HEAT DISTRIBUTIONS IN A TRANSIENT DRY-RUN DISTILLATION REACTOR

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ABSTRACT

The transient behaviour of the dry distillation reactor has been achieved. The continuous studies were approached by considering two methods: Special homogenization method which is based on averaging and the numerical method based on the calculation of the eigenvalues of the Jacobian matrix. The latter are derived from the derivation of heat with respect to reactor size and time. The study under boundary conditions gives us the heat distribution: radial and axial distribution. The effect of temperature from the wall was studied as a function of time, so the influence of time was considered.

Keyword: *dry-process distillation, reactor, homogenization, heat distribution*

1. INTRODUCTION

Distillation is one of the most important separation methods available for resolving a mixture into its various constituents. It is based on the fact that a vapour phase surmounting a boiling liquid and in equilibrium with it does not have the same composition. By separately collecting the liquid on the one hand and the vapour on the other, which is cooled and condensed, two different liquids are obtained, called residue and condensate or distillate respectively. An elementary separation step is thus carried out, the repetition of which may make it possible to obtain the constituents of the initial mixture.

Dry distillation or solid distillation is a process to purify a solid or to separate it into its different constituents. This method generally requires higher temperatures (at atmospheric pressure) than liquid distillation.

The purpose of this research work is to determine the heat distribution in a dry process reactor designed at the laboratory level.

Chemical reactors are of both industrial and laboratory importance. In fact, continuous dry-process distillation reactors have a significant place in this field, and their study has been widely covered in the literature (J. B. Rawlings , 2002 and S. Li, 1994).
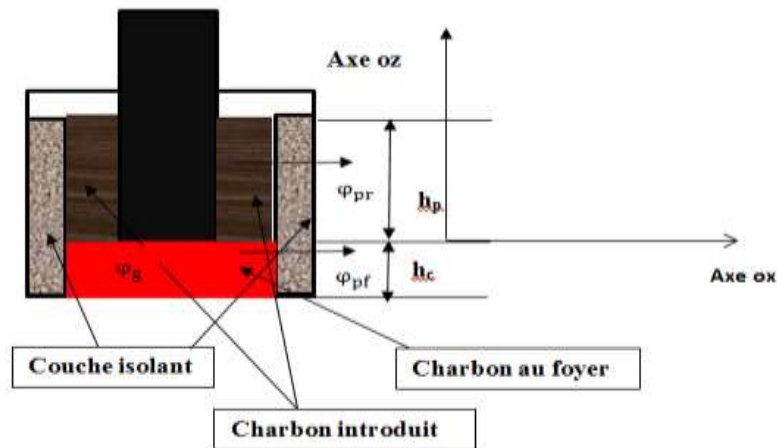
Figure 1: Representation of the system

We consider the reactor (Figure 01) to be in a transient state. We are in the presence of a highly heterogeneous three-dimensional domain with a large variation in thermo-physical parameters from one region to another and with space scales ranging from 0.4m to 0.005m.
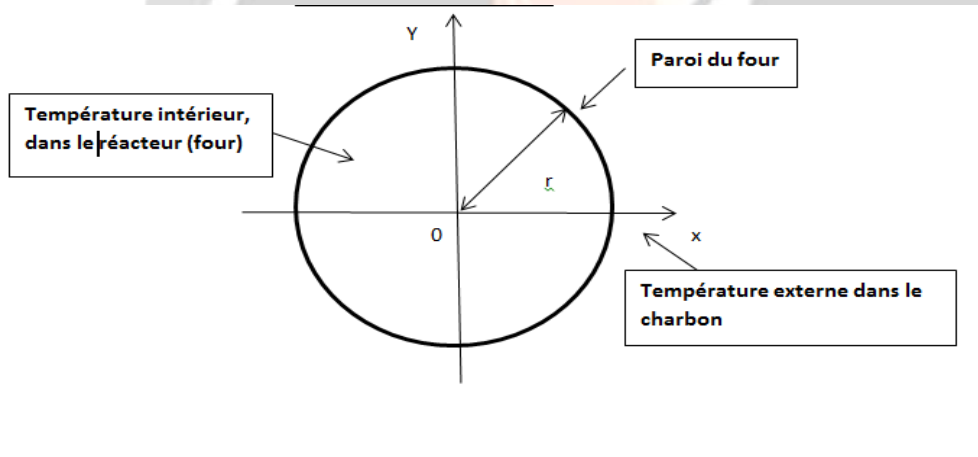

Figure 2: Axial representation of the system

In addition, the boundary conditions of the conduction problem (Figure 02) show singularities that may distort the flow and temperature calculations. The global exchange coefficient h will therefore be deducted from the estimated exchange coefficient according to Garamoon (2009) which gives a justification of the approach.

