COMPROMETIDA COM A PROMOÇÃO DO DESENVOLVIMENTO DA ENGENHARIA E DAS CIÊNCIAS MECÂNICAS

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EVALUATION OF THE INFLUENCE OF THE SOOT DEPOSITION ON THERMOCOUPLE MEASURES IN COMBUSTION EXPERIMENT

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Abstract. *Soot formation in industrial combustion systems constitutes an important theme of the engineering interest. The presence of the soot in the flame increases the transfer of the heat from the combustion gases by thermal radiation, yet it may constitute an environmental problem when is emitted in the atmosphere. This work evaluates the influence of the soot deposition in the thermocouple's measures in an acetylene diffusion flame, produced in a burner with parallel coaxial oxidizer flow that has problems of accurating the temperatures measures with thermocouple. The evaluation about the date explains the influence of the soot deposition in the measures of temperatures and how these errors influence the analysis of physical phenomenon.*

Keywords*: soot deposition, temperature measurement, thermocouple*

1. INTRODUCTION

Soot formation in industrial combustion systems constitutes topic of engineering interest, because the presence of soot in the flame increases the heat transfer from the combustion gases by thermal radiation, and when emitted in the atmosphere constitutes an environmental problem, besides increasing the need for burner maintenance. The phenomenon of soot formation still is not fully explained, a consequence of the fact that the formation process isn't slow enough to allow the precise observation of each step. The demand for new scientific knowledge concerning soot, including the use of chemical additives to control its formation, has been attended by works that, in their majority, are performed with elementary flames, as in the present study. Besides possessing problems in its measurement and understanding, the soot formation causes problems in readings of temperatures through of the thermocouples introduced directly in the flames in experimental analyses. For so much qualitative evaluations for a detailed analysis of the temperature aspects in the flame associated on the soot formation should be accomplished in order to improve the understanding of the problem. Oxygen, one of the possible soot oxidizers, has been considered as an additive. The enrichment of combustion air with oxygen can improve the combustion process, as mentioned by Baukal, by determining improved flame characteristics - larger inflammability limit, better ignition, stability and shape control; smaller combustion gas volumes; increased productivity and thermal efficiency: larger efficiency of the heat transfer processes; improved product quality; fuel consumption reduction, raw material costs reduction, reduced costs of new equipments and, possibly, production increase in existing equipments. Atmospheric air has about 21% of oxygen in volume. Low levels of oxygen enrichment of the combustion air, which correspond to an O_2 index in the combustion air below 30%, are usually used in retrofit applications in that only small modifications are necessary in the existent equipment.

Goldstein Jr, L. et al. (2002) verified the influence of the O_2 index on the oxidizer side in a partially premixed acetylene/air flame. The authors used the submerged flame in the atmospheric air, and involved by a N_2 shield. It was verified that with the N_2 shield, the soot formation in the flame was increased, fact explained by the lack of available O_2 to intensify the oxidation process. The uncertainties of thermocouple measures caused for soot deposition were also verified for the authors.

Santos, et al. (2009) also studied the influence of the O_2 index on the oxidizer side in combustion of acetylene flames. Also, the uncertainties of thermocouple measures caused for soot deposition were also verified for the authors.

The flame studied in the present work was generated in a vertical axis burner in which the discharge of acetylene was surrounded by a coaxial annular flow of oxygen enriched air. The applied enrichment levels were 23 and 25%, which, when used in retrofit applications, require only small modifications in the existent equipment. The purpose of the study was to explore the effect of the oxygen content and the combustion air velocity on the soot concentration along the height of an acetylene diffusion flame. A second analysis of the work, that it is described in this paper, is the evaluation of the results in the methodology for explains the influence of the soot deposition in the temperatures measures and how this errors influence in the analysis of physical phenomenon.

2. EXPERIMENTAL APARATUS

The experimental setup is shown in Figure l. The flame was generated in burner QM1 in which acetylene flew up through a vertical tube, and air or enriched air flew through the annular region between this tube and a larger diameter concentric tube. The diffusion air and oxygen were premixed in PM1, before being fed to the burner QM1. Gas flow rates were controlled by valves V1, V2, V3 and metered by rotameters R1, R2 and R3.

