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Modeling of Convection in Enclosed Cavity

Abdelhadi BEGHIDJA [1], Hamza GOUIDMI, Razik BENDERRADJI and EL Haj ROUACHE

[1] Laboratoire d'Energie Appliquée et de Pollution
Mechanical Engineering Department, Faculty of Engineering;
Mentouri University, Constantine - ALGERIA -

Abstract: Last years research went numerically and experimentally on the study of the phenomena responsible for the appearance of instabilities in cavity. However, the quantity of numerical results obtained is disproportionate compared to the experimental results in particular in ranges of high Raylegh number. The three-dimensional effect of the flow no foreseeable, due to the boