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SOMMAIRE

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THERMAL DESTRUCTION OF GAS GENERATED FROM HOUSEHOLD WASTE

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A B S T R A C T

The burning of industrial, agricultural wastes and garbage into ashes is source of significant air pollution due to the following gas components CO, CO_2, CH_4, C_2H_4, H_2O… etc. Thermodestruction remains one of the effective technologies used in the depollution of these components. This paper is devoted to the modelling of the thermodestruction in a cylindrical incinerator of gas waste produced by the combustion of garbage. Dimensionless transfer's equations are solved using an implicit numerical scheme, Thomas and Gauss algorithms. We analyze the influence of the mass rate of the inlet smoke on the effectiveness of depollution. .

R É S U M É

La combustion des ordures industrielles, agricoles et ménagères avec des cendres est source de pollution atmosphérique significative due aux composants gazeux suivants CO, CO_2, CH_4, C_2H_4, H_2O etc. La thermodestruction des gaz reste l'une des techniques les plus efficaces utilisées pour la dépollution de ces composants gazeux. Cette étude est consacrée à la modélisation de la thermodestruction dans un incinérateur cylindrique de gaz produits par la combustion des ordures ménagères. Les équations de transferts sont adimensionnalisées et résolues en utilisant une méthode numérique implicite, les algorithmes de Thomas et de Gauss. Nous analysons l'influence du débit de la fumée d'admission sur l'efficacité de la dépollution.

NOMENCLATURE

Cp : Heat capacity of gas-air mixture ($\boldsymbol{J\ kg^{-1}\ K^{-1}}$)
d: Incinerator Diameter (m)
S: surface (m^2)
Δt : time step (s)
D: Diffusion coefficient de ($m^2\ s^{-1}$)
E: Activation Energy ($J\ mol^{-1}$)
g: Acceleration of gravity ($\cong$ 9,81 $m\ s^{-2}$)
h : Heat transfer coefficient by natural convection ($W\ m^{-2}\ K^{-1}$)
H: Height of the incinerator (m)
ΔH: Enthalpy ($kJ\ mol^{-1}$)
Q: Heat released during combustion (kJ)
Q' : Combustion heat ($W\ m^{-3}$)
M: Molar mass ($kg\ mole^{-1}$)
n: Number of moles ($mole$)
ΔH_0^{298} : Standard combustion enthalpy at 298 K ($kJ\ mol^{-1}$)
k: Reaction rate constant ($m^3 mol^{-1} s^{-1}$)
k_0 : Frequency or pre-exponential factor ($m^3 mol^{-1} s^{-1}$)
P: Dynamic pressure (Pa)
Q: Reaction heat (kJ)
r: Radial ordinate (m)
R: Ideal gas constant ($\cong$ 8.314 $J\ mol^{-1}\ K^{-1}$)
R_t : Thermal resistance of the insulation ($W^{-1}\ K$)
Re: Reynolds number ($= \frac{V_0 de}{\nu_0}$)
T: Temperature (K)
U: Radial speed component ($m\ s^{-1}$)
V: Axial speed component ($m\ s^{-1}$)
$\dot{W}$: Overall smoke combustion speed (s^{-1})
x: Mole fraction
Y: Mass fraction
z: Axial ordinate (m)
t: time (s)
λ : Thermal conductivity ($W\ m^{-1}\ K^{-1}$)

μ : Dynamic viscosity of the mixture ($kg\ m^{-1}\ s^{-1}$)
ρ : Density of air – smoke mixture ($kg\ m^{-3}$)
σ : Speed of disappearance or appearance of the species (s^{-1})

INDEXES:
amb: Ambient.
e: Incinerator entrance.
F: Fluid
i: Types of insulation.
inci: Incinerator
k: Various species contained in smokes.
pe: External wall.
pi: Internal Wall.
rea: Smoke combustion reaction
s: Incinerator exit.