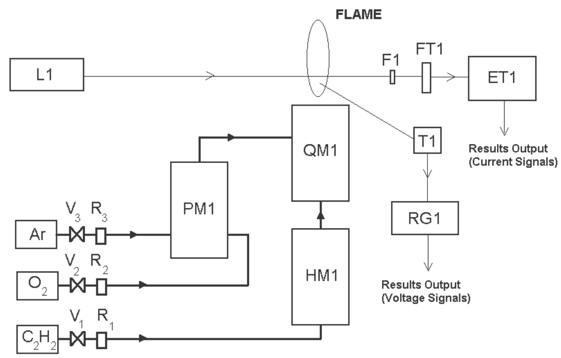


Figure 1: Experimental Setup.

Soot concentration was measured along the flame height by means of the laser light extinction technique. The burner was mounted on a step-motor driven vertical translation table, which allowed the beam coming from laser L1 to reach the flame at any desired level. The laser L1 was of He-Ne, with a wavelength of 632.8 nm. Since the power output from the laser was only about 1mW, background radiation was blocked from the flame by a narrow band pass mterference filter Fl, at the laser wavelength. The light was transformed in a electrical current signal by the photodiode FT1, and registered by electrometer ET1.

Flame temperatures were measured by an uncoated type S thermocouple Tl (Pt-Pt/10%Rh) along the central axis of the flame, and the signals were registered by the temperature meter RG1. The thermocouple tip was cleaned out before every temperature reading. The obtained results were not corrected for radiative and convective losses, considering the uncertainty in evaluating the effect of soot deposition on the thermocouple surface.

Soot volume fraction was calculated from the laser light extinction data, using the Rayleigh limit of the Mie theory. To examine the effect of the oxygen content on the combustion air, tests were performed comparing experiments with 23 and 25% of oxygen content to experiments with plain air, stagnant or flowing. The air velocities, Var, were 0.10, 0.15, 0.85 and 1.39 m/s, and the acetylene velocities, Veg, were 0.22 and 0.36 m/s, referred to 20°C and atmospheric pressure. The burner power was 0.72 and 1.16 kW. Table l summarizes the combination of fluid velocities in the tests.

Table 1: Var/Veg in the Experiments

Veg	Var (m/s)						Power
(m/s)	0	0.10	0.15	Veg	0.85	1.39	(kW)
0.22	0	0.45		1	3.86		0.72
0.36	0		0.42	1		3..86	1.16

3. ANALYSIS AND DISCUSSION

For the measurements of the temperature in flames with the use of thermocouples, the reading that was found is only the indicative of the real values of the temperatures, once the readings are influenced by the accumulation of the soot in the thermocouple. We can also mention that the uncertainty about the value of the soot emission as another factor that makes difficult the execution of the necessary corrections of the temperature for the evaluation of the inherent heat losses to the thermocouple reading process. These uncertainties were also commented by Tesner, et al. (1971), McEnally and Pfefferle, 1998 and Melton et al., 2000.

As attempt to explain the influence of the soot accumulation in the reading of the thermocouple, some hypotheses were idealized through the results gotten in the readings. The reply of the thermocouple reading, which was covered by the soot in the curves located in the used instrument, was idealized as described in the figure 2. The reading that was made in the regions, where the concentration of the soot was low, would have a reply inclination until the value of the peak, after the thermocouple being covered by the more accented soot, while the opposite would be verified for regions where the concentration of the soot was raised. The fall of the reading signal, after the peak values, would possess different signals as well. For the curve with less soot, the soot would be softer; for the ones with more soot, the fall would be more intense.

The ascent until the point where the thermocouple is covered is intense, probably because of the difference of the temperature between the environment- place of the beginning of the thermocouple reading, and the flame.

The resistance of the temperature conduction causes the influence of the generated soot layer. It would cause a temperature difference between the external region of the soot layer and the thermocouple that is in the internal region of the layer. The reading of the thermocouple would be attenuated through the layer of the formed soot.

However, after a detailed verification of the results, it was evidenced that the inclination of the curves in the ascent, after the thermocouple being covered by the soot, either in curves of reading with less or great accumulations of soot, would depend on the flame region where the thermocouple was being inserted. Two flame regions were imagined being:

The first region in the begin of the flame where had more fuel and intermediates than products.

A second region where more combustion products existed, located at the upper flame position.

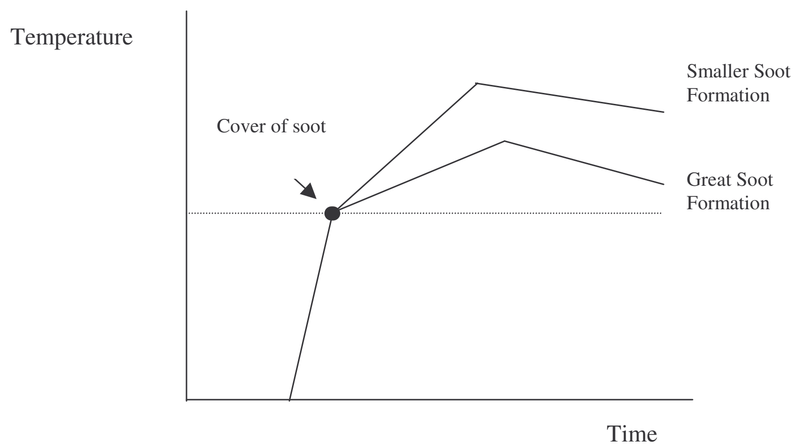


Figure 2: Temporary Variation of the Thermocouple Reading with Greater Soot Accumulation.

The proposals hypotheses for the first region were:

1. Growth of the soot rind, which is given quicker.

2. Greater loss of the heat for the environment, due to the lesser thickness of the flame in this region being closest to the side of the air, because of the inexistence of the products to execute a barrier.

While the proposals hypotheses for the second region were:

1. Growth of the soot rind that is given slower.

2. Lesser loss of the heat for the environment because the flame possesses greater thickness in this region due the products.

Now we present the Table 2 with the possible inclinations of the reading curves leading, considering the hypotheses above, being the greater inclination indicated through the symbol plus (+), and the lesser inclination indicated through the symbol less (-).

Table 2: Slopes Table of Accenting Curves in Reading Thermocouple.

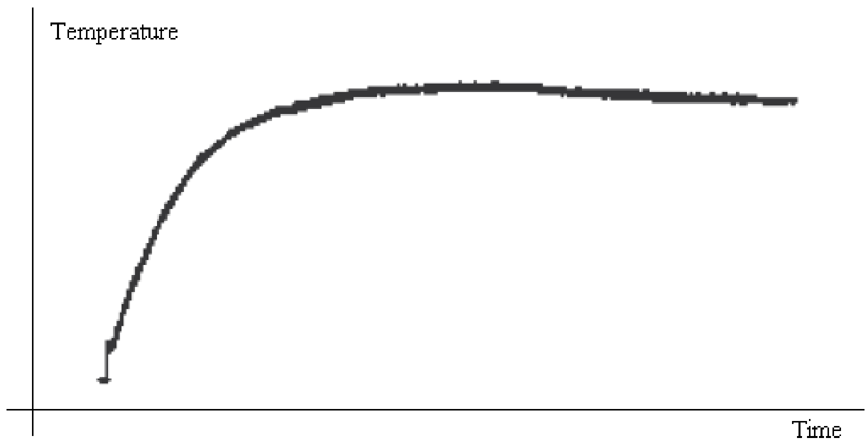
Region	**Hypothesis**	**Great Soot Formation**	**Smaller Soot Formation**
1			
	Growth Soot peel	-	-
	Heat Loss for the atmosphere	-	-
	Global Effect	-	-
2			
	Growth Soot peel	-	+
	Heat Loss for the atmosphere	+	+
	Global Effect	-	+

The temperature reading curves are presenting in the following; they are made by the thermocouple, which served as base to the proposals hypotheses.

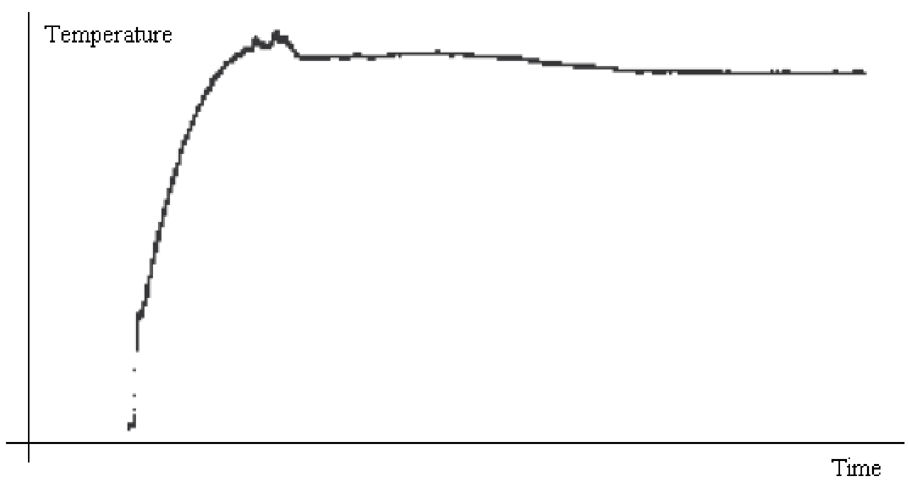
3.1. Region 1.

The Figure 3 presents the reading curves of the thermocouple for the situations like gas and air that are dragging in regions where there is few soot formation; which we verify that the reply of the thermocouple, until it reaches the peak value, possesses a lesser accented inclination, taking some time to get the peak value as indicated in the Table 2; getting in the peak value, as suggested by the model of Figure 1, the fall, in this situation, is slow and gradual.

In the Figure 4 we have the situation of the reading curve for a position with greater soot for the air that is dragging, where we verify that the thermocouple answer, until to reach the peak value, possesses a lesser accented inclination, until the lesser case that is describing in the Figure 3, taking some time to get in the value with greater temperature. Getting in this value, the fall is fast and constant.



(a) Power[kW]= 1.16; y[mm]=3.0; dimensionless position=0.02; gas dragging



(b) Power[kW]= 1.16; y[mm]=3.0; dimensionless position=0.02; air dragging

Figure 3. Temporary Variation of the Thermocouple Reading with Lesser Soot Formation in the Region 1.

3.2. Region 2.

The Figure 5 presents the thermocouple reading curves for the gas and air dragging situations in regions where there is less formation of the soot. In these regions we verify that the reply of the thermocouple until it reaches the peak value possesses a more accented inclination, getting faster in this value. Getting in the peak value, the fall is slow and gradual. The fluctuations in the readings presented in the figure are attributed to the instability of the flame in these regions (close to the top), which were more intense throughout time.

In Figure 6 we have the situation of a reading curve for a position with greater soot for the gas and air dragging, where we verify that the thermocouple reply until reaching the peak value possesses a lesser accented inclination, taking some time to get into this value. Getting into this value, the fall is fast and constant. In the case of the gas dragging, we perceive that the temperature falls and returns after certain time that is close to the value of the peak. The fact is consequence of the intense soot formation, where a thick layer of the soot was formed and did not have enough mechanical resistance to contain the executed effort through the gases draining, and it unfastened of the thermocouple, going back to a situation closest to the original; therefore, the layer growth process is initiated again.

The value of the peak in all the boarded cases is considered as being the closest value, which was reached, to the temperature of the flame considering the losses due to the soot rind that was formed and the loss of heat for the environment.

A preliminary estimative of the temperature correction of the radiation and convection combined effect, disdaining the effect of the conduction through the soot layer that covers the thermocouple, considering the transparent radiation gas, and admitting that the speed of the combustion gases is equal to the speed of the combustible gas in the base of the burner, in the ambient temperature; indicates a maximum value of correction inferior to 200ºC.

