



## INVESTIGATION THE EFFECT OF THE PERCENT COMPOSITION OF EXHAUST GASES FROM A COMBUSTION CHAMBER OF A THREE-BED REGENERATIVE THERMAL OXIDIZER IN THE HEAT RADIATION EXCHANGE DEVELOPED DURING COMBUSTION, THAT NEUTRALIZES GASEOUS POLLUTANTS FOR A GIVEN PLANT CAPACITY



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### Abstract:

*The purpose of this paper is to study the influence of the composition of the flue gases on the thermal radiation inside the combustion chamber of a three-stage regenerative oxidizer that neutralizes gaseous pollutants for a given plant capacity. This composition is expressed by the corresponding partial pressure of each constituent gas. It is assumed that the flue gases are gray and obey Lambert's law, so that the gas mixture is assumed to be composed of water vapor and carbon dioxide plus a neutral one. Accurate estimates of each gaseous component emissivity were calculated from the experimental data charts provided by H. Hottel by employing regression analysis. The total emissivity coefficients of the gaseous mixture are evaluated with the help of the above emissivities and they are incorporated into the energy conservation equation that relates the heat exchange among the chamber walls.*

**Keywords:** Gas Mixture Emissivity; Radiation; Combustion Chamber; Thermal Three Bed Oxidizer; Coefficient Absorption.

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### 1. Introduction

In this paper, is being studied the effect of thermal radiation on the percentage composition of waste gas, outcoming from the smoking cabin of a three-stage regenerative oxidizer concerning the thermal radiation exchange during combustion. This thermal oxidizer is used for neutralization of gas pollutants in industry. (Source EPA, Pollution engineering 1996) [1].

It has been used by us for the neutralities of malodorous gases coming from productive industrial processes or even waste water treatment plant. (see European Patent Application. EPO 1409924 **Patent N.Pittas**[2]) this issue is globally known and it is caused by every waste water treatment plant after 2-3 months of operation and by every industrial unit that releases malodorous and pollutant gases.

There are various techniques such as scrubber chemicals and other biologicals and active carbonate beds as well or a combination of the above for solving this bad smell problem effectively, but the efficiency varies between 8-12%, as it comes from the operational experience of the units. It is a very low percentage of neutralization of bad smell in comparison to the problem that is created to the surrounding residents and the workers as well (health problems and property devaluation).

The operation of these units with different dynamics, that we installed in industry, with identical use for this purpose, had excellent results in reducing the malodorous air pollutants and the aim is now, to optimize the function of these units for a further reduction of atmospherically pollution.

The limitation concerning the emission of waste gas is very strict globally, about the cleaning waste gas systems. In the particular unit, the following numbers were measured in waste gas.

Concentration COT in chimney  $\leq 20 \text{ mg/Nm}^3$

«  $\text{NO}_x$  « «  $\leq 50 \text{ mg/Nm}^3$

«  $\text{CO}$  « «  $\leq 100 \text{ mg/Nm}^3$

Specifically, the existing European legislation sets a much higher limit in the numbers of usual waste gas concentration.

In order to succeed this, because the temperature of the combustion chamber is about  $750^\circ\text{C}$ , and heat transfer is transferred completely through thermal radiation, we use the model of thermal zone of H. Hottel [3] in order to define the thermal flows and temperatures in the combustion chamber, so as to get clear the correlation between radiation and composition of waste gases.

In this way is established theoretically the operation of the unit and become clear the details that need to be taken in consideration for the functional optimization of the units.

In addition, developing the theoretical foundation of the thermal layers model, and by resulting is the same theoretical and measured values, we end up in certification of H. Hottel [3] theory.

In specific, the measured percentage of composition of waste gas, leads to the calculation of partial pressure per waste gas, through Dalton's law.

We assume that waste gases (vapor and carbon dioxide) are grey and follow Lambert's law.

The theoretical model of this mixture of waste gas is composed of vapor,  $\text{CO}_2$  and a pure gas.

From the approved diagrams of H. Hottel[3] and the use of regression analysis we define the emitting functions of vapor and carbon dioxide depending on the wavelength PL regression analysis in each gas being under standard temperature after we have first specified the mean beam length of combustion chamber. Accordingly, we define the overlap and after we have elaborated the equations that express the model, we end up in the function that associates the emissivity of each gas with the thermal absorption coefficient.

Furthermore, we determine the correction coefficients of emissivity through other diagrams because the combustion cabin works in sub pressure and all numbers should be adjusted in a different price of 1 atmosphere in which all H. Hottel[3] diagrams are calculated. In this way we have determined the emissivity of the waste gas mixture for a PL wavelength. To estimate the absorption coefficient, the whole procedure must be repeated for double geometrical length.

Subsequently, we replace in the equation that connects the emissivity of waste gas mixture with absorption coefficient. The absorption coefficient is directly connected with thermal radiation through R.J.Tucker[4] equation but H. Hottel[3] diagrams as well, which results that the increasing composition of waste gas evokes in absorption coefficient reduction and this leads to increase of thermal radiation and gets the max value for  $K=0$ , where  $K$  is the absorption coefficient.

To specify the thermal flows inside the combustion chamber, we first have to define the thermal radiation which falls, is absorbed and partially reflected for numerous times on the walls and the molecules of gases in the chamber, the possible exchange ways as well.

Applying the thermal zones model, the thermal zones must be appropriately chosen (surface and gas zone) dividing the chamber in specifically 11 zones, because due to the construction details the wall materials are different and have different absorption-emissivity coefficient for each zone.

The aim is to calculate the thermal balance of each zone and measure the emitted power per thermal zone. Therein after, with Stefan Boltzmann law, calculate the corresponding temperatures.

## **2. Short Description Three Bed Thermal Regenerative**

During the normal operation these ceramic beds contain stored heat from previous operating cycle. The contaminated waste gas stream enters one of the three beds (e.g. bed A). As the travels through the ceramic bed heat is transferred from the ceramic medium to the gas stream. It exits the bed and enters the combustion-oxidation chamber at a temperature that approaches the final operating temperature of the oxidation chamber.

A standard gas fired burner is then used to raise the temperature of the now preheated waste stream to the final operating temperature.

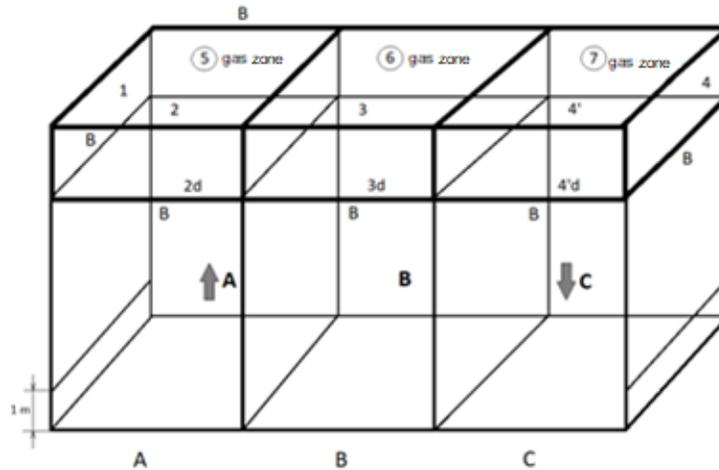


Figure 1: Tree bed thermal regenerative oxidizer

The hot combustion of gasses then exit the RTO through one of the remaining beds (e.g. bed C), transferring most of their heat to the ceramic heat transfer medium for recovery in a reverse cycle. During this reverse cycle, waste gas is diverted to enter through the third bed (e.g. 3) and exits through bed B. Bed B was purged during the previous cycle.

At the same time, fresh air is used to purge residual gases remaining in bed A into the combustion chamber for destruction of their VOCs. Cycle are then repeated alternately cooling one bed, heating another, and purging the third.

Since the complete cycle of operation during three minutes, and for malodorous gas to crossing the bed A after the combustion chamber and then the bed C and after exit in the chimney require one minute. We will adapt our calculations in time 1 min. The obtain results of calculation must be identical if the entry and the exit of malodorous gas change.

With the use of experimental data of H. Hottel[3] diagrams and Leckner[5] equations concerning the emissivity, as also the experimental data of H. Hottel[3] and R.J. Tucker[4] diagrams concerning the total exchange areas between thermal zones the final purpose is to define the thermal radiation exchange between the zones and the achievement of thermal equilibrium for every thermal zone.

Solving the equation system of thermal balance obtain the values of temperatures of each zone (surface or gas) in which the chamber is divided. The equation system is stable, and the determinant are symmetrical a fact that leads to a simpler solution.

The values of the resulting temperatures are close to 98-99% with the real-time measured values which are transferred to thermocouples and depicted on the control panel of the operating unit of thermal oxidizer in Lecheo Korinthos.



Figure 2: The three bed thermal regenerative oxidizer 22K Lecheo-Korinthos–ZOOMOMI AEBE

This unit has been established in Lecheo since 2005 with excellent results, 100% success in neutralization of malodorous waste gas, of a flow rate  $22000\text{Nm}^3/\text{h}$  total supply, coming from the fish feed manufacturing industry, ZOOMOMI AEBE Lecheo Korinthos.

The basic geometry of the thermal oxidizer is depicted in fig. 1, the combustion chamber and the longitudinal section of it as well, in fig.3, along with the measured fuel consumption and the chemical analysis of waste gases.

The values of measurements reported in this paper (hourly supply of waste gas for processing, consumption per hour and composition percentage) are real and measured in the operating unit in Lecheo Korinthos.

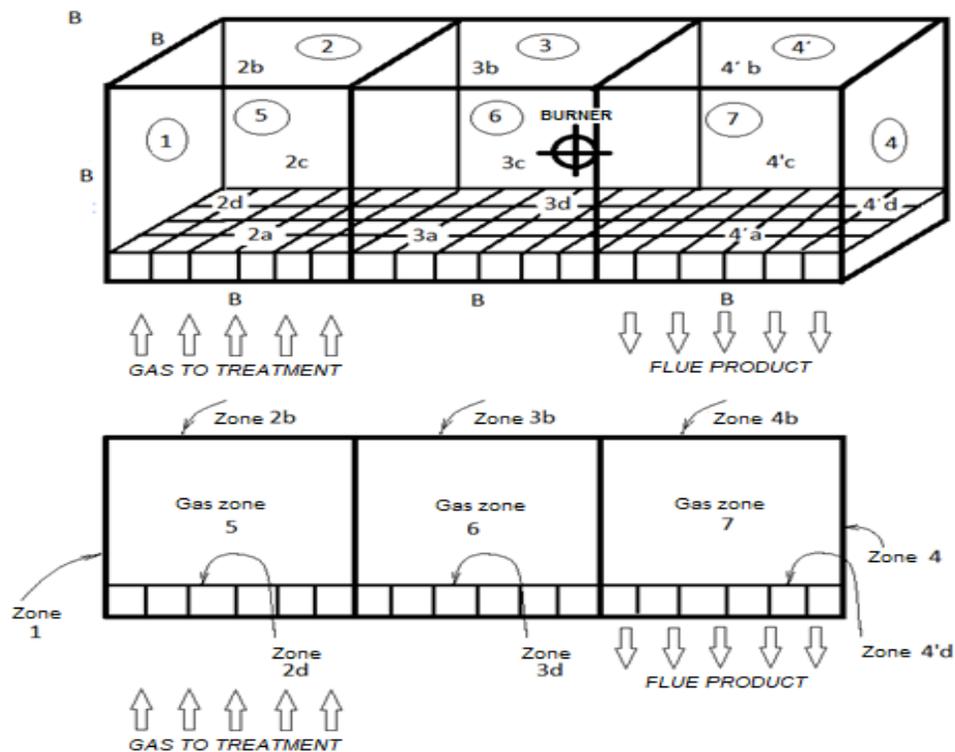


Figure 3: Chamber of combustion chamber-three bed thermal regenerative oxidizer and longitudinal section

Below exposed the values of temperature after 47 sec for every thermal zone of the divided combustion chamber. When the entry is the bed A and the exit is the bed C.

To the right column are the values of temperature become from the theoretical calculation and to the left the values depicted in the control panel of the unit.

$T_1=724\text{ }^{\circ}\text{C}$	$T_1=724\text{ }^{\circ}\text{C}$
$T_2=719\text{ }^{\circ}\text{C}$	$T_2=718.8\text{ }^{\circ}\text{C}$
$T_{2d}=712\text{ }^{\circ}\text{C}$	$T_{2d}=713.3\text{ }^{\circ}\text{C}$
$T_3=730\text{ }^{\circ}\text{C}$	$T_3=729.5\text{ }^{\circ}\text{C}$
$T_{3d}=733\text{ }^{\circ}\text{C}$	$T_{3d}=732.7\text{ }^{\circ}\text{C}$
$T_4=755\text{ }^{\circ}\text{C}$	$T_4=756.5\text{ }^{\circ}\text{C}$
$T_{4'}=758\text{ }^{\circ}\text{C}$	$T_{4'}=758\text{ }^{\circ}\text{C}$
$T_{4'd}=745\text{ }^{\circ}\text{C}$	$T_{4'd}=743.2\text{ }^{\circ}\text{C}$
$T_5=673\text{ }^{\circ}\text{C}$	$T_5=671.6\text{ }^{\circ}\text{C}$
$T_6=710\text{ }^{\circ}\text{C}$	$T_6=711.4\text{ }^{\circ}\text{C}$
$T_7=802\text{ }^{\circ}\text{C}$	$T_7=800\text{ }^{\circ}\text{C}$

In advance, the thermal equilibriums involve the wavelength through the absorption coefficient, which depends on the average geometrical length, which is also depended on the dimensions of the combustion chamber. In conclusion the results are general and give the opportunity to design and measure similar thermal regenerative oxidizers with every possible function and dimension, which will have identical temperature allocation inside the combustion chamber, same composition percentage but different fuel consumption depending on its power.

The thermal oxidizer we study, has a complex geometry and furthermore, the surfaces that combine it are of different material with different thermal endurance and thermal storage, a detail that results to different emissivity, something that makes it more complicated to analyze this specific oxidizer.

This project is a tool for every projects' in order to help dimensionalise the three bed thermal regenerative oxidizer with the emitting composition percentage of coming out waste gases, inside the regulation framework of the existing legislation.

The existing international bibliography does not contain a validation of the H. Hottel[3] - R.J. Tucker[4] method, about thermal zones in a complex combustion chamber such as the 3 bed regenerative oxidizer in a specific real time operating unit with measured data during operation. The aim of this paper is to optimize the functional parameters of the unit with the final goal, neutralization of malodorous waste gases under process, with the minimum fuel consumption, and the chemical composition of the combustion products will not be a further burden on the environment. Accordingly, we need to correspond to the highly strict framework of criteria in European legislation about air pollutants and waste gases, by studying the effect of thermal radiation on the composition of gases.

### 3. Methodology

Initially, we need to calculate the emissivity of each gas that composes the waste gas mixture. Subsequently, construct a model of this waste gas mixture, so by adding the different emissivities of each gas and subtracting the overlap, we get the total emissivity of the mixture for a certain wavelength. Furthermore, the chamber is working in subpressure so we need to define the correcting coefficients with which we multiply the corresponding emissivities.

In order to calculate the emissivity's we use regression analysis and transform the H. Hottel [3] charts for vapor and CO<sub>2</sub> to corresponding relationships of emissivity with the standard temperature of the combustion chamber. We also need calculate the mean beam length of the combustion chamber.

Finally, we work on the equations of the model of gas mixture which leads to a relation between the composition percentage of waste gas and the absorption coefficient of thermal radiation. The supreme parameter in thermal radiation exchange among thermal zones.

### 4. Theoretical Analysis

In first we determine the model of exhaust mixture gas created inside the combustion gas consisting from water vapor and carbon dioxide and supposed to be grey. Once the radiation pattern has been determined, the radiation absorption coefficient and the mean beam length of the combustion chamber must be calculated.

We transform the parametrical charts fig 6.11 page 232, fig 6.9 page 229, fig 6.12 page 233 from Hottel [1] use the regression analysis with the constant temperature  $T=1841 \text{ }^{\circ}\text{R}_a$  of combustion chamber in function depends only from the wave length PL.

The obtain polynomial functions link the emissivity for every one of the exhaust gas w (water vapor and carbon dioxide) with the wavelength  $P_w L_m$  and  $P_{co2} L_m$  respectively.

We suppose that the model of gas mixture from combustion gas can be depicted with greater approach as consisting from two grey gas and one pure and the total emissivity from gas mixture given by the following relationship.

$$\epsilon_g = \alpha_{g,1}(1 - e^{-K_1 L}) + \alpha_{g,2}(1 - e^{-K_2 L}). \quad (1)$$

We also emphasize that we do not consider the others gas how like oxygen and nitrogen why not have remarkable emissivity.

The gas absorptivity and emissivity are described empirically as a weighted sum of gray gases

$$\epsilon_g = \sum_0^n [\alpha_g, n(Tg)](1 - e^{-knPL}) \quad (2)$$

$$\alpha_g = \sum_0^n [\alpha_s, n(Ts)](1 - e^{-knPL}) \quad (3)$$

The emissivity-pL relationship for each gas can be depicted as the sum of the weights of a sufficient number of gray gases, and this relationship can be expressed by the highest desired approach as

$$\epsilon_g = \sum a_{g,i} (1 - e^{-k_i pL}) \tag{4}$$

with the limit that  $\epsilon_g$  is an increasing function of pL having a limit of the unit  $\sum a_{g,i} = 1$  and all its values are positive. (5)

For  $K = 0$  we have the pure gas as one of the components that make up the gas mixture

$$\sum_{i=1}^n a_{g,i} = 1 - a_{g0} \tag{6}$$

$$\sum_{i=1}^n a_{g,i} - \epsilon_g = a_{g,1} e^{-k_1 pL} + a_{g,2} e^{-k_2 pL} + \dots + a_{g,n} e^{-k_n pL} \tag{7}$$

$$k_1 > k_2 \dots k_n \tag{8}$$

$$\epsilon_g = a_{g0}(1 - e^{-0pL}) + a_{g,1}(1 - e^{-k_1 pL}) = a_{g,1}(1 - e^{-k_1 pL}) = a_{g,1} (1 - e^{-K_1 pL}) \tag{9}$$

giving the pLm and 2pLm values in the above equation results in the following relations

$$\epsilon_{g,Lm} = a_{g,1}(1 - e^{-k_1 pLm}) \quad \epsilon_{g,2Lm} = a_{g,1}(1 - e^{-2k_1 pLm}) \tag{10}$$

$$a_{g,1} = \frac{\epsilon_g \epsilon_{g,Lm}}{2\epsilon_{g,Lm} - \epsilon_{g,2Lm}} \quad e^{-k_1 pLm} = \frac{\epsilon_{g,2Lm} - \epsilon_{g,Lm}}{\epsilon_{g,Lm}} \tag{11}$$

$$k_1 pLm = \ln \left[ \frac{\epsilon_{g,Lm}}{\epsilon_{g,2Lm} - \epsilon_{g,Lm}} \right] \tag{12}$$

and replacing the product  $k_1 p = K$

$$K_1 = \frac{1}{Lm} \ln \left[ \frac{\epsilon_{g,Lm}}{\epsilon_{g,2Lm} - \epsilon_{g,Lm}} \right] \tag{13}$$

become

$$K_1 = \frac{1}{Lm} \ln \left[ \frac{\epsilon_{g,Lm}}{\epsilon_{g,2Lm} - \epsilon_{g,Lm}} \right] = 0.143, \quad K_2 = \frac{1}{2Lm} \ln \left[ \frac{\epsilon_{g,2Lm}}{\epsilon_{g,4Lm} - \epsilon_{g,2Lm}} \right] = 0.0908 \tag{14}$$

We divided the combustion chamber as depicted in the figure (3) in 11 isothermal zones surface and gaseous or more zones if the dimension of combustion chamber is greater. The purpose is to identify the total exchange area between the thermal zones. From the chart 6-11 Emissivity of water vapor at 1 atm, reduced to  $p_w \rightarrow 0$  (H. Hottel [3] Radiative transfer page 232) through regression analysis with constant temperature  $T=1841 \text{ } ^\circ\text{R}_a$  we have the figure 4.

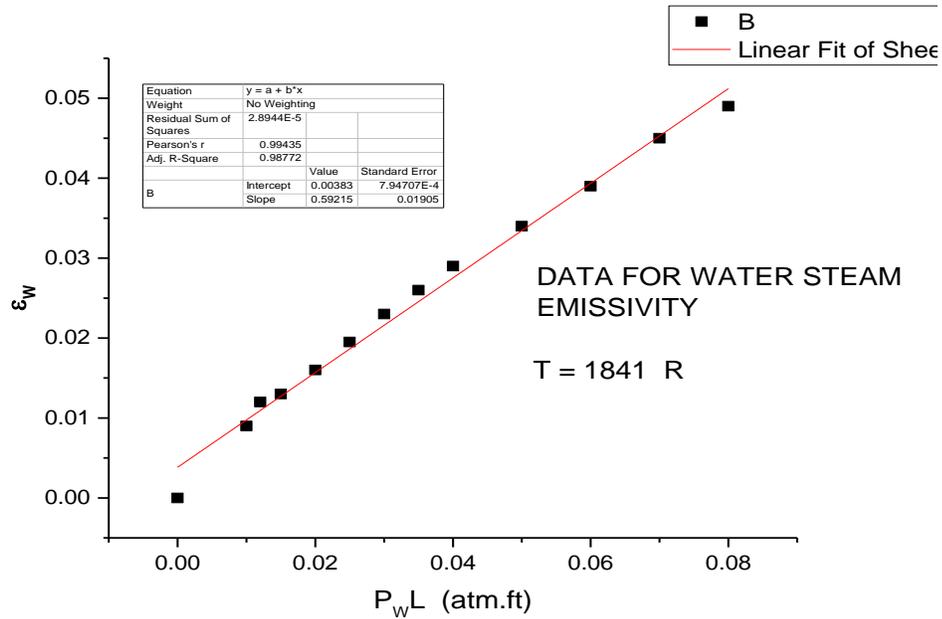


Figure 4: Emissivity of water vapor function  $P_wL$  at  $T=1841 \text{ }^0R_a$  and  $P=1\text{atm}$

From the chart 6-9 Emissivity of carbon dioxide at 1 atm, (H. Hottel[3] Radiative transfer page 229) through regression analysis with constant temperature  $T=1841 \text{ }^0R_a$  we have the figure 5.

From the chart fig. 6-12 correction due to spectral overlap for calculation of emissivity of a  $\text{CO}_2\text{-H}_2\text{O}$  mixture from those of its components (H. Hottel[3] Radiative transfer page 233) through regression analysis we have the figure 6.

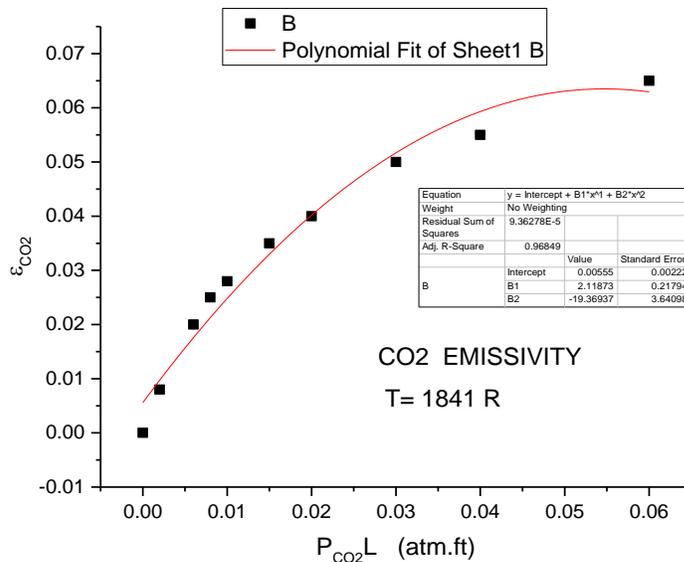


Figure 5: Emissivity of carbon dioxide function of wavelength  $P_{CO_2}L$  at  $T=1841 \text{ }^0R_a$  and  $P=1\text{atm}$

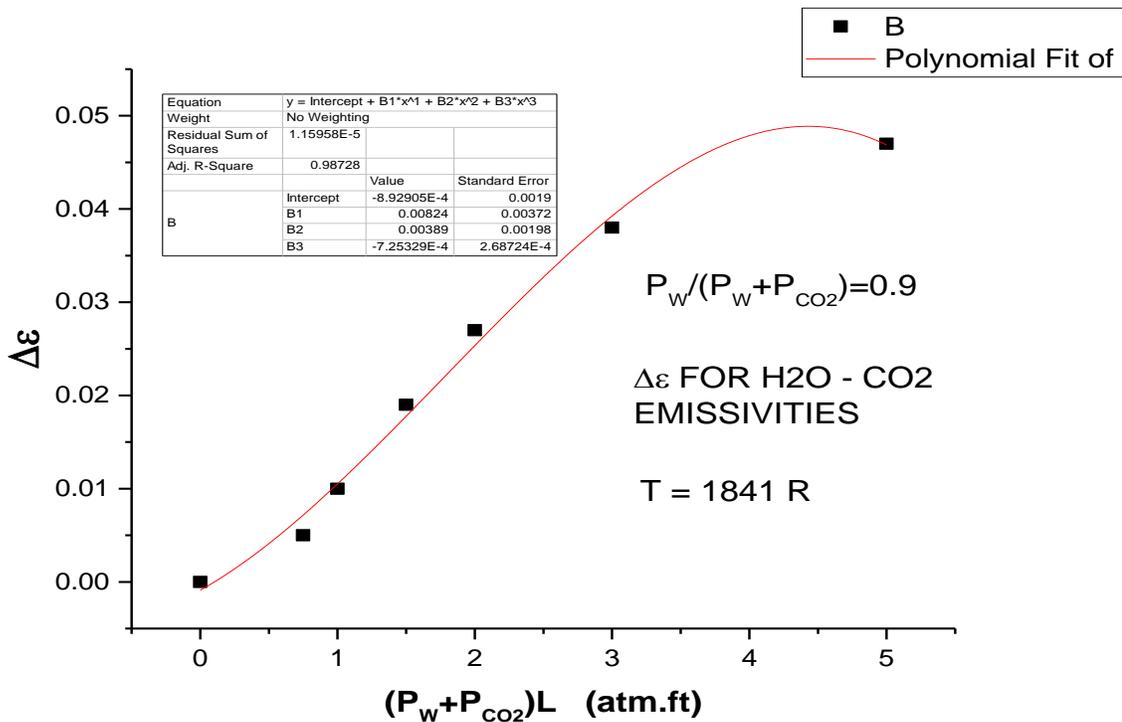


Figure 6: Overlap  $\Delta_E$  in function of  $(P_w + P_{CO_2}) L$  at  $T=1841 \text{ } ^0R_a$  and  $P_w/(P_w + P_{CO_2}) = 0.9$

The above charts generally apply for atmospheric pressure inside the combustion chamber. When the pressure is different from the atmospheric like in our case, then we need to readjust the values of the already determined emissivities with correcting coefficients  $C_w$  and  $C_{co_2}$  which are multiplied with the emissivities to get the real values.

For the determination of the correction factors  $C_w$  and  $C_{co_2}$  we use the parametrical charts (fig.13.56, fig13.57 engineering Heat Transfer/Rathore, Kapuno[6]), as an attachment to pressure and wavelength. But because of the reasons:

- 1) Safety. We wish the combustion chamber works under sub pressure to avoid the possible escape of gases resulting an inflammation and explosion.

The choice of a specific value of sub pressure must follow the next rules.

- Exclude the possibility of the flame going out with everything this implies, that might occur if the sub pressure is beyond 0.6 atm.
  - Increasing sub pressure leads to electrical power consumption increase. Along with the operating cost because the ventilator must refill the loses caused by the ceramic masses.
- 2) Increasing sub pressure leads to velocity increase of the processed gases and this creates noise and annoying sounds.

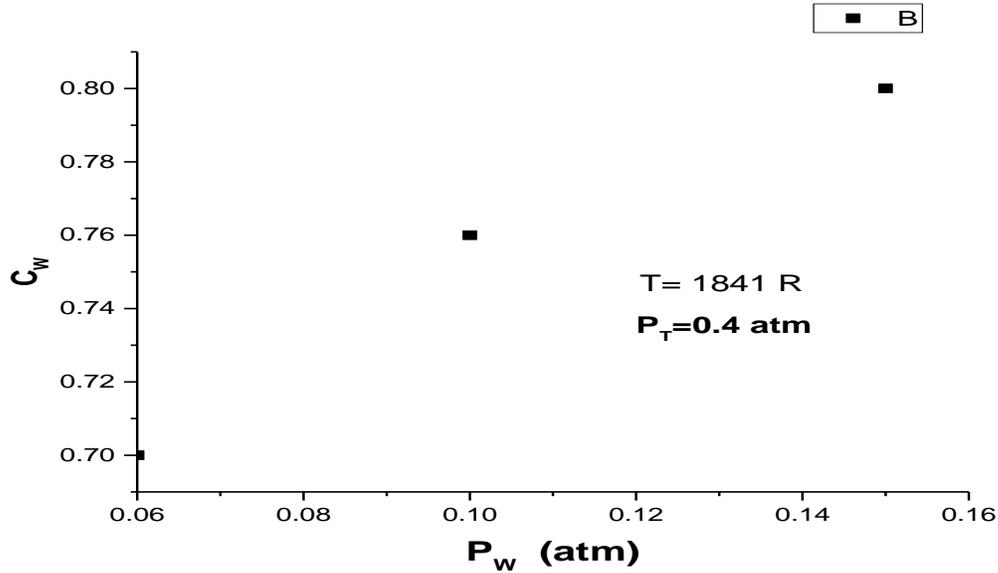


Figure 7: Correction factor for the emissivity of water vapor at pressures 0.4 atm and at  $T=1841$   $^{\circ}R_a$

For all the above reasons the average recommended subpressure is 0.4-0.5 atm so the calculations for the definition of correcting coefficients will be done according to this given value. Furthermore, the calculations for the correction factors will be based this value and furthermore the value of percentage composition of water vapor is too small. Why the exhaust gas crossing the hot labyrinth –exit. That limited the values of percentage of water vapor and the range of these values is between 0.6 % και 0.65%. And the middle value is 0.62 and the value of carbon dioxide is 0.8.