I. INTRODUCTION

Household waste disposal remains a major challenge for cities, notably due to increasing urbanization and the volume of waste produced by consumers. Among waste treatment techniques, there is heat treatment which is widespread despite the air pollution it generates (Gordon McKay, 2002, Nammari and al, 2004). Indeed, smokes produced by the incineration of household waste contain many pollutants, including (CO, CO_2, CH_4, NO, NO_2, etc.) (Gordon McKay, 2002, Nammari and al, 2004). Thus, a study by Baillot et al, 2004, on the incineration of leather shoe waste in Spain, shows that 60% of this waste turns into smokes composed of NO, NO_2, NH_3, SO_2, Cr_2O_2, Cr_2O_3, SiO_2 and carbon gases. The releases of atmospheric effluent during the incineration of waste packaging through controlled fire are composed of CO, CO2, SO2, NO, NO2 with particles of Hg, Cd, HCl, HF, HBr, NH, Ni, Cr, Mn, Cu, Co and Sb which are toxic and harmful to the environment (Nammari and al, 2004). To address the environmental pollution issue, it is essential to mitigate these discharges by acting, for example, on waste treatment techniques to reduce pollutants due to smokes or by treating smokes so that they become non-polluting for the environment. Among techniques used to decontaminate these atmospheric effluents, thermodestruction has proven to be effective. It can be associated with the production of electricity in cogeneration (Olsommer and al, 1997) and meets the characteristics of waste incineration plants, which functioning can be through partial load or in overload.

This presentation focuses on the modelling of transfers during thermodestruction in a cylindrical incinerator of smokes produced by the combustion of household waste. Transfers generated by chemical reactions due to thermodestruction of the smoke main compounds (CO, CO_2, CH_4, C_2H_4, H_2O) are coupled with the transfers of heat, mass and impulse. One of the aims of this study is to analyze the efficiency of the burning of smokes generated by the combustion of household waste.

II. MATERIAL AND METHOD

2.1. Description of the System:

The incinerator is a vertical cylinder, with the following dimensions H = 1 m, d = 1 m, equipped with an inlet and a chimney located on the lower and upper parts of this cylinder (de = ds = 0.20 m), respectively (figure 1). The walls of the incinerator are made of refractory bricks, insulated by a layer of glass wool within a steel sheet.

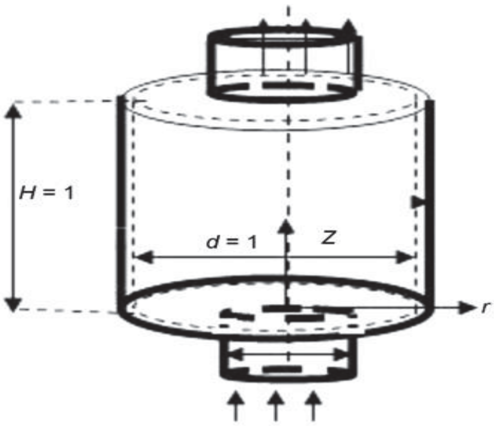

Figure 1: System diagram and repository

Let us consider the incinerator repository (O, r, z), in such a way that the origin O is located at the center of its base, the ordinate z counted positively in the direction opposite to the acceleration vector of gravity and the abscissa r perpendicular to the axis [O z).

Let us make the following simplifying assumptions:

- Viscous dissipation is negligible.
- Smokes composition is homogeneous.
- Dufour and Soret effects are negligible.
- Pressure gradient along the axis [Or) is negligible.
- The system has a revolution symmetry based on the axis [O z).
- Air is composed of 21% of O_2 oxygen and 79% of N_2 nitrogen.

Smokes produced by the combustion of household waste enter the furnace through the lower inlet and gases generated by their incineration are discharged outside through the chimney. We consider the smokes made of a simple mixture of gases (sorted waste) which composition may vary according to the following table (Table 1). We consider two compositions of the fume which we obtained in function of the masses composition of the various combustible components of waste. We use here composition 1 for the results.