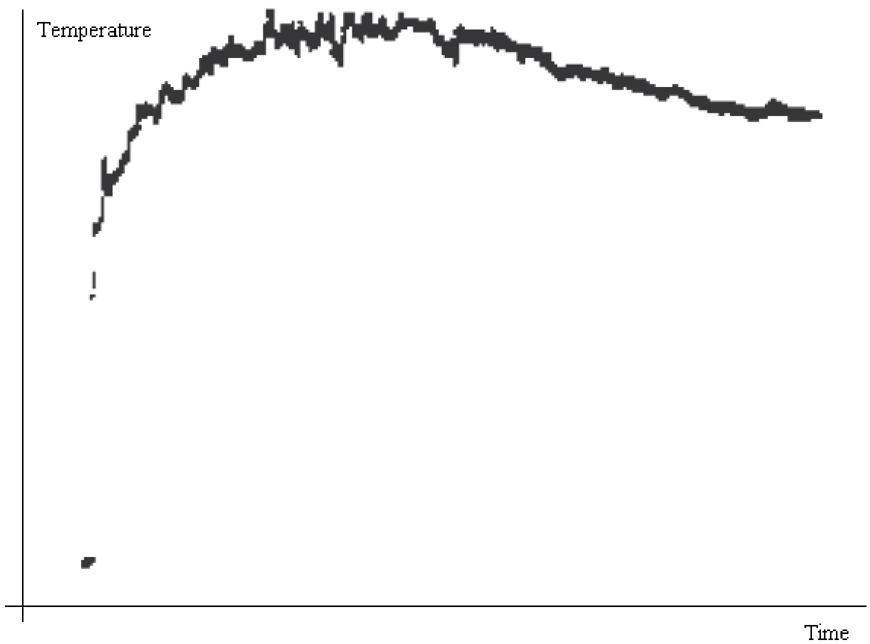
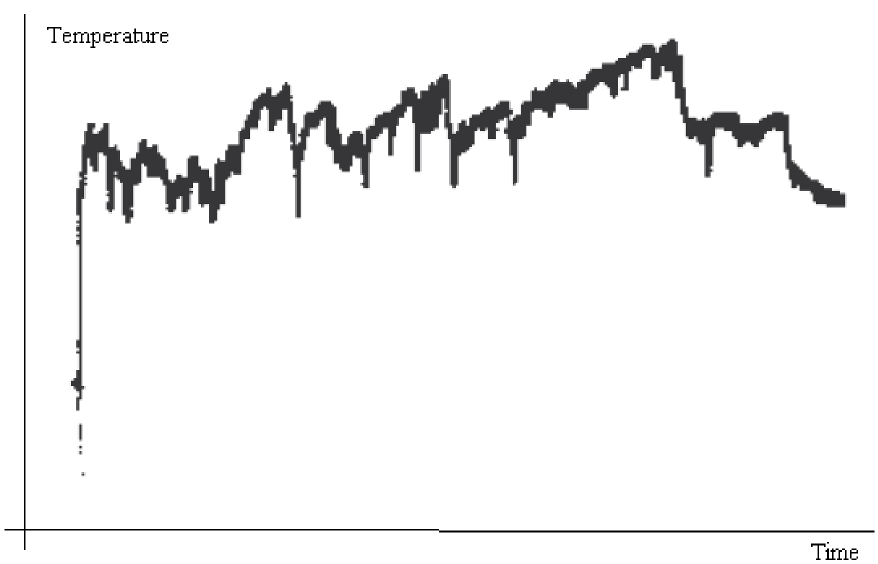
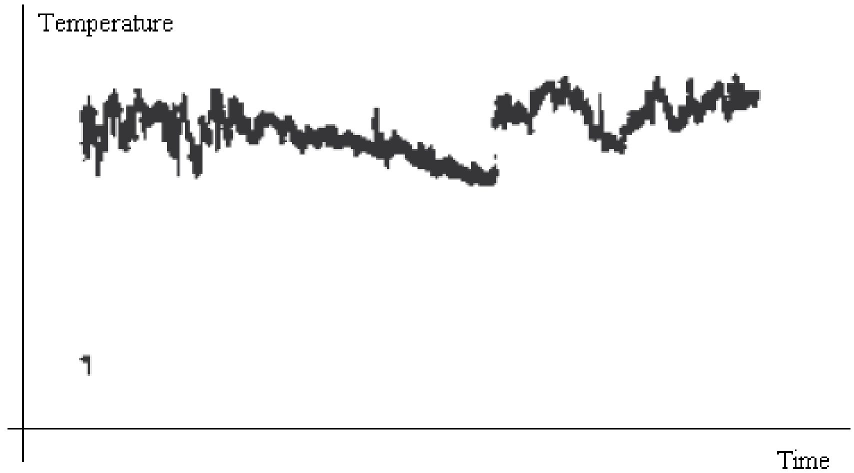


