980) the amount of movement of the fluid at high speed leaving the internal tube of the burner is partially used to increase the speed of the reagents to be compressed, and the mixture passes through the throat of the cone at a higher speed lower than the fluid leaving the lower cone. In the divergent section, the mixture is compressed by the pressure of discharge at the expense of kinetic energy of flow of fluid.

As technical literature of the area, the construction of ejectors can be made by casting, machining or welded plates. To design the nozzle driving usually is followed by the standards of knowledge. However, the convergent and positioning of the diffuser nozzle on convergent diffuser are based only and exclusively for the formulation of empirical procedures. (Silva, 2003)

The figure 2 shows a picture of a simple stage ejector, the diameter of the hole of the ejector nozzle must be carefully designed, as directly affects the amount of fuel introduced into the burner and, consequently, as the burning and power of the burner. Therefore, it is necessary to apply a back exit of the venturi tube, as the burner, where the primary air-gas mixture is a resistance when it collides with the tiles and the interior of flows microholes. (Silva, 2003)

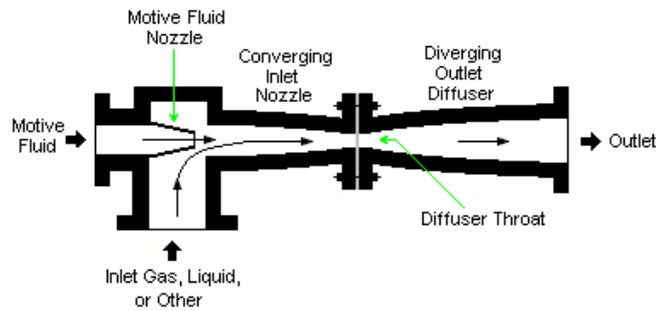


Figure 2. Figure aimed at cutting of a single stage ejector.

<<http://obscurelybeautiful.wordpress.com/2009/02/23/2001-ejector/>> acessado em: 28/05/2009

The cones of entry of the diffuser may have a slope that can vary from 2 to 20 and the cone angle of divergence of discharge can vary from 3 to 10. The throat of the diffuser is sized for sonic speed or critical flow, where the ratio of discharge pressure and suction pressure than 2:1. The length of the throat of the diffuser varies for ejector ejector, however, empirical data suggest that this length is equal to 2 to 4 times the diameter of the throat.

The critical condition of project means that the velocity of the fluid in the throat of the ejector is sonic and sub-critical condition, the velocity of the fluid is lower than the sonic.

Both the engine nozzle and the diffuser has the shape of a venturi. A convergent-divergent nozzle is used to accelerate the fluid power to a supersonic speed. In the section of the convergent nozzle driving the fluid to enter engine subsonic speed and is accelerated to a sonic speed. The driving fluid enters the divergent section with sonic speed and is accelerated to a supersonic speed in the output of the engine nozzle.

The application of the whole ejector venturi tube / burner works as a pre-mixing chamber, where the primary air and atmospheric gas admission form a turbulence, enriching thus the mixture, and mixed with oxygen molecules to the molecules of fuel dual, in the case, molecules of propane, propene, butane and butene together with glycerol. The venturi tube, illustrated in Figure 3 below, also has the function of suction by the air drag. This is the bottleneck at the entrance of the tube, which increases the velocity inlet gas with a pressure drop (vacuum), leading to incorporation of air.

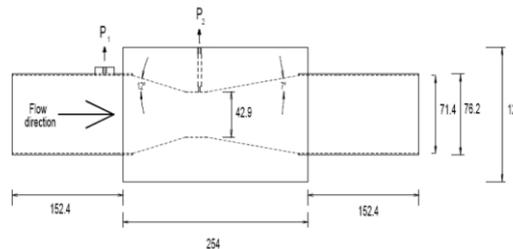


Figura 3. Tubo venturi.

The flow through the engine nozzle is described by classical equations of compressible fluids and the continuity and speed of the driving fluid in the nozzle throat is sonic power. The throat of the nozzle diameter determines the flow of motive fluid driving. The velocity of the fluid in the diffuser throat is sonic.

In the convergent section of the diffuser, the velocity of the mixture of steam and gas engine or steam process is reduced from supersonic to sonic and pressure increases. In the divergent section is reduced again, to sub-sonic sonic and the pressure increases further. Supersonic flows in a reduction in the area of the cross section causes the pressure increase and decrease speed.

Sub-sonic flow in the opposite occurs, an increase in the cross section, the pressure increases and decreases the speed. Energy loss in a well designed engine nozzle is insignificant and expansion through the nozzle driving is juxtaposed to an isentropic.

