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## THERMAL STUDY OF TRANSFER IN AN EXCHANGER MADE UP OF TWO CYLINDRICAL TUBES PLACED IN A CLOSED ENCLOSURE

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### SUMMARY

An experimental study is made to determine the thermal output by convection and radiation inside a closed enclosure, crossed by two cylindrical tubes. The objective of this study is to determine the quantity of energy necessary, then to model it for current applications (drying, solar collectors etc.). A quantity of dry biomass is burned in two interdependent hearths with two cylindrical tubes which crosses a closed enclosure. The determination of the quantity of energy emitted by radiation and convection in the closed enclosure and which constitutes the useful energy in the case of drying, accounts for 33% of the natural energy contained in the fuel (wood).

**Keywords:** Thermal transfer, combustible, cylindrical tubes, convection and radiation.

### 1. INTRODUCTION

The optimization of the heat balance of an energy converter depends on the control which one can have on primarily radiative heat exchange and convectifs [1]. If the assumption of an isothermal hot surface makes it possible to correctly consider the total importance of the thermal transfers of convective and radiative origin inside an enclosure, the taking into account of the distribution of the temperatures of this surface is essential for the control and the evaluation of the various heat flows emitted. Whatever its use, a heat exchanger cannot function constantly in steady operation. Transitional stages intervene in particular for the period of startup or stop of the system [2]. Varied modes are to be considered since a flow or an inlet temperature varies in the course of time. Substantial increases in transfer of heat are due to the increase in turbulence [3]. In order to better

evaluate the quantity of energy transmitted in the enclosure by the exchanger, we put forth the following assumptions.

- The flow of energy brought into play comes from the radiative transfer of the exchangers and the natural convection around the exchangers.
- The fuel (wood) has a constant water content
- The phenomena of thermal inertia relating to the air and the thermal losses in the pipes of connection are negligible.
- The mode of the flow of smoke in the pipe is turbulent and the flow rate of is constant [ 4 ].
- The air is transparent with the infra-red radiation.
- The inlet temperature of the smoke in the pipe are identical to each period of introduction of wood into the hearths.
- The properties of the air and smoke are appreciably equal.
- The phenomena of flow are identical in the two pipes.

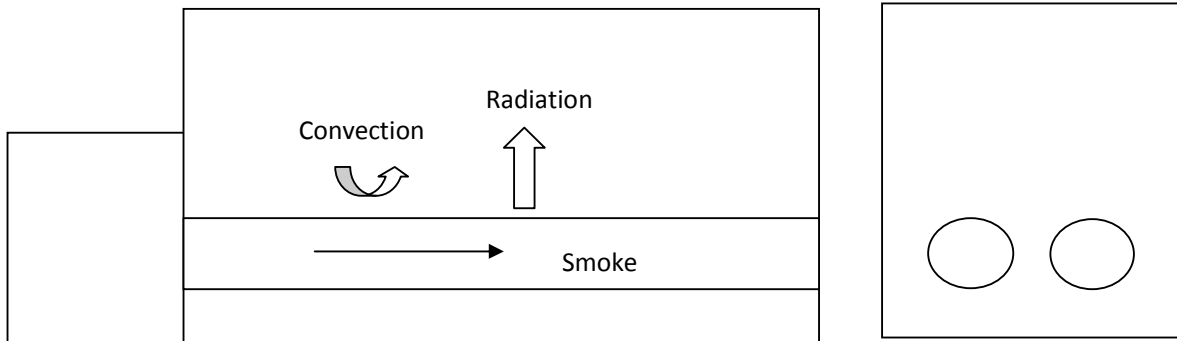
## **2. MATERIAL AND METHOD**

### **2.1. Material**

The closed enclosure, of dimension 3 m X 2 m X 1,2 m, is built in small ground bricks of 22 cm X 11 cm X 6,5 cm. It is the framework of a drier. Each heat exchanger consists of two galvanized steel pipes of external diameter 134mm and internal diameter 125mm. Each pipe measures 3m length. One of the ends of the pipe emerges in the hearth and the other closed end, allows the drain of smoke in the chimney of racking (figure 1). The material used for measurements consists of a mechanical balance (spring balance) of maximum loading of 10 kg and which is used to weigh wood in heaps of 1, 2, 4, and 6 kg. An electronic thermometer makes it possible to measure the temperatures of smoke inside the pipes and on surfaces of the pipe through the thermocouple. The temperature in the enclosure is measured by a thermocouple. A ventilated drying oven [ 5 ] is used to determine the anhydrous mass of wood. An electronic balance Sartorius is used for the measurement of the losses of mass of wood during the determination of the anhydrous mass. Type K thermocouples makes it possible to measure the temperature of the smoke, of the surface of pipe and the enclosure. An electronic chronometer makes it possible to follow the evolution of the various parameters in time.

### **2.2. Experimental method**

The wood beforehand was weighed and put in heaps and introduced in equal quantity into the two hearths. The various temperatures and the air velocity at the entry are recorded with regular interval (15 to 20 min). As soon as the temperatures in the enclosure drops up to 55 °C, the two hearths are in charge of the same quantity of wood as previously and the cycle starts again. The same experimental procedure is taken again for several flow rates of wood. The temperature measurement of the smoke is made on only one pipe. In parallel, a sample of wood is put in the drying ventilated oven to determine its anhydrous mass in order to deduce the water content of wood.



**Figure 1:** Cut in length and width of the device with the modes of transfers

### 3. RESULTS AND DISCUSSION

#### 3.1. Water content of wood

The water content (wet base) of wood obtained is 22.7 %. This result is used to determine the potential energy of wood.

#### 3.2. Heat balance of the enclosure

The knowledge of the thermophysical properties of some materials used in the construction of device is necessary to establish an energy balance. Table 1 presents these properties for materials used where  $\rho$  is the density,  $\lambda$  thermal conductivity and  $\epsilon$  the coefficient of emission.

**Table 1: properties of materials**

Materials	$\lambda(\text{W/m}^\circ\text{C})$	$\rho(\text{kg/m}^3)$	$\epsilon$
Galvanized steel	43.3	7805	0.81
Ground brick	1.15	1800	-
Coconut fiber or sawdust of wood	0.059	-	-
plexiglass	0.78	2700	-
Concrete	0.76	-	-

The tests made it possible to obtain the average temperature exchanger and values at the various points in the device. These values are consigned in table 2 where  $\theta_{ef}$  is the average temperature of smoke at the entry of the pipe,  $\theta_f$  the average temperature of smoke inside the pipe,  $\theta_{sf}$  the average temperature of smoke at the outlet side of the exchanger,  $\theta$  the average temperature of the exchanger,  $\theta_{ai}$  the average temperature of the air in the enclosure,  $\theta_{pi}$  the average internal temperature of the walls of the enclosure and  $\theta_{am}$  the ambient temperature.

**Table 2: Average temperatures at the various points of the enclosure**

Flow rate of wood (kg/h)	Temperatures (°C)						
	$\theta_{ef}$	$\theta_f$	$\theta_{sf}$	$\theta_{se}$	$\theta_{ai}$	$\theta_{pi}$	$\theta_{am}$
2.7	236	183	143	113	65	49	32
4	382	284	197	138	70	56	31
6	429	327	175	234	74	63	30

The values of table 2 are used to determine the thermophysical properties of the air or smoke which will make it possible to calculate the various coefficients of heat exchange. The higher calorific value of wood lies between 18 and 22 MJ/kg [6]. The water content of wood used, measured at the laboratory, is 22.7% wet base. The lower calorific value of wood ( $P_{Ci}$ ) is equal to 2800 kcal/kg [6].

### 3.2.1. Exchange by convection

The energy flow exchanged by convection between the pipe and the air in the enclosure is determined by:

$$\varphi_c = 2.h.S (\theta_c - \theta_a) \quad (1)$$

where  $\varphi_c$  is the energy flow exchanged by convection, h the coefficient of exchange by convection, S the heat-transferring surface,  $\theta_c$  and  $\theta_a$  the temperature of the exchanger and air in the enclosure respectively. The coefficient h, in the case of a natural convection, is determined by the following correlations of Mac Adam [7, 8]

$$Pr = \frac{c_p}{\lambda} \mu \quad (\text{Number of Prandtl}) \quad (2)$$

$$Gr = \frac{\beta g \Delta \theta \rho_2 D^3}{\mu_2} \quad (\text{Number of Grashof}) \quad (3)$$

$$Nu = C.(Gr.Pr)^m \quad (\text{number of Nusselt}) \quad (4)$$

$$h = \frac{\lambda Nu}{D} \quad (5)$$

C and m vary according to  $(Gr.Pr)$ . Taking into account dimensions of the exchanger, the value of h is estimated at  $6 \text{ W/m}^2 \text{ } ^\circ\text{C}$  and the equation (1) becomes:

$$\varphi_c = 14,4.( \theta_c - \theta_a) \quad (6)$$

### 3.2.2. Exchange by radiation

The flow exchanged by radiation is determined by the correlation:

$$\varphi_r = 2 \cdot \epsilon \cdot \sigma \cdot S \cdot ((\theta_c + 273,18)^4 - (\theta_a + 273,18)^4) \quad [9] \quad (7)$$

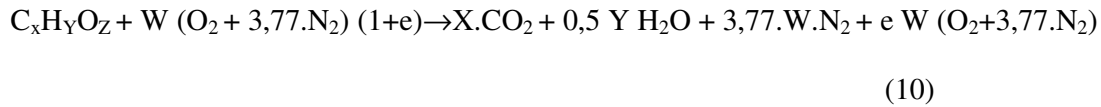
where  $\epsilon$  is the coefficient of emission of the pipe and  $\sigma = 5,675E-8 \text{ W}\cdot\text{m}^{-2}\cdot\text{°K}^{-4}$ . The equation (7) becomes.

$$\varphi_r = 11 \cdot (((\theta_c + 273,15)/100)^4 - ((\theta_a + 273,15)/100)^4) \quad (8)$$

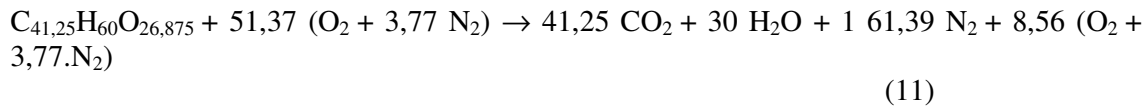
$$\text{The total energy flow received by the enclosure is: } \varphi_t = \varphi_r + \varphi_c \quad (9)$$

### 3.2.3. Energy flows resulting from combustion

We make the assumption that combustion is done with an excess of 20% of air (value generally advised in the literature). By neglecting the presence of nitrogen in wood, the equation of combustion is given in the following general form.



Where  $e$  represents the excess of air ( $e = 0,2$ ). By taking account of the constitution of wood, the equation (10) becomes.



The smoke-producing capacity (PF) deduced from the equation (11) is of  $6,125 \text{ Nm}^3 / \text{kg}$  of wood. The energy flow transmitted by smoke through the exchanger is determined by the expression.

$$\varphi_f = 2 \cdot m_f C_{pf} (\theta_e - \theta_s) \quad (12)$$

where  $\theta_e$  (°C) and  $\theta_s$  (°C) are respectively the temperatures at the entry and the outlet side of the exchanger,  $m_f$  (kg/s) is mass flow of smoke,  $C_{pf}$  ( $\text{J}\cdot\text{kg}^{-1}\cdot\text{°C}^{-1}$ ) is heat-storage capacity of smoke.

Mass flow of smoke at the temperature  $\theta$  is determined by the following equation.

$$m_f = \frac{D_b \cdot PF \cdot \left( \frac{\theta + 273,15}{273,15} \right)^{\rho\theta}}{3600} \quad (13)$$

where  $D_b$  (kg/h) is the flow rate of wood, and  $\rho_\theta$  is density of smoke at the temperature  $\theta$ .

The energy flow transmitted by smoke to the environment (smoked loss) is determined by the expression below.

$$\phi_{pf} = 2.m_f C_{pf} (\theta_s - \theta_{am}) \quad (14)$$

where  $\theta_{am}$  is the temperature of the environment. The potential energy ( $Q_b$ ) of the wood is determined by the equation below.

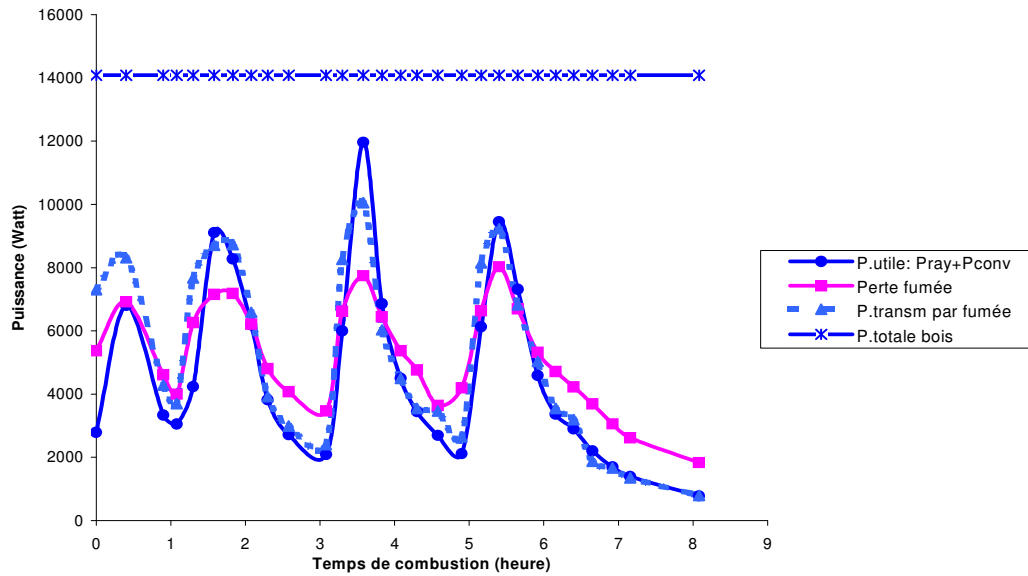
$$Q_b = P_{ci} \cdot (1 - X_b) - L_v \cdot X_b \quad (15)$$

$L_v$  (J/kg) and  $X_b$  (%) are respectively the latent heat of vaporization of water and the water content of wood. Table 3 presents various energy flows for three flow rate of wood.

**Table 3: Value of various flows of energy for various flow rate of wood**

Flow rate of wood (kg/h)	$\phi_b$ (Watt)	$\phi_f$ (Watt)	$\phi_{pf}$ (Watt)
6	14076	$26,45 \cdot (\theta_e - \theta_s)$	$25,45 \cdot (\theta_s - \theta_{am})$
4	9384	$17,63 \cdot (\theta_e - \theta_s)$	$15,85 \cdot (\theta_s - \theta_{am})$
2.7	6334	$11,6 \cdot (\theta_e - \theta_s)$	$15,85 \cdot (\theta_s - \theta_{am})$

$\phi_b$  is the potential energy flow of wood. The variations of energy flows for various flow rate of wood are represented on figures 2 a, b and c. The various curves show that the useful energy flow transmitted by smoke in the enclosure is equal to the sum of the energy flow radiated by the exchanger and the energy flow transmitted by convection.