Table 1: Composition smokes used to incinerate waste selected and pre-mixed with air

Mass fraction	Composition1	% /of smokes	Composition2	%/of smokes
Y_{air}	0.546522	100% excess air	0.546522	100% excess air
Y_{O2}	0.145278	21% air	0.145278	21% air
Y_{CO}	0.00389	1.26	0.00778	2.52
Y_{CO2}	0.1738	56,4	0.1738	56,4
Y_{H2O}	0.12251	39.75	0.11262	36.54
Y_{CH4}	0.003	0.97	0.006	1.95
Y_{C2H4}	0.005	1.62	0.008	2.59

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2.2. Mathematical Formulation

2.2.1. Transfer equations

Given the simplifying assumptions made above, the conservation equations for mass, motion, energy and those of species diffusion (Euvrard, 1994 and Saatdjian, 1998) are written in the repository (O, r, z):

- **Mass conservation *equation***

$$\frac{1}{r}\frac{\partial(rU)}{\partial r}+\frac{\partial(V)}{\partial z}=0 \qquad (1)$$

- **Motion equation**

- *Following the axis* [or)

$$\rho\left(\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial r}+V\frac{\partial U}{\partial z}\right)=\mu\left[\frac{\partial^2 U}{\partial r^2}+\frac{1}{r}\frac{\partial U}{\partial r}-\frac{U}{r^2}+\frac{\partial^2 U}{\partial z^2}\right] \qquad (2)$$

- *Following the axis* [oz)

$$\rho\left(\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial r}+V\frac{\partial V}{\partial z}\right)=-\frac{\partial P}{\partial z}+\mu\left(\frac{\partial^2 V}{\partial r^2}+\frac{\partial^2 V}{\partial z^2}+\frac{1}{r}\frac{\partial V}{\partial r}\right)-\rho g \qquad (3)$$

- **Energy equation**

$$\rho C_p\left(\frac{\partial T}{\partial t}+U\frac{\partial T}{\partial r}+V\frac{\partial T}{\partial z}\right)=\lambda\left(\frac{\partial^2 T}{\partial r^2}+\frac{\partial^2 T}{\partial z^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right)+Q'_{rea} \qquad (4)$$

- **Species diffusion equation**

$$\frac{\partial Y_k}{\partial t}+U\frac{\partial Y_k}{\partial r}+V\frac{\partial Y_k}{\partial z}=D_k\left(\frac{\partial^2 Y_k}{\partial r^2}+\frac{\partial^2 Y_k}{\partial z^2}+\frac{1}{r}\frac{\partial Y_k}{\partial r}\right)+\sigma_k \qquad (5)$$

k= O_2, CO, CO_2, H_2O, CH_4, C_2H_4.

These equations are discretized by considering an implicit numerical method with the finished differences and solved with the algorithms of Gauss and Thomas.

2.2.2. Modelling of the chemical kinetics:

Smokes produced by the incineration of household waste mainly contain CO_2, CO, H_2O, CH_4, C_2H_4 and NO_x. We assume that the nitrogenous compounds are removed by filtration and the chemical kinetics described at the macroscopic level, as well as full chemical reactions of the combustion of the compounds CO_2, CO, H_2O, CH_4, C_2H_4 contained in the smokes produced by the incineration of household waste are characterized by:

$$CO+\frac{1}{2}O_2\rightarrow CO_2 \qquad (6)$$

$$CH_4+2O_2\rightarrow CO_2+2H_2O \qquad (7)$$

$$C_2H_4+3O_2\rightarrow 2CO_2+2H_2O \qquad (8)$$

The reaction rates of these three chemical reactions cannot be used separately since the reaction rate of each type of combustible depends on the local mass fraction of oxygen, which depends on the level of the other so-called concurrent reactions. To handle this, we consider an overall kinetics model that enables to couple the speeds of the three chemical reactions described above.

$\dot{W}=-kYY_{O_2}\frac{\rho(T)}{M_{O_2}}exp\left(-\frac{E}{RT}\right)$: Overall smoke combustion speed (Bergeron and al, 1989) (9)

With:

$$k=\sum_i x_i\,k_i,\ k_i=k_{0_i}\,exp\left(-\frac{E_i}{RT}\right),\ Y=\sum_i Y_i,\ M=\sum_i x_i\,M_i,\ E=\sum_i x_i\,E_i. \qquad (10)$$

For each combustible, the values of the kinetic constants are reported in table 2.