From the charts fig.13.56, fig13.57 engineering Heat Transfer/Rathore, Kapuno[6] , Correction factor  $C_w$  for converting  $H_2O$  emissivity's to values of  $p_w$  and  $P$  other than 0 and 1 respectively through regression analysis we have the figure.7

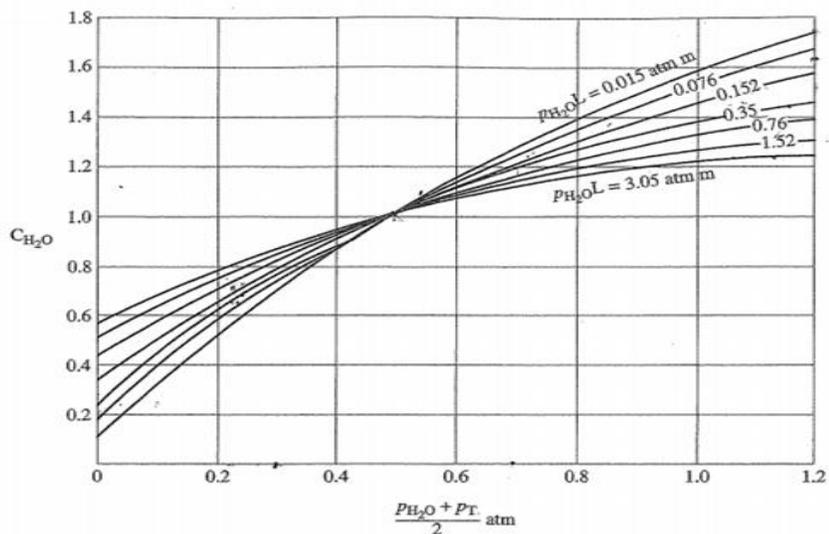


Figure 8: Correction factor for the emissivity of water vapor at pressures other 1 atm

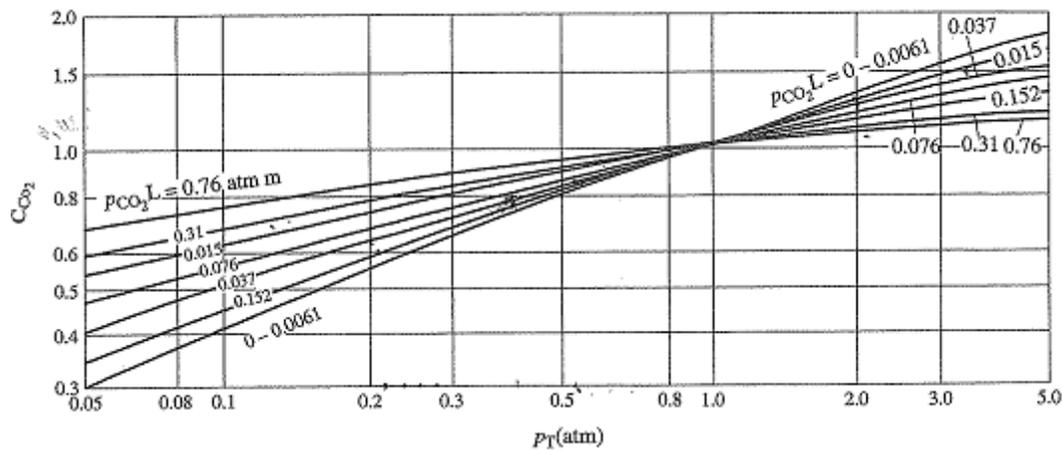


Figure 9: Correction factor for the emissivity of carbon dioxide at pressures other 1 atm.

The volume of the combustion chamber is  $V = (2d + 3d + 4d) \times 2d \times 2d$  and since  $2d = 3d = 4d$

$$V = 3 \times (2d) \times 3. \tag{15}$$

The surface of the combustion chamber is equal to  $A = 3 \times 2d \times 2d \times 2 + 2 \times 2d \times 2d + 3 \times 2d \times 2d \times 2 = 14 \times (2d) \times 2$  and thus the mean beam length is equal

$$L_m = 0.88 \times 4 \times V / A = 0.88 \times 4 \times 3 (2d) / 14 (2d) \times 2 = 0.739 (2d) \tag{16}$$

According to Dalton's law the exhaust gas concentration is correspondent to the partial pressure of them and multiplied with the mean beam length we obtain the wavelength  $P_{H_2O} \times L_m$ .

The mean beam length from the inventor of H. Hottel [3] is defined to represent the required radius of a hemisphere equivalent so that the incident flow at the center of the hemispherical base equals the average radiation flux incident to the surfaces surrounding the gas volume.

$$Q_{\lambda, i/k} = 1 - e^{-\alpha_{\lambda} L_e} \tag{17}$$

Definition and evaluation of mean beam lengths for applications in multidimensional radiative heat transfer (fig. 7.1 page 257) H. Hottel [ ] Radiative transfer).

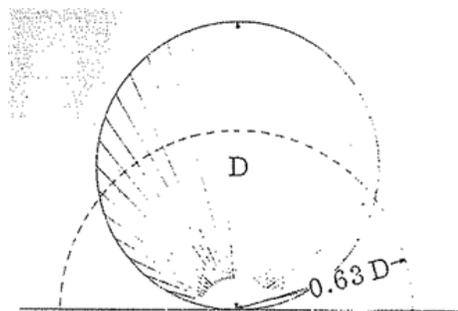


Figure 10: Mean beam length for a sphere.

The determination of mean beam length for every combustion chamber is fundamental for the calculation the exchange heat radiation between the isothermal zones on which is divided the combustion chamber and in this way is possible apply the theory of thermal zones.