Figure 4. Temporary Variation of the Thermocouple Reading with Greater Soot Formation in the Region 1 - Power[kW]= 0.72; y[mm]=5.0; dimensionless position=0.08; air dragging.

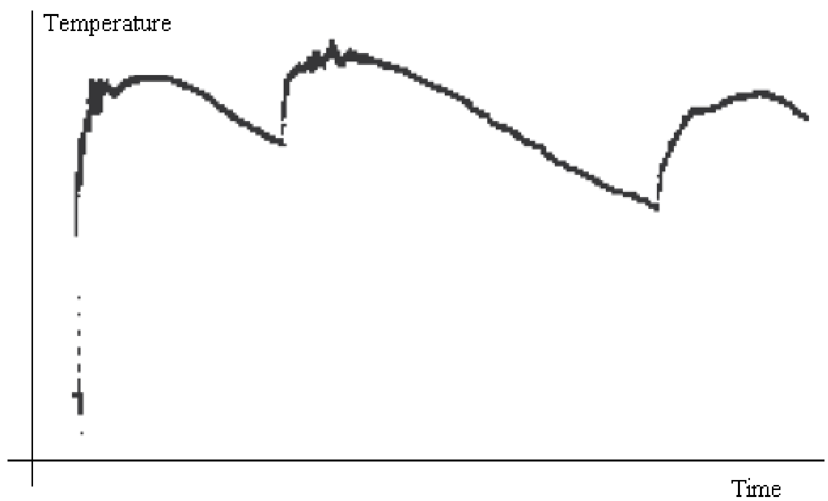


(a): Power[kW]= 1.16; y[mm]=103.0; dimensionless position =0.76; gas dragging.

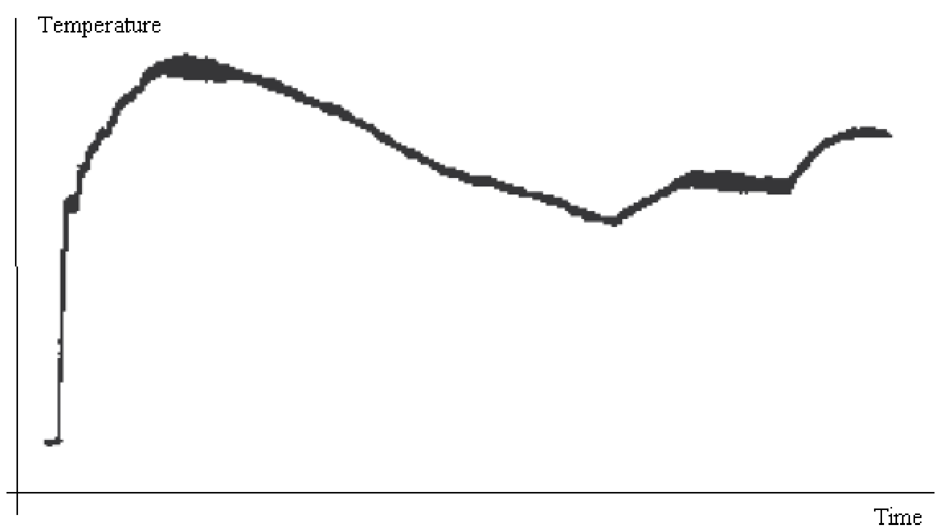


(b): Power [kW]= 0.72; y[mm]=50.0; dimensionless position=0.72, air dragging.