Table 2: Values of kinetic Constants (Kulasekaran and al, 1999)

Component i	k_{0_i} (10^{11}) $m^3\,mol^{-1}\,s^{-1}$	E_i/R (K) T<1073 K	E_i/R (K) T>1073 K
Ethylene C_2H_4	37	22 753	27 679
Hydrogen H_2	2.45	19 551	23 855
Carbon monoxide CO	22.3	19 655	20 734
Methane CH_4	7	30 196	31 706
Carbon Cgas	2.5	21890	21890

Heat from the combustion of the components selected in this study is assumed to be equal to the sum of the heats released during the various combustions of these components. Thus, for the reactions (6-8), it is (Oturan and al, 1997):

$$\Delta H_{CO} = \Delta H_{0CO}^{298} + \int_{298}^{T} \left(M_{CO_2} Cp_{CO_2} - M_{CO} Cp_{CO} - \frac{1}{2} M_{O_2} Cp_{O_2} \right) dT \quad (11)$$

and $Q_{CO} = n_{CO} \Delta H_{CO}$.

$$\Delta H_{CH_4} = \Delta H_{0CH_4}^{298} + \int_{298}^{T} \left(M_{CO_2} Cp_{CO_2} + 2M_{H_2O} Cp_{H_2O} - M_{CH_4} Cp_{CH_4} - 2M_{O_2} Cp_{O_2} \right) dT \quad (12)$$

$$\Delta H_{CO} = \Delta H_{0C_2H_4}^{298} + \int_{298}^{T} \left(2M_{CO_2} Cp_{CO_2} + 2M_{H_2O} Cp_{H_2O} - M_{C_2H_4} Cp_{C_2H_4} - 3M_{O_2} Cp_{O_2} \right) dT \quad (13)$$

Therefore, $Q_{CH_4} = n_{CH_4} \Delta H_{CH_4}$,

$Q_{C_2H_4} = n_{C_2H_4} \Delta H_{C_2H_4}$.

Lastly, the amount of the total combustion heat during the incineration of CO, CH_4, C_2H_4 aligns with the following:

$$Q_{rea} = Q_{CO} + Q_{CH_4} + Q_{C_2H_4} \quad \text{and} \quad Q'_{rea} = \frac{Q_{rea}}{de\ S\ \Delta t} \quad (14)$$

2.3. Numerical methodology:

The numerical resolution of adimensionalized equations (1-5), associated with the boundary conditions is made using an implicit finite difference method, in which the axial concentration term is discretized using upstream differences, while the other terms are solved through centered differences (Euvrard D, 1994 and Saatdjian E, 1998).

III. RESULTS AND DISCUSSIONS:

Calculations were made for different values of the Reynolds number ($500 \leq Re \leq 1750$). But here, for the reasons of respect for the number of pages, we have only the results for Re=500 and Re=1750.

As for the combustion balance, Figures 2 and 3 show that all combustibles disappear quickly (nearly ten seconds) at the outlet of the incinerator, producing water vapor and carbon dioxide Figures 4 and 5. This result is very interesting since the household waste combustion cycle is about one hour and a half (1 h 30 min). Also, none of the harmful gases released by the combustion of household waste is therefore not found in the atmosphere. Concerning the concentration of smoke components, the flow increase does not significantly impact the thermal destruction. This system used to incinerate smokes produced by the combustion of household waste is therefore effective for the decontamination of these smokes.

It is noted that when Re is increasingly large, there is a significant reduction in the time of disappearance of harmful gases (figures 2 and 3). On the other hand, it is the contrary effect which is observed for the appearance of CO_2 and H_2O (figures 4 and 5).

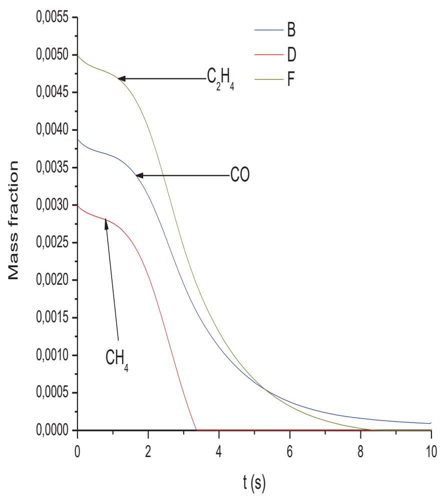

Figure 2: disappearance of gaseous effluents at the outlet of the incinerator over time Re=500 (Kalifa Palm and al, 2008)

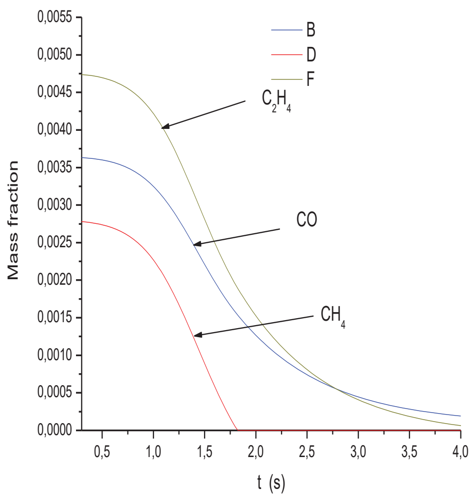

Figure 3: disappearance of gaseous effluents at the outlet of the incinerator over time Re=1750 (Kalifa Palm and al, 2008)

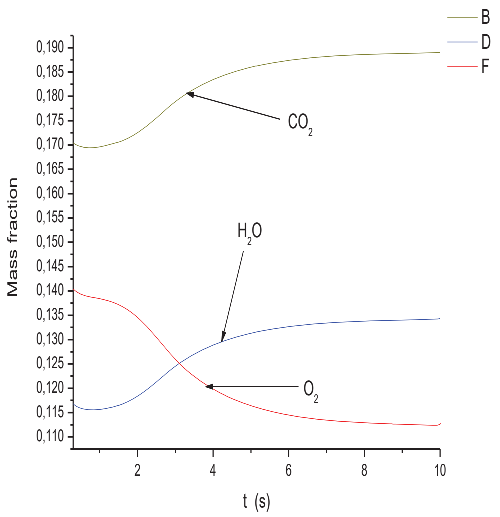

Figure 4: Appearance and disappearance of gas at the incinerator outlet over time. Re=500 (Kalifa Palm and al, 2008)

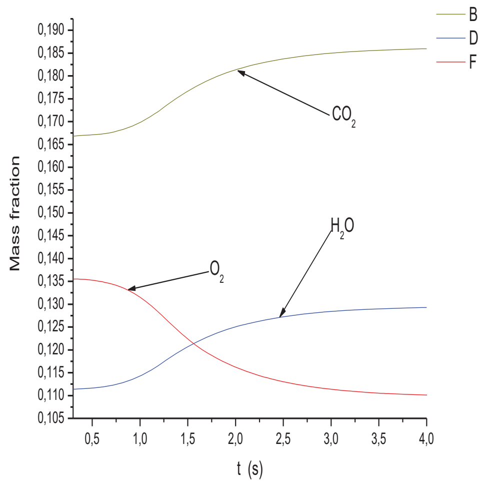

Figure 5: Appearance and disappearance of gas at the incinerator outlet over time. Re=1750 (Kalifa Palm and al, 2008)

IV. CONCLUSION

We have performed a numerical study of the incineration of smokes produced by the combustion of household waste in laminar regime. We have analyzed, by adopting an overall chemical kinetics model, the influence of the flow rate of smokes on the evolution over time of the composition of smokes. Thus, we have shown that the polluting compounds of these smokes are destroyed very quickly. This system of incinerating smokes generated by the combustion of household waste seems therefore effective.

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