**Figure 2 a: Variation of various energy flows for a wood flow rate of 6 kg/h**

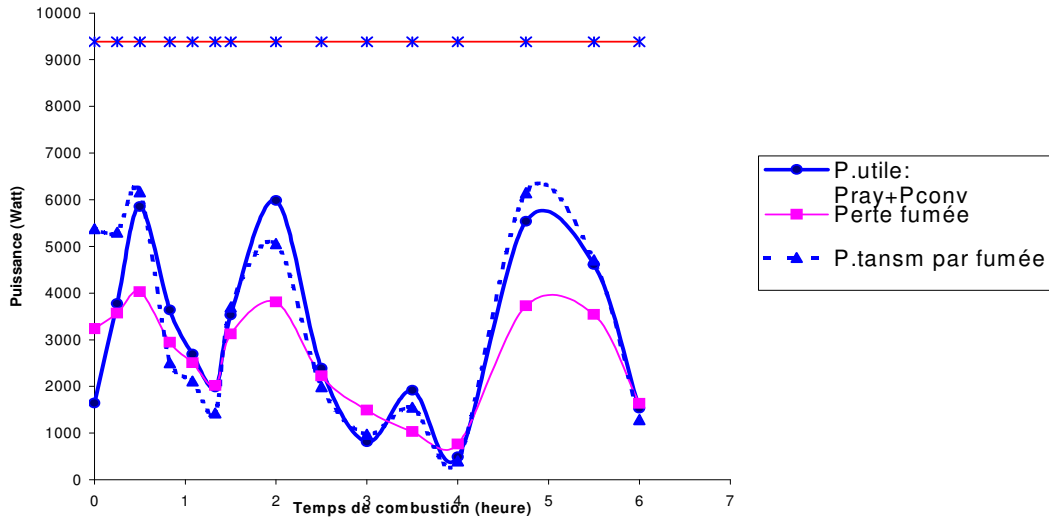


Figure 2 b: Variation of various energy flows for a wood flow rate of 4 kg/h

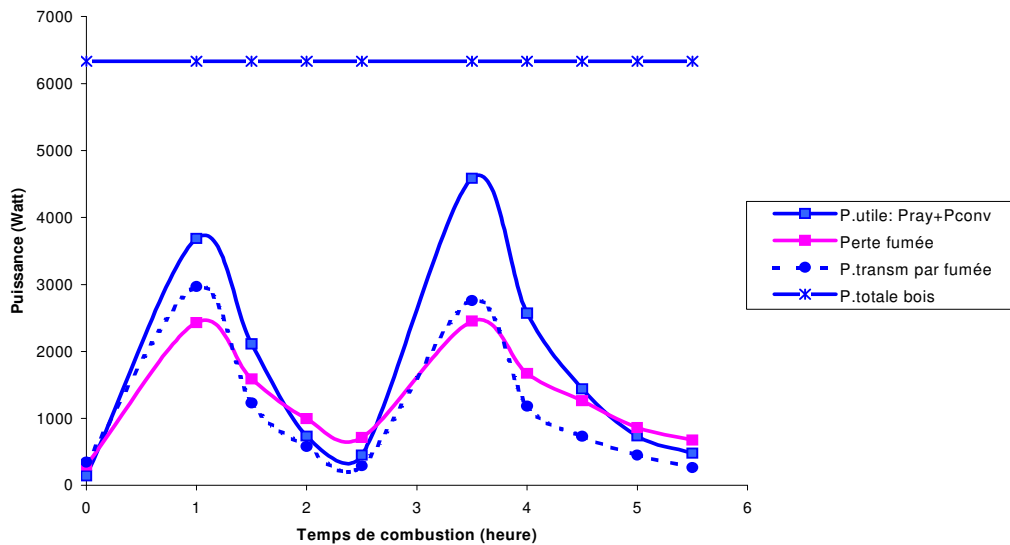


Figure 2 b: Variation of various energy flows for a wood flow rate of 2.7 kg/h

The flow of energy transmitted by smoke in the enclosure is equal to the sum of the power transmitted in the enclosure by radiation of the exchanger and the power exchanged by natural convection between the exchanger and the enclosure. Figure 3 presents a mathematical model of the useful output for a wood flow rate of 6 kg/h.