2. METHODOLOGIES

Temperature rises and falls are studied at different points in the dry process reactor. Whatever the coal feed and the reagent (here defatted bone) used, the temperature at the reagent level evolves according to a first-order model. The energy of combustion is the product of the mass of substance and its calorific value. Lower calorific value LCV: represents the energy released by the complete combustion of one kg or one m3 of fuel, the water being produced in the vapour state (unit kJ.kg-1 or kJ.m3 depending on whether the fuel is gaseous or not).

$$Q = q_c . m \quad (01)$$

q_c : Calorific value of fuel

m: fuel mass

$$\varphi_g = \frac{dQ}{dt} \qquad (02)$$

$\varphi_{g =}$ bulk energy density

2.1. Transitional regime

Heat flows under the influence of a temperature gradient from high to low temperatures. The amount of heat transmitted per unit time and per unit area of the isothermal surface is called the heat flux density, the general equation for heat in the furnace gives us :

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q}{\lambda} = \frac{1}{a}\frac{\partial T}{\partial t} \qquad (03)$$

The report $a = \dfrac{\lambda}{\rho c}$ is called the thermal diffusivity (m2.s-1) which characterizes the speed of propagation of a heat flow through a medium (spatial homogenization).

2.2. Temperature as a function of time

$$\begin{cases} \dfrac{q}{\lambda_c} = \dfrac{1}{a_c}\dfrac{\partial T}{\partial t} \\ T(0) = T_0, \\ T(t) \le T_{mc} \end{cases} \qquad (04)$$

2.3. Temperature as a function of Z

In this problem, the unidirectional transfer along the OZ axis is considered to be the internal heat source at the bottom. We can see that at the raw material tube there is no heat source (no energy generation), so: q =0. However, the energy balance is written in the form according to (03):

:

$$\frac{\partial^2 T}{\partial^2 z} = \frac{1}{a}\frac{\partial T}{\partial t} \qquad (05)$$

The reactor and the raw material are considered to have different thermal diffusivity. Finally, we have the following system:

$$\begin{cases} \dfrac{\partial^2 T}{\partial^2 z} = \dfrac{1}{a_r}\dfrac{\partial T}{\partial t}, 0 \le z \le h_p \\ \\ T(z,0) = T_0 \end{cases} \qquad (06)$$

2.4. Radiale

The problem is now governed by the following heat equation:

$$\frac{\partial^2 T}{\partial x^2} = \frac{\partial^2 T}{\partial y^2} = 0 \qquad (07)$$

The heat equation in polar coordinates gives:

$$\frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} = 0 \qquad (08)$$

2.5. Digital resolution

To simplify the resolution, a multi-group discretization of energy is made and it consists in breaking down the energy domain into several intervals. We will consider the heat equations 04, 06 and 08. For the resolution, the following steps are followed:

- Initialization of parameters (x, y, T, WS,i ,j and k)
  WS: energy flow coefficient
- Calculation of WS(x,y, k)

$$W(x,y) = \frac{2}{\pi}\sum_n \frac{2}{n}\sin\left(\frac{n\pi x}{L}\right)\frac{\sinh(\frac{n\pi y}{L})}{\sinh(\frac{n\pi D}{L})}$$

  D : furnace diameter
  L : Height of the oven
- Calcul de T(x,y,i).

$$T(x,y) = (T_f - T_i)w(x,y) + T_i$$

- Generation of the thermal matrix M(x,y,j)

$$M(x,y) = \sum_{j=1}^{k}((T(x,y),k)$$

- Verification of convergences according to i, j and k
- Numerical simulation and exploitation of results.

3. RESULTS

We applied conditions to the internal and external boundaries. The source term is the heat from the coal. The domain is meshed with 2000 points.

3.1. Simulation parameters

It is of paramount importance to specify the operating conditions and the various parameters of the continuous reactor (Table 1 and Table 2).

Table 01: Reactor Parameters

Dimension	Valeur (m)
H	$4.\,10^{-1}$
D	$1{,}5.\,10^{-2}$
e	$5.\,10^{-3}$

Table 02: Operating condition

Parameters	Temperature en °C
T (ext)	200
T (int)	60
T(foyer)	300

The thermodynamic properties are listed in Table 3. For calculation and simulation purposes, it must be assumed that the heat capacities are not dependent on temperature.

Table 3: Thermodynamic parameters

Materials	Cp (JK^{-1}C^{-1})	Lam (Wm^{-1}C^{-1})
Air	F(P)	F(T)

Eau	F(P)	F(T)
Os	930	0.21
Steel	465	54

3.2. Temperature as a function of time (T=f(t))
Figure 3, shows the temporal evolution of the temperature in the oven. It can be seen that the temperature rises to a steady state after approximately 150 min.
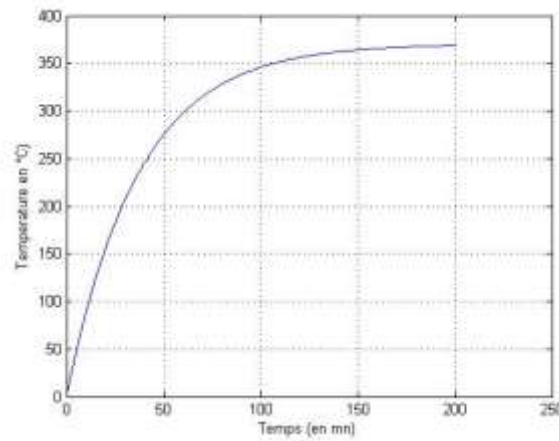

Figure 3: Temperature rises observed at different points of the reactor

At the first moments, we can consider that the temperature increases linearly as shown in Figure 03. The temperature rise of the system is here 0.772°C.min-1.