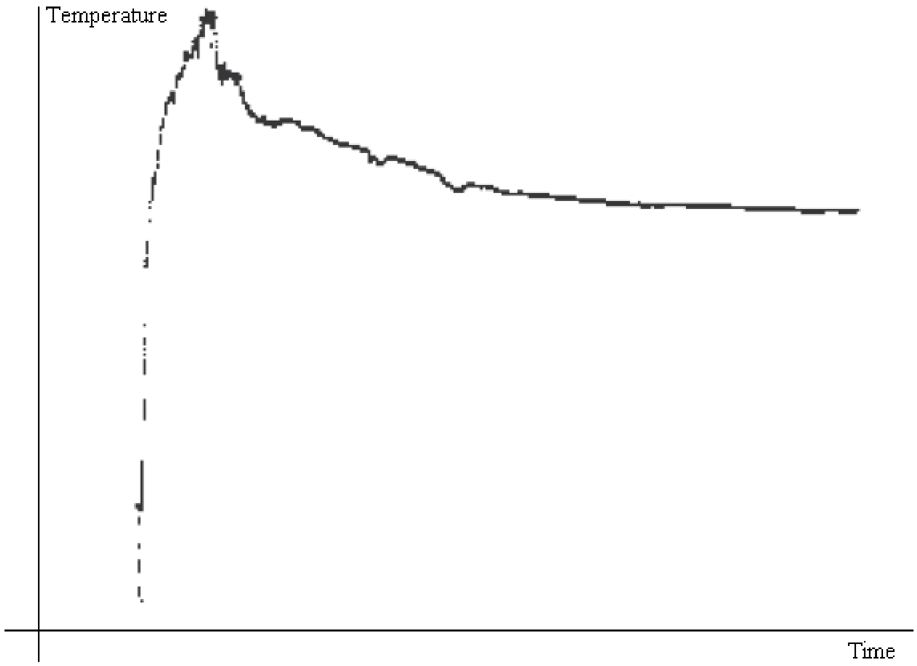
Figure 5. Temporary Variation of the Thermocouple Reading with Lesser Formation of the Soot in the Region 2.



(a) Power[kW]= 1.16; y[mm]=50.0; dimensionless position = 0.37; gas dragging.



(b) Power[kW]= 1.16; y[mm]=43.0; dimensionless position = 0.32, gas dragging.



(c) Power[kW]= 1.16; y[mm]=10.0; dimensionless position=0.11, air dragging.

Figure 6. Temporary Variation of the Thermocouple Reading with Greater Formation in the Region 2.

4. CONCLUSIONS

The influence of soot deposition for temperature measures in acetylene diffusion flame with oxygen enriched air, produced in a burner with parallel annular coaxial oxidizer flow, was explored. The applied enrichment levels were 23 and 25%, which, when used in retrofit applications, require only small modifications in the existent equipment.

An analysis was suggested for the explanation of the effect of the soot deposition that has a great important for the uncertainties for temperature measures with intrusive techniques. The evaluation of the found results verified that the influence of soot deposition depends of the flame region that the measure has been done. For areas with a larger soot formation, the reduction factor of the soot deposition possesses important hole for the uncertainties of readings in the thermocouple. In areas with low soot formation, the effect of the deposition is decreased.

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AVALIAÇÃO DA INFLUÊNCIA DA DEPOSIÇÃO DE FULIGEM NA MEDIÇÃO DE TEMPERATURA POR TERMOPAR EM EXPERIMENTOS DE COMBUSTÃO

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Resumo. *A formação da fuligem em sistemas de combustão industrial constitui um importante tema de interesse em engenharia. A presença da fuligem na chama aumenta a transferência de calor dos gases de combustão por radiação térmica, no entanto, pode constituir um problema ambiental quando é emitida na atmosfera. Este trabalho avalia a influência da deposição de fuligem nas leituras de temperatura por termopar em uma chama de difusão de acetileno, produzido em um queimador com o fluxo de oxidante coaxial e paralelo, apresentando problemas de precisão nas medidas de temperatura com termopar. A avaliação dos dados, explica a influência da deposição de fuligem nas medidas das temperaturas e como esses erros influenciam a análise do fenômeno físico.*

Palavras-chave*: deposição de fuligem, medidas de temperatura, termopar.*

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