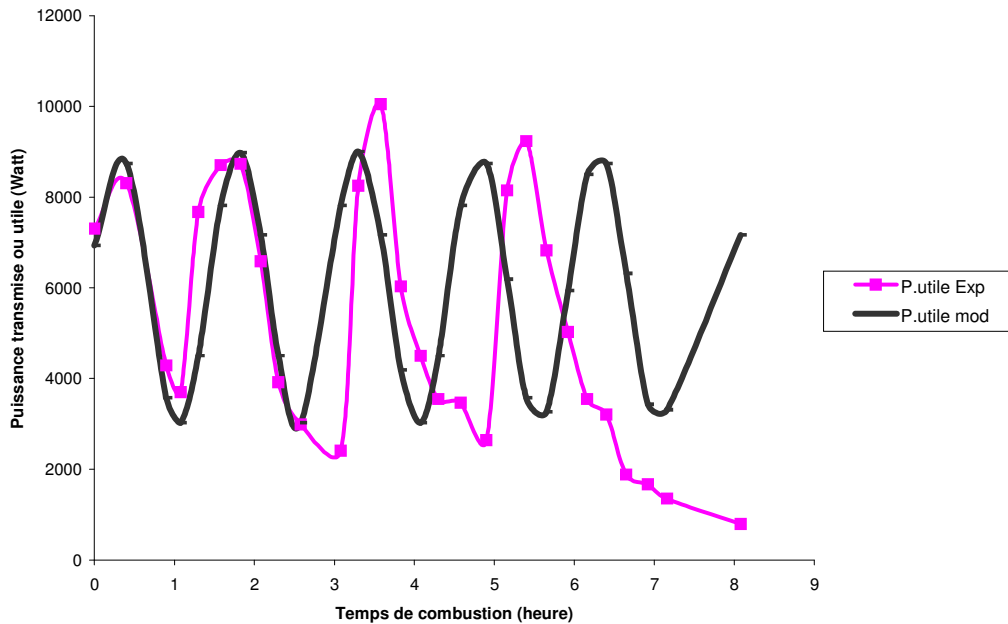


Figure 3: Modeling of the useful output for a wood flow rate of 6 kg/h

### 3.2.4. Thermal efficiency of the exchanger

If  $\varphi(t)$  is the energy flow transmitted by a source to a environment. During a time T, total energy Q is determined by:

$$Q = \int_0^T \varphi(t) dt \quad [10] \quad (16)$$

The total energy transmitted in the enclosure during a time T is deduced from the equations (9) or (12). It is determined by the following equations.

$$Q_t = \int_0^t (\varphi_r + \varphi_c) dt = \int_0^t 2m_f c_{pf} (\theta_e - \theta_s) dt \quad (17)$$

The wood extracted energy during the same time is defined by the formula

$$Q_b = \int_0^t \varphi_b dt \quad (18)$$

where  $\varphi_b$  is the power provided by wood. The thermal efficiency  $\eta$  exchanger is defined by the following formula.

$$\eta = \frac{Q_t}{Q_b} \quad (19)$$

The useful energy is the surface ranging between the curve of the energy flow and the x-axis. The energies deduced from figures 1 a, b, c, are consigned in table 4.

**Table 4: Energy and output for various flows of wood**

Flow rate of wood (kg/h)	$Q_b$ (Méga joules)	$Q_t$ (Méga joules)	$\eta$ (%)
6	354.7	121.5	34.25
4	202.5	68.4	33.8
2.7	125.1	37.6	30.05

#### 4. CONCLUSION

The study of the thermal transfer in a closed enclosure made it possible to determine the various heat flows exchanged in the enclosure and the heat exchanger composed of two galvanized steel pipes. The determination of the useful output or the useful energy by two different methods of calculation made it possible to obtain a thermal efficiency of the exchanger of about 33%. This result can be used for the modeling of the drier in load.

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