3.3. Axial temperature as a function of r (T=f(x,y) or T=f(r))
Figure 4 shows a zoom of the isotherms at the outer limits. These results thus show that the convective transfer can be considered to be effectively one-dimensional and radial.
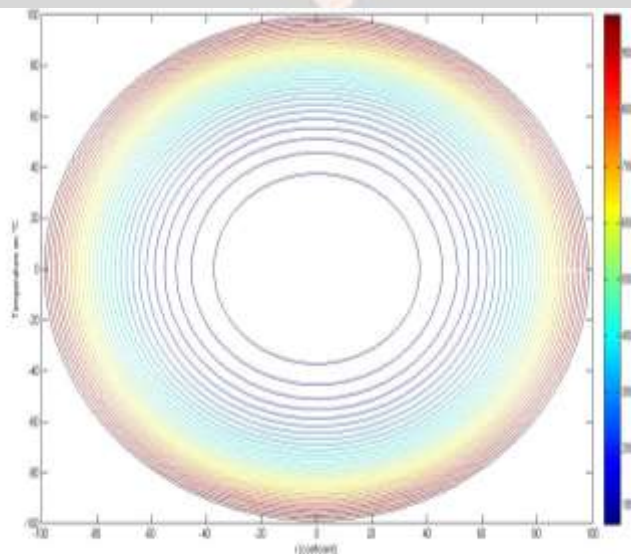

Figure 4: Axial temperature observed in the reactor

3.4. Radial temperature as a function of z (T=f(x,z) or T=f(z))

Figure 5 shows the longitudinal and radial temperature profiles. The radial gradient is large as would be expected for a very dense reagent.
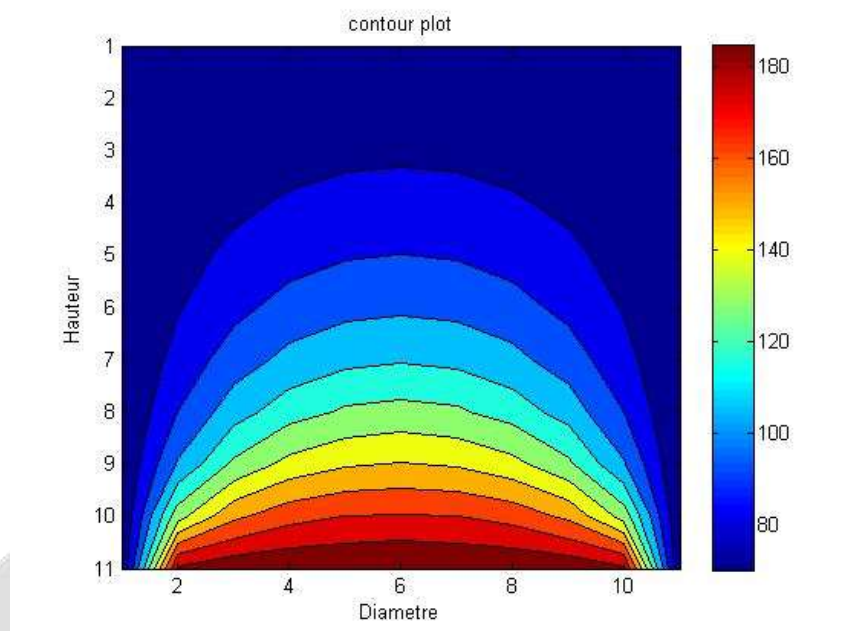

Figure 5: Radial temperature observed in the reactor

4. DISCUSSION AND CONCLUSION

The temperatures calculated at different points increase with time until a stationary state is reached. Figure 03 shows the temperature rises obtained at different points in the reactor.

A discussion on the consideration of the source term related to the thermal power generated is first taken into account as the power will increase from the 4h. The proposed two-dimensional thermal model offers the representation of the heat, but it can also estimate the overall thermal coefficient of the system (Radiation, conduction and convection) with the properties of the reagent.

Numerical resolution was performed using a method adapted to the geometries and calculation of the Jacobian matrix under MATLAB. This numerical study will make it possible in particular to estimate the exchange coefficients by natural convection outside the reactor as well as the fraction of the thermal energy that is evacuated by thermal losses.

5. REFERENCES

[1] [Garamoon, 2009] A. A. Garamoon, F. F. Elakshar, M. Elsawah, Optimizations of ozone generator at low resonance frequency, *Eur. Phys. J. Appl. Phys.*, 48, 21002 (2009)

[2] [J. B. Rawlings and J. G. Ekerdt], *Chemical Reactor Analysis and Design Fundamentals*. Nob Hill Publishing, 2002.

[3] R. S. Li, "Continuous flow stirred tank reactor with two inflows reactants: a versatile tool for study of bifurcation in chemical systems," *Chem. Engng Sci.*, vol. 49, p. 2029, 1994