However, with increasing velocity of the fluid, the need to transform the speed in pressure becomes increasingly difficult. The supersonic flows cause the development of shock waves in the diffuser. The losses in the diffuser of shock

waves become more severe with increasing speed of entering the same (compression rate). This in turn limits the pressure of discharge at which the velocity can be converted. The losses caused by shock waves of the diffuser limit the speed of compression, and compression speed limits the rate of compression through the ejector. The suction pressure of a gas ejector which aspirates process is affected by the transfer of energy from the steam engine to the fluid aspirated. If you use an extension in the nozzle driving to place within the diffuser, reducing the distance is, achieve a higher compression rate, however, diminish the capacity of the ejector. The result is a greater pressure to discharge and a lower suction pressure. (Junior, 2008)

According to Junior (2008) the flow of fuel needed for an ejector can be calculated directly with the application of the basic laws of thermodynamics and mechanics of fluids. The operation of an ejector is close to a isentropic. The total efficiency of an ejector can be expressed as a function of efficiency of mixing or aspiration and the relationship between energy input and energy output.

## 2.3. RESULTS AND DISCUSSION

The results for the values, calculated during the development of the system are presented below. During the design, it took into account the power of the infrared burner.

### 2.3.1 Dimensioning

## 2.4. CONCLUSION

The variation in diameter of the ejector nozzle glycerin / LPG implies an increase of gas flow and change the characteristics of the quantity of air drag, as the proportion of the air / gas, essential to the process of combustion. These variables must be carefully observed and monitored during testing to achieve the proposed objectives.

Given the different physical and chemical characteristics of glycerin and LPG, maintain unchanged the conditions of combustion is a complex task.

The sizing of the ejector (from the balance of mass and energy), the system as a whole and the infrared burner, has been technically feasible.

Despite the difficulties reported, the work represents a very interesting challenge by the proposed improvement that is objective, often with changes in low cost. The limitations are present, but a systematic work of research and deployment of improvements could bring significant progress both in energy consumption, low emission of pollutants, as well as the quality of combustion.

## 3. ACKNOWLEDGEMENTS

The authors would like to thank the Brazilian National Petroleum Agency (MCT/PRH/ANP-14), FINEP and NUPEG/UFRN for providing financial support for this research.

## 4. REFERENCES

- Möbbauer, S., Pickenäcker, O., Pickenäcker, K. e Trimis, D., "Application of the porous burner technology in energy- and heat- engineering", in *Proc. Fifth International Conference on Technologies and Combustion for a Clean Environment*, Lisboa, Portugal, Jul. 1999, p. 519-523.
- Malico, I. e Pereira, J. C. F., "Numerical predictions of porous burners with integrated heat exchanger for household applications", *Journal of Porous Media*, Vol. 2, 1999, p. 153-162.
- Mahallawy, Fawzy El; Habik, Saad El-Din; *Fundamentals and Technology of Combustion*. Ed Elsevier Science Ltd, UK, 2002.
- EPA, "Toxicological Review of Acrolein," CAS No. 107-02-8, EPA/635/R-03/003, (2003).
- Garcia, Roberto. *Combustíveis e Combustão Industrial*. Ed. Interciência, Brasil, 2002.
- Metzger, Brian. *Glycerol Combustion*. North Caroline University, USA, 2007.
- Wylen, Gordon Van; Sonntag, Borgnakke et al. *Fundamentos da Termodinâmica Clássica*. 5 ed. São Paulo: Edgar Blucher, 589 p.
- Malico, Isabel. *Modelação de queimadores porosos para aquecimento doméstico*. Departamento de Física, Universidade de Évora, Portugal, 1999.
- Espinoza, Fidel Romel M.; *Ensaio para avaliar a potência nominal do protótipo de um queimador infravermelho de ar forçado de placas cerâmicas*. SENAI-RS/CNPQ 550186/01-8, Esteio/RS, Brazil. 2004.

Silva, Carlos José da; Ensaio de Potência nominal do queimador atmosférico Jackwal de 5500kcal/h (6,4KW). SENAI-RS/CNPQ 550186/01-8, Esteio/RS, Brazil. 2003.

Silva, Carlos José da; Ensaio de queimador atmosférico Jackwal de 5500 Kcal/h (6,4KW) em diferentes posições. SENAI-RS/CNPQ 550186/01-8, Esteio/RS, Brazil. 2003.

## **5. RESPONSIBILITY NOTICE**

The authors are the only responsible for the printed material included in this paper.