We determine  $\epsilon_{g,w,L_m}$  from the chart 6-11 of Hottel[3] as a function only the wavelength  $P_w L_m$  through regression analysis with constant temperature equal  $1382^{\circ}F=1841^{\circ}R_A$  and parameter  $P_w L_m$ .

We determine  $\epsilon_{g,co2, L_m}$  from the chart 6-9 of Hottel[3] as a function only the wavelength  $P_{co2}L_m$  through regression analysis with constant temperature equal  $T=1382^{\circ}F=1841^{\circ}R_A$  and parameter  $P_{co2}L_m$ .

The values of emissivity's we replace in the relationship

$$\epsilon_{g,L_m} = C_w \cdot \epsilon_{g,H_2O,L_m} + C_{co2} \cdot \epsilon_{g,co2,L_m} \quad (18)$$

and which corresponds the emissivity of gas mixture for wavelength  $P L_m$

$$\epsilon_w = a + b L_m P_w = 0.00383 + 0.59215 \times 9 (L_m P_{CO_2}) \quad (19)$$

$$\epsilon_{co2} = \text{intersept} + B_1 x + B_2 x^2 + B_3 x^3 = 0.00555 + 2.11873 (L_m P_{co2}) - 19.36 (L_m P_{co2})^3 \quad (20)$$

and because

$$\Delta \epsilon = \text{intersept} + B_1 x + B_2 x^2 + B_3 x^3 = -8.929 + 0.000824 (p_w + p_{co2}) L_m + 0.00389 ((p_w + p_{co2}) L_m)^2 - 7.25329 (p_w + p_{co2}) L_m^3 \quad (21)$$

We express the values of emissivity's  $\epsilon_w$  and  $\epsilon_{co2}$  and overlap  $\Delta \epsilon$  through regression analysis from H. Hottel[3] (2),(4),(6) charts with correspondent polynomials (14), (15), (16) and replace these relationship on (13) relationship for wavelength  $P L_m$ .

Also replace the value product of partial water vapor pressure with the partial pressure of carbon dioxide by the mean beam length  $L_m$  according the relationship

$$P_w / (P_w + P_{co2}) = 0.9 / (P_w + P_{co2}) = 0.9 \quad \text{και} \quad P_w = 9 P_{co2} \quad (22)$$

Numerator

$$(0.00383 + 0.59215 \times 9 L_m P_{co2}) C_w + (0.00555 + 2.11873 L_m P_{co2} - 19.36 (L_m P_{co2})^2) C_{co2} + 8.929 - 0.00824 \times 10 (L_m P_{co2}) - 0.00389 \times 100 (L_m P_{co2})^2 + 7.25 \times 10^3 (L_m P_{co2})^3 = 8.938 + 4.911 (L_m P_{co2}) - 15.877 (L_m P_{co2})^2 + 7.25 \times 10^3 (L_m P_{co2})^3 \quad (23)$$

Denominator

$$(0.00383 + 2 \times 0.59215 \times 9 (L_m P_{co2})) C_w 2 L_m + (0.00555 + 2 \times 2.11873 (L_m P_{co2}) - 19.36 (2 \times (L_m P_{co2}))^2) C_{co2} 2 L_m + (8.929 - 0.00824 \times 2 \times 10 (L_m P_{co2}) - 0.00389 \times 4 \times 100 (L_m P_{co2})^2 + 7.25 \times 8 \times 10^3 (L_m P_{co2})^3 -$$

$$(8.035+4.911(L_m P_{CO_2})-15.877(L_m P_{CO_2})^2+7.25 \times 10^3(L_m P_{CO_2})^3)=50.77.10^3(L_m P_{CO_2})^3 - 47.629(L_m P_{CO_2})^2+4.922(L_m P_{CO_2}) \quad (24)$$

From the relationship (9), (18), (19) we have

$$K_1=1/L_m \ln (8.938+4.911(L_m P_{CO_2})-15.877(L_m P_{CO_2})^2+7.25 \times 10^3(L_m P_{CO_2})^3 / 50.77.10^3(L_m P_{CO_2})^3 -47.629(L_m P_{CO_2})^2+4.922(L_m P_{CO_2}) \quad (25)$$

For  $L_m = 7.54$  ft from the above relationship we have

For concentration  $CO_2$  equal  $P_{CO_2} = 0.006$  and  $L_m P_{CO_2} = 0.0452$  atm ft, we obtain  $K_1 = 0.093$ .

For concentration  $CO_2$  equal 0.7% and  $P_{CO_2} = 0.007$  we obtain  $K_1 = 0.044$

The direct and the total exchange areas between surface-surface, surface-gas and gas-gas depend from the absorption coefficient, how depicted in the below relationship.

$$\frac{\overline{SS}}{B^2} = C^* e^{-A^*KB}, \text{ R.J.Tucker[4]} \quad (26)$$

Increasing the concentration of exhaust gas decreases the absorption coefficient, and finally increasing the thermal radiation.

## 5. Conclusions

From the relationship (26) appears to increase the concentration of exhaust gas decreases the adsorption coefficient with the value  $e^{AKB}$  to decreasing, instead the value  $e^{-AKB} = 1/e^{AKB}$  to increasing and finally the direct exchange area radiation to increasing (first member of equation (21) and definitively increasing the total exchange radiation.

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