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# Thermodestruction of Wastes Generated by Thermal Processing of Household Wastes: Thermal Study of the Equipment in Laminar Regime

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Authors KP and BZ designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors AO and BZ managed the literature searches, analyses of the study performed the spectroscopy analysis. Authors MOZ and SI managed the experimental process. Author KN identified the species of plant. All authors read and approved the final manuscript.*

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## ABSTRACT

In this work, we conduct a thermal study on the installation of an incinerator of gas generated by the carbonization of household wastes. We used a forced and laminar flows, with Reynolds number ranging between 500 and 2,000. Beyond 2,000, in our simulation, computer programs are become more and more unstable, therefore showing that the regimen is no longer laminar. This combustion

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phenomenon is handled with Navier-Stokes equations, those on the energy and distribution of the species contained in smokes. Temperatures, around 650 K for a Reynolds number of 500, increase when this Reynolds number increases. Results show that the highest temperatures are near the walls of the incinerator. Given the quantity of energy released in these areas, thermal recovery is possible, but this must be properly done to minimize losses.

*Keywords: Incineration; temperature; combustion; thermal treatment; thermal recovery.*

## NOMENCLATURE

$U$: *Radial speed component (m/s);* $V$: *Axial speed component (m/s);* $T$: *Temperature (K);* $Y$: *Mass fraction (%);* $P$: *Pressure (N m$^{-2}$) ;* $c$: *Concentration (mole m$^{-3}$) ;* $\rho$: *Density (kg m$^{-3}$);* $\mu$: *Dynamic viscosity (kg m$^{-1}$ s$^{-1}$);* $C_p$: *Mass heat with constant pressure (J kg$^{-1}$ K$^{-1}$);* $\lambda$: *Thermal conductivity (W m$^{-1}$ K$^{-1}$);* $\sigma$: *Speed of appearance and disappearance of species (s$^{-1}$);* $D$: *Diffusion coefficient (m$^2$ s$^{-1}$) ;* $h$: *Coefficient of heat transfer by natural convection between the external wall and the environment (W m$^{-2}$ K$^{-1}$);* $g$: *Speed up of the gravity (m s$^{-2}$);* $r$: *X-axis (m);* $z$: *Y-axis (m);* $t$: *Time (s);* $H$: *Height of the incinerator (m);* $d$: *Diameter (m);* $Re$: *Reynolds number.*

## INDEX

$k$: *Species contained in smokes;* $e$: *Entry;* $pi$: *Internal wall;* $pe$: *External wall;* $F$: *Fluid.*

## 1. INTRODUCTION

These recent decades have been characterized at the environmental level, by a steady increase in the quantity and types of wastes, and whatsoever the country. This may be due both to industrial activities, with the growing urbanization and the development of a number of synthetic products related to new types of wastes. The municipal wastes include the following:

- Household wastes produced through household activities ;
- Jumbling wastes and small rubbles ;
- Wastes generated by car industry ;
- Wastes generated with the maintenance of green areas ;
- Mud generated by water purification plants ;
- Wastes from individual sanitation ;
- Various quantities of toxic wastes disseminated and special wastes.

In the part below, we particularly focus on household wastes. They constitute for example two thirds of municipal wastes in France. Thus putrescible volume and the quantity of papers / cardboards included in these wastes are relatively high with 28.8% and 23.5% of the volume of household wastes respectively.

The amount of waste produced is often the result of consumption patterns. This varies by country depending on its level of development and income. A study by The World Bank [1] shows that the quantities of various types of household wastes produced in large cities in various countries may vary widely based on the average annual income per capita. Wastes disposal chain comprises four steps:

- The collection ;
- The transportation to waste processing site ;
- The actual processing ;
- The storage of finite wastes.

The treatment systems strive to make residues from human activities eco-friendly, by reducing the outflow toward the external environment and by properly stabilizing substances contained in wastes. The sound knowledge of the technology of waste combustion in closed stoves is new. Indeed, the first municipal waste incinerators in Europe appeared in late 19$^{th}$ century. This technology was then developed with the steady increase in the quantity of wastes during the whole 20$^{th}$ century [2]. In the proposed thermal treatment, we distinguish incineration which aims to reduce into ashes (etymologically “in ciner”) and energy valorization, which consists in producing energy from wastes to reuse as heat or electricity.

The incineration of household wastes is a highly polluting activity. Indeed, 90% of the initial mass is in smokes and reduced into dust, pollutant gas and condensable organic compounds that develop in smoke. The high concentration of pollutants [3] that impacts on the environment and the toxicity of smokes released from incineration [4] require treatment prior to discharge [5]. Most often, in the thermal processing of wastes, we do not focus on the valorization of the energy released during this process [6]. In this area, works are often directed toward the characterization of gaseous effluents deriving from this process [7]. The impact of pollution is being highlighted [7]. In the research work we have conducted in this area, we have demonstrated in previous publications, the possibility to destroy harmful components of smokes from the carbonization of household wastes [8,9].

In this paper on the management of smoke from incineration [10], we investigate how to develop energy generated from the combustion of these airborne effluents. This study is carried out under laminar flow (Reynolds number between 500 and 2, 000), with complete combustion of smokes. [11] Temperatures are above 650 K inside the incinerator (Fig.1) and increase with the Reynolds number (Re) [4]. This combustion is governed by the Navier-Stokes equations, those on energy and the distribution of species contained in smokes.

## 3. RESOLUTION METHODS

During the incineration of smokes produced by the combustion of household wastes, transfers are described using Navier-Stokes equations, equations on energy and the conservation of species contained in the incinerator and the equation of radiative transfer. The following simplifying assumptions are made:

- Transfers are two-dimensional ;
- At the entry of the incinerator, smokes pre-mixed with air are assimilated to an homogenous gaseous mixture made of : CO, $CO_2$, CH4, HCl, $H_2O$, $H_2$, $O_2$, $N_2$, NO et $NO_2$ ;
- The driving pressure gradient along the horizontal axis is not considerable ;
- Viscous dissipation is negligible ;
- Dufour and Soret effects are not considerable ;
- Physical properties of smokes are constant;
- Smokes are incompressible and similar to a perfect gas ;
- The incinerator accepts a rotational symmetry with respect to the axis [Oz).

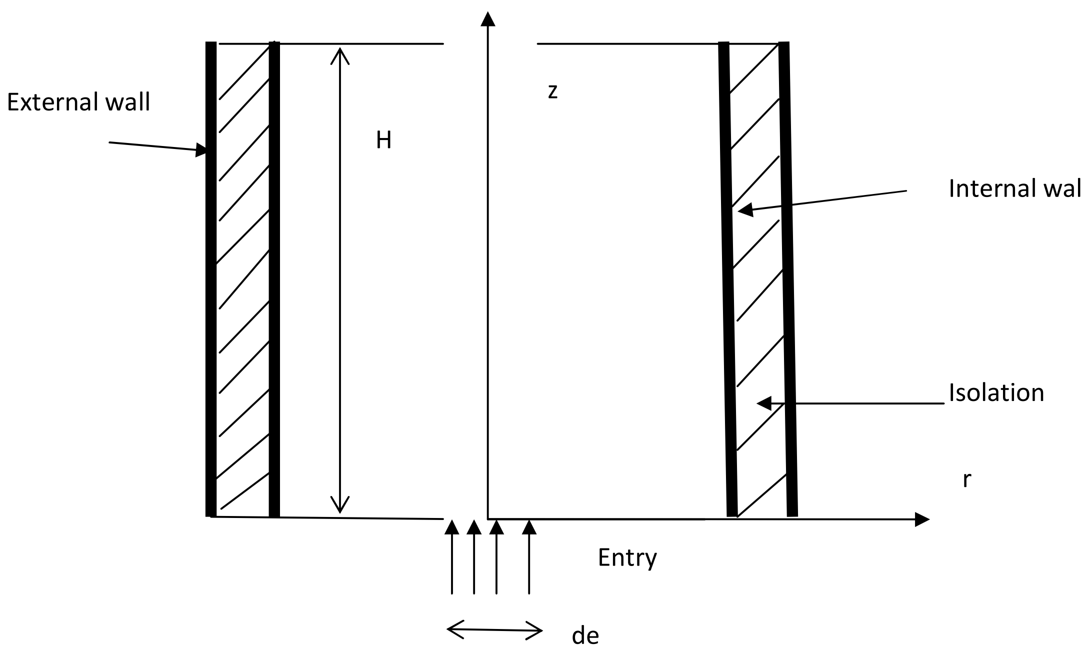


**Fig. 1. Descriptive outline of the incinerator model**

- **Equation of the movement quantity :**

Component following the axis [Or):

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

Component following the axis [Oz):

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

- **Energy Equation :**

$$\rho C_p\left(\frac{\partial T}{\partial t}+U\frac{\partial T}{\partial r}+V\frac{\partial T}{\partial z}\right)=\lambda\left(\frac{\partial^2 T}{\partial r^2}+\frac{\partial^2 T}{\partial z^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right)+Q_{rea}+Q_{rad} \quad (3)$$

- **Equation for the conservation of k species :**

$$\frac{\partial Y_k}{\partial t}+U\frac{\partial Y_k}{\partial r}+V\frac{\partial Y_k}{\partial z}=D_k\left(\frac{\partial^2 Y_k}{\partial r^2}+\frac{\partial^2 Y_k}{\partial z^2}+\frac{1}{r}\frac{\partial Y_k}{\partial r}\right)+\sigma_k \quad (4)$$

Initial conditions and the conditions to the limits for this combustion phenomenon are:

- $\forall\ \mathbf{t} \le \mathbf{t_0}$ , The incinerator is filled with smoke at rest and at the preheating temperature. The initial time $t_0$ corresponds to the time when the fuel mixture enters in the incinerator. Therefore, it gives:

$$U=V=0 \quad (5)$$

$$T=T_0 \quad (6)$$

$$Y_{O_2} = 0.21\, Y_{\text{air of the mixture}} \quad (7)$$

$$Y_{N_2} = 0.79\, Y_{\text{air of the mixture}} \quad (8)$$

Air concentration is given as follow:

$$c_{air}=\frac{\rho_{air}(T_0)}{M_{air}} \quad (9)$$

$$Y_k=Y_{smokes} \quad (10)$$

- **When entering in the incinerator:** $0 \le r \le \frac{d_e}{2}, z=0$

We use Poiseuille's profile for the speed when entering in the incinerator:

$$V=\frac{3}{2}V_0\left(1-\frac{4}{d_e^2}r^2\right); U=0; T=T_e;\ Y_k=Y_{ke} \quad (11)$$

- **When going out of the incinerator:** $0 \le r \le \frac{d_e}{2};\ z=H$

The outflow pipe is long enough to enable a proper flow.

$$\frac{\partial U}{\partial z}=\frac{\partial V}{\partial z}=0 \quad (12)$$

$$\frac{\partial T}{\partial z}=0 \quad (13)$$

$$\frac{\partial Y_k}{\partial z}=0 \quad (14)$$

- **On the lateral walls:** $r=\frac{d}{2}$ et $0 \le z \le H$

$$U=V=0 \quad (15)$$

$$\frac{\partial Y_k}{\partial r}=0 \quad (16)$$

$$-r_1\lambda_F\left(\frac{\partial T}{\partial r}\right)=\left(\frac{1}{\sum_i \frac{1}{\lambda_i}\mathrm{Log}\frac{r_{i+1}}{r_i}}\right)(T_{pi}-T_{pe})=r_5 h_{air}(T_{pe}-T_{amb}) \quad (17)$$

- **On the horizontal walls:** $\frac{d_e}{2} \le r \le \frac{d}{2}$ et $z=0$ ou $z=H$

$$U=V=0 \quad (18)$$

$$\frac{\partial T}{\partial z}=0 \quad (19)$$

$$\frac{\partial Y_k}{\partial z}=0 \quad (20)$$

- **On the axis of symmetry:** $r=0$ et $0 \le z \le H$

$$U=0;\ \frac{\partial V}{\partial r}=0;\ \frac{\partial T}{\partial r}=0; \frac{\partial Y_k}{\partial r}=0 \quad (21)$$

Equations (1), (2), (3) and (4) as well as the related initial conditions and conditions on limits are discretized by using an implicit finite difference method. Systems of algebraic equations thus obtained are solved using Thomas and Gauss algorithms.

$Q_{rea}$ is the heat released during the combustion of the various chemical species of smokes. According to Berthelot's rule, combustion reactions are total [5]. This enables, according to that same rule, the assumption of reactions of simple and total combustion [10]. The energy released during the combustion of smokes generated by the burning of household wastes, calculated by taking the reaction rate into account, confirms the following equation [11,12]:

$$Q_{rea} = \frac{\dot{W}_{glo}}{M} \sum_i h_i \quad (22)$$

$Q_{rea}$ = Heat released during the combustion of species contained in smokes.
$\dot{W}_{glo}$ = Overall speed of the fading out of species that constitute incinerated smokes [13].
$h_i$ = Standard heat content of the species I at 298 K
$M$ = Molar mass of the incineration smokes.
$i$ = Species contained in the incineration smokes.

$Q_{rad}$ is the amount of heat generated by the radiative radiation. We used the area method to calculate the amount of heat released during the combustion of the smokes. The area method enables to assess the radiative exchange in multidimensional geometries with semitransparent anisothermal environments. Recent research has shown that this method offers real opportunities [14]. It easily complies with the nodal analysis of decomposing the system into a series of nodes. Each node is the center of an area (volume or surface). An energy balance, performed at each area, links the problem of radiative transfer to solving nonlinear algebraic equations depending on the temperature. The term due to radiation in the energy balance is expressed following the radiation factors (exchange areas) depending on the temperature of the various nodes of the system.

These exchange areas are calculated in three successive stages (a- direct exchange areas, b- total exchange areas and c- directed exchange areas) [14,15] with the first two independent of temperature. This leads to a significant reduction of the calculation time. However, this method hardly solves complex geometries (radiative exchange between areas not necessarily placed opposite each other; visibility of areas among them), spreading anisotropy and the spectral variation of the radiative properties of the environment and the walls that confine it.

## 4. RESULTS AND DISCUSSION

Data were entered using the software SURFER 11. It provides the maximal and minimal values of isotherms given in Figs. (2), (3), (4), (5) and (6). By changing the Reynolds number between 500 and 1,750, we get the following isotherms:

The minimum value of isotherms is 480 K and is located at the entry of the incinerator. The lower temperature on these lines is 20 K while the maximal temperature is located near the walls. The maximal value is 880 K.

Isotherms are located in the median plane and near the walls. In the central plane, they describe parabolas from the entry of the incinerator that extends towards the outlet as their values increase. The proximity of the walls describes parallel lines among which the value of the maximal isotherm is the closest line to the wall. Isotherm values increase from the median plane toward the insulation walls. This allows us to know that most of the combustion occurs near the walls [17]. To recover heat released from this combustion, you must circulate a coolant near the walls of the incinerator. The coolant can flow, for example in cylindrical pipes set in coils throughout the walls. We will see the reaction of isotherms and their values when the Reynolds number (Re) increases.

With this value of the Reynolds number, only one parabola extends to the outlet. The others do not exceed the lower half of the incinerator. This enables to see that the time the combustible gaseous mixture takes within the incinerator in the central plane decreases. The lines near the walls tighten increasingly showing a further increase of combustion in this part of the incinerator. At the entry of the incinerator, the minimal value of isotherms is 700 K and near the walls, the maximal values are 840 K. Most of combustible smoke is blown increasingly towards the walls; this result is confirmed by the other walls, when Re = 1,000; 1,250; 1,500 and 1,750.

For this Reynolds number, we find that in the median plane, no isotherm reaches the exit. All curves, with almost parabolic forms, end at the entry where the minimal value is 690 K and the temperature space is 10 K. The lines near the walls get closer and closer. The maximal values are immediately near 880 K.

The remark above is confirmed. In the median plane, isotherms are less and less high. The minimal value is 690 K while the maximal is 910 K with a space of 10 K. Around the walls, the temperature keeps on increasing, showing an increased combustion in this part of the incinerator.

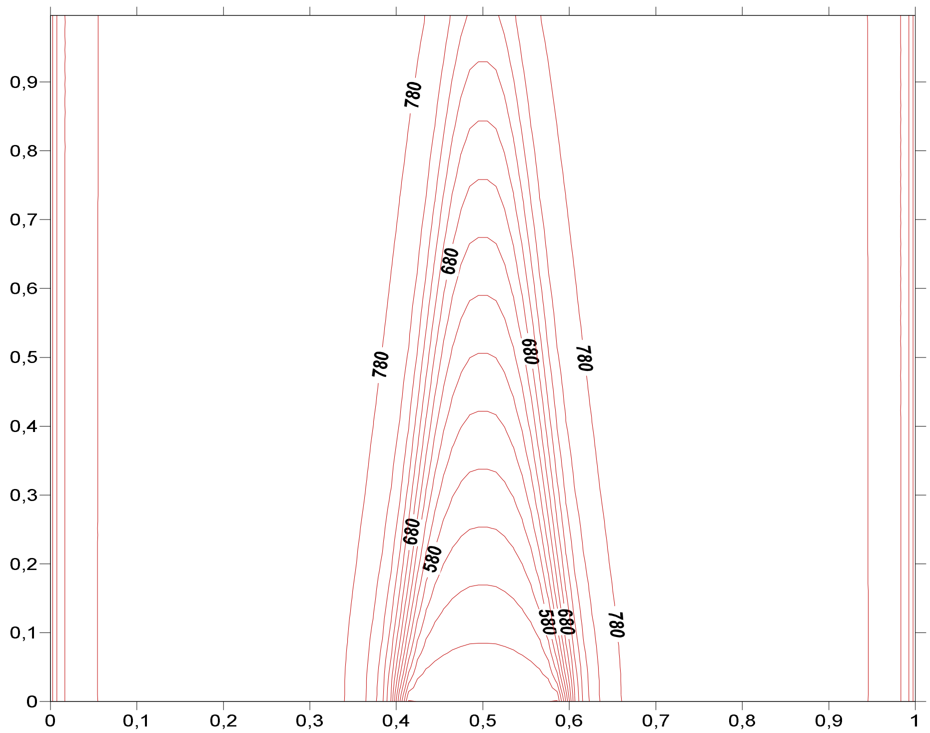


**Fig. 2. Isotherms when Re=500 [16]**

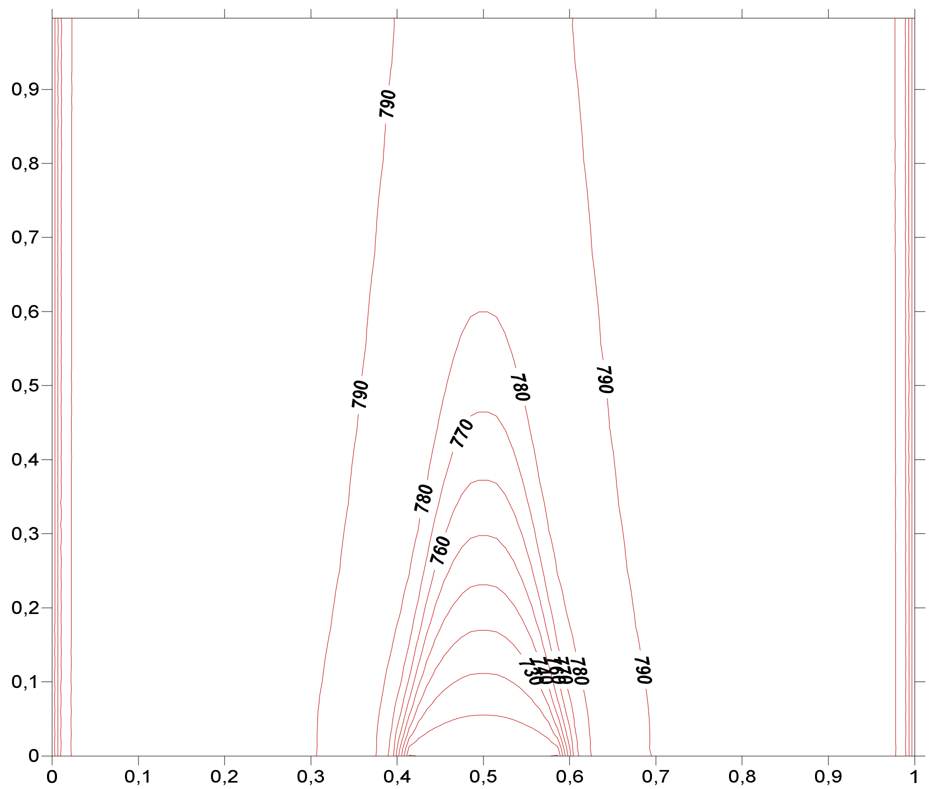


**Fig. 3. Isotherms when Re=750 [16]**

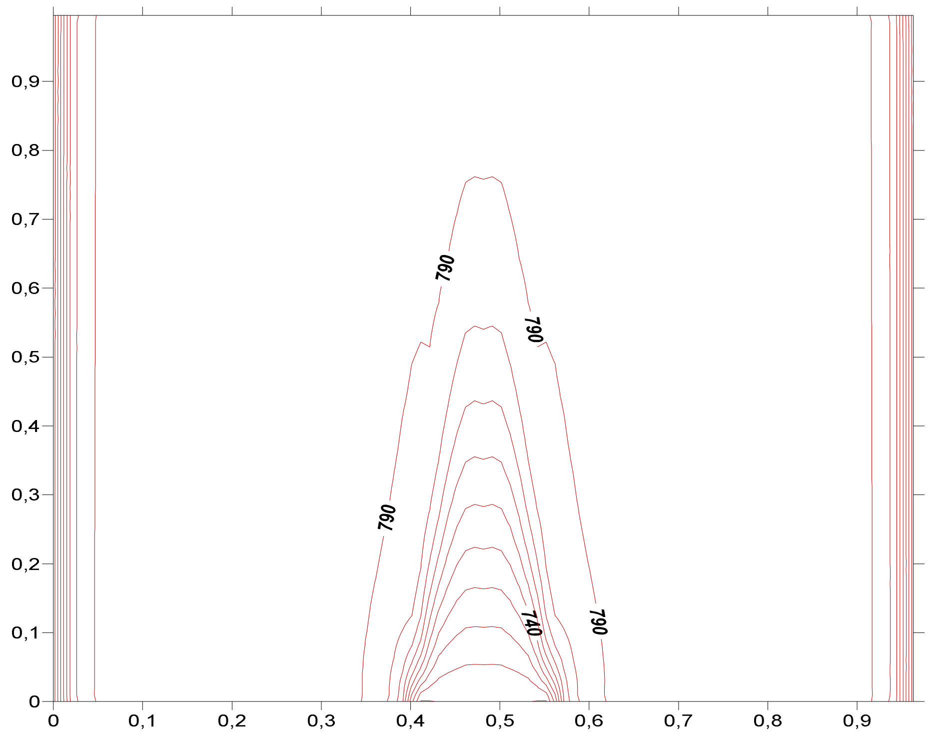


**Fig. 4. Isotherms when Re=1000 [16]**

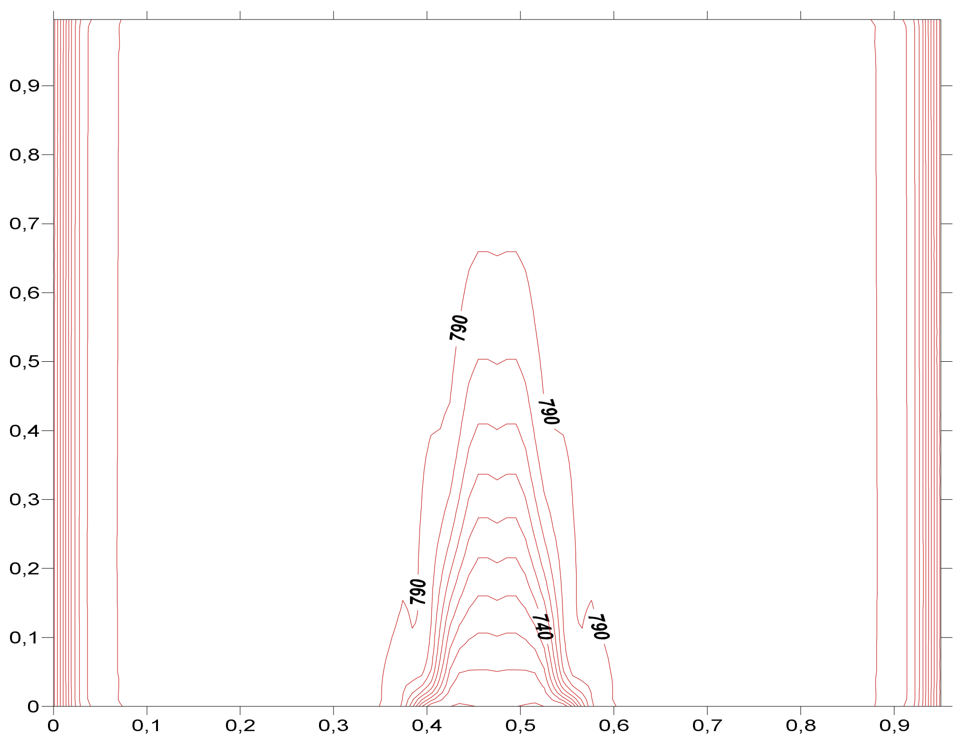


**Fig. 5. Isotherms when Re=1250 [16]**

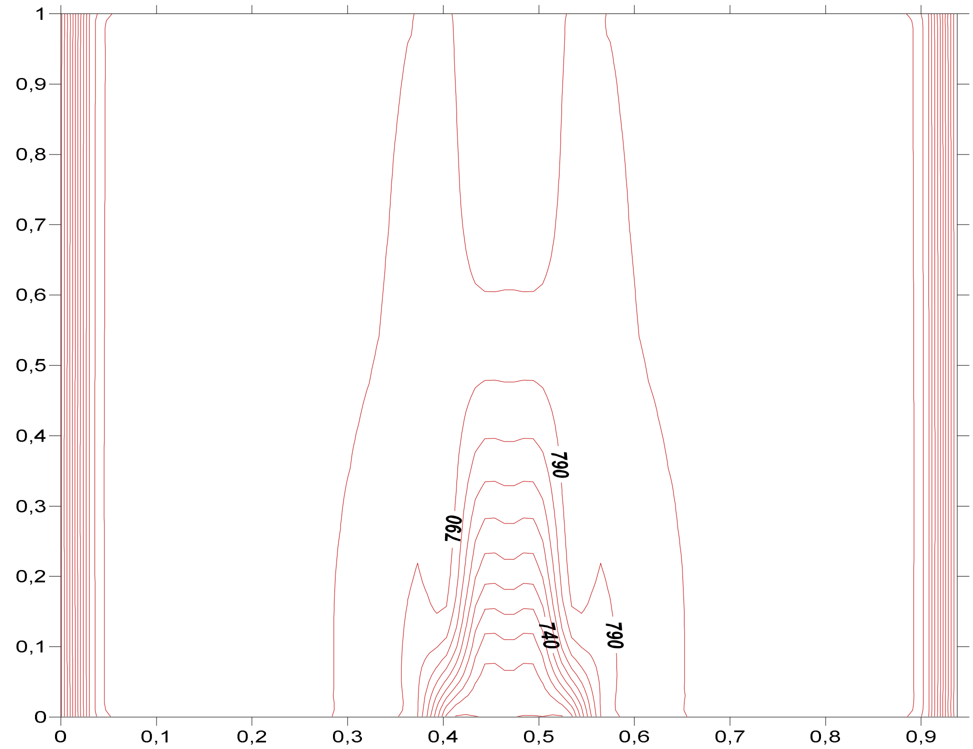


**Fig. 6. Isotherms when Re=1500 [16]**

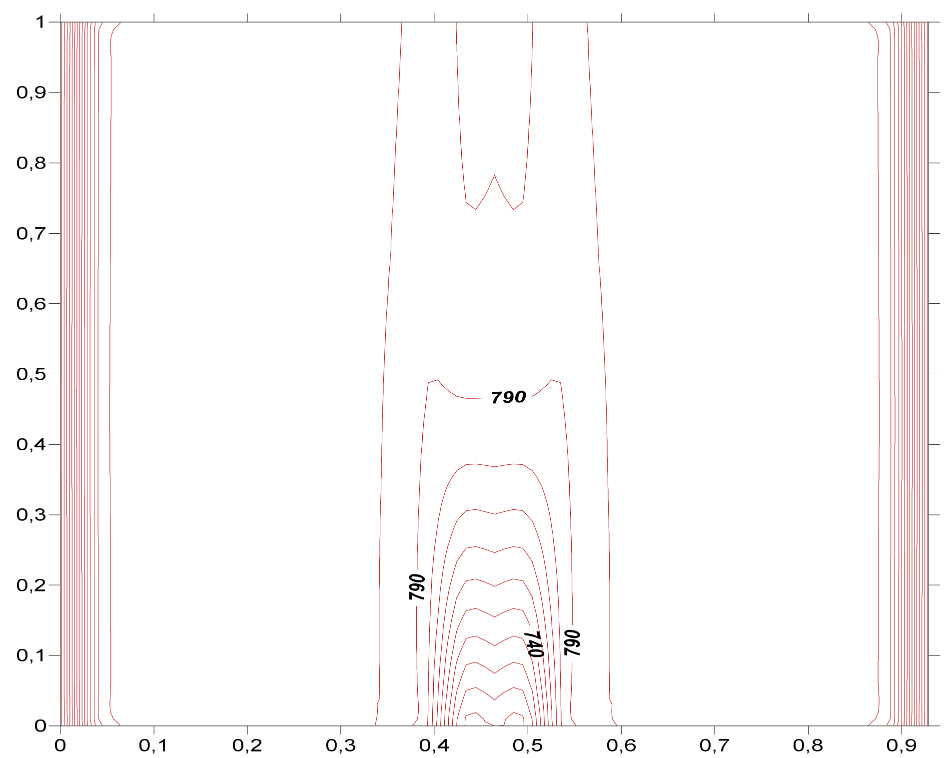


**Fig. 7. Isotherms with Re=1750 [16]**

We notice that with this Reynolds number, although isotherms are the halfway down the incinerator, there is one that reaches the exit and another that goes from the exit to close on it. However, around the walls, there is a real intensification of lines that get much closer. The minimal value of isotherm is always 690 K while the highest values are 940 K with a space of 10 K.

The organization of isotherms in median plane is similar to that when Re = 1,500. Around the walls, the number of lines is higher and they are much more closed up. The combustion occurs most in this part of the incinerator than in the others. The thermal use of heat should be based on this part of the incinerator. The minimum value of isotherms is 690 K while the highest values are 960 K, with a space of 10 K.

Since we notice that combustion occurs near the walls, it would be interesting to study the evolution of the temperature of the inner walls over time. The figure below gives the evolution of the temperature of the inner wall over time and Reynolds numbers used in this study.

Results (Figs. 2 to 7) clearly show that combustion occurring near the incinerator sides is found in literature [17]. Indeed, Palm et al have conducted thermal studies on various types of incineration that show the location of flames during this type of process.

Fig. 8 gives an almost vertical evolution of temperature in less than one second before evolving toward a horizontal asymptotic line. When the Reynolds number reaches or exceeds 1,000, the temperatures on this wall may go beyond 900 K. With these high temperatures, a pipe made of good heat conductive material will enable to send a great amount of heat to the coolant that is there. This coiled piping must be placed directly against the inner wall of the incinerator to absorb a large amount of energy.

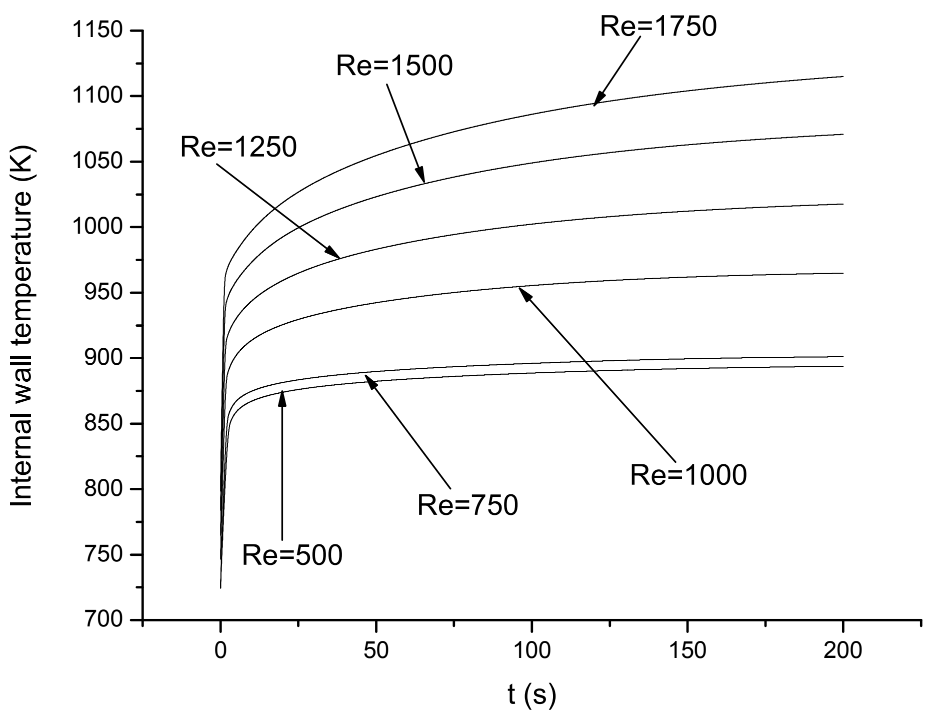


**Fig. 8. Evolution of the temperature of the internal wall for various Reynolds numbers to Z=0.25 m [16]**

## 5. CONCLUSION

We equated this incineration phenomenon of smokes generated by the combustion of household wastes in laminar regime using the Navier-Stokes equation and those on energy and the dissemination of species included in smokes. The discretization of these equations using an implicit method with finite differences leads to algebraic equations we solved with Gauss' algorithm for the equation of motion, and Thomas' algorithm for the other equations. We associate them with a model of overall kinetics and the equation of radiative transfer in the incinerator. Thermal results (isothermal and temperature of the inner walls) of the phenomenon for Reynolds numbers that range between 500 and 1,750 show that combustion occurs near the internal walls where temperatures exceed 900 K for Reynolds numbers higher than or equal to 1,000. The thermal use of the incinerator should be done near these walls where they would circulate a coolant through coils to recover a significant quantity of heat.

However, literature provides other types of thermal studies on incineration [18]. The particularity of our study is on the incineration of gaseous effluents derived from the carbonization of household wastes [8]. Our study implies the association of two incinerators: one to burn household wastes and the other to burn smokes from this carbonization. PhD research works focused on the second incinerator [8] led us to conduct a thermal study on it.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Cointreau JS, Environnemental Managment of Urban Solid Wastes in Developing Countries. Washington D.C: The World Bank, Technical Paper Number. 1982;5:210.
2. ADEME, Wastes collect and treatment; 1996.
3. Rogaume T, Auzanneau M, Jabouille F, Goudeau JC, Torero JL. The effects of different airflows on the formation of pollutants during waste Incineration. Fuel. 2002;81:2277–2288.
4. Kalifa Palm, Serge W Igo, Inoussa Zongo, Kokou N'Wuitcha, Alioune Ouédraogo, Belkacem Zeghmati. Thermo-destruction of atmospheric effluents resulting from household wastes carbonization. Journal of Applied Sciences. 2011;11(19):3362-3371. ISSN 1812-5654/DOI: 10.3923/jas. 2011.3362.3371.
5. Logan S. Introduction to chemical kinetics. Dunod Chemistry Editions; 1998.
6. Antoine Beylot, Jacques Villeneuve Environmental impacts of residual Municipal Solid Waste incineration: A comparison of 110 French incinerators using a life cycle approach. Waste Management. 2013;08.
7. Clive Brereton. Municipal solid waste - incineration, air pollution control and ash management. Resources, Conservation and Recycling. 1996;16:227-264.
8. K Palm. Modeling of a thermo-destruction process of gaseous effluents resulting from the combustion of household wastes. PhD Thesis, University of Perpignan Via Domicia, France; 2008.
9. Kalifa Palm, Serge W Igo, Inoussa Zongo, N'Wuitcha Kokou, Alioune Ouedraogo, Belkacem Zeghmat Thermo-destruction of Atmospheric Effluents Resulting from Household Wastes Carbonization Journal of Applied Sciences. 2011;11(19):3362-3371.
10. Esposito E. Combustion in gaseous pre-mixture. Ingineer Technique. 1995;B8: 31511.
11. Zhou X, Brenner G, Weber T, Durst F. Finite-rate chemistry in modeling of two-dimensional jet premixed CH4/air flame. International Journal of Heat and Mass Transfer. 2003;46:3841-3851.
12. Oturan MA, Robert M. Chemical Thermodynamics Grenoble University Press; 1997.
13. Bergeron CA, Hallet WLH. Autoignition of single droplets of two-component liquid fuels Science and Technique. 1989;65:181-194.
14. Méchi R, Farhat H, Radhouani MS. Modeling of radiative transfers in an incinerator with the release of pollutants from wood pyrolysis. International Journal of Thermal Sciences. 2004;43:697-708.
15. Olsommer B, Von Spakovsky M, Favrat D. Radiation-based heat transfer in an industrial incineration furnace: Use of area method. General Review of Thermics. 1997;36:125-134.

16. N'wuitcha K, Palm K, Igo SW, Atchonouglo K, Ndiho A, Ouedraogo I, Banna M, Zeghmati B. Contribution to environmental protection by reducing pollutants emissions during municipal solid wastes incineration. International Journal of Scientific & Technology Research. 2014;3:1. ISSN 2277- 8616.
17. Palm K, Ouédraogo A, Ouédraogo I, Chesneau X, Zeghmati B. The flue gases cleaning. Modelling of fumes thermo destruction in a cylindrical Incinerator. International Scientific Journal for Alternative Energy and Ecology. 2010;5:85.
18. Takahiro Murakami, Yoshizo Suzuki, Hidekazu Nagasawa, Takafumi Yamamoto, Takami Koseki, Hitoshi Hirose, Seiichiro Okamoto. Combustion characteristics of sewage sludge in an incineration plant for energy recovery. Fuel Processing Technology. 2009;90:778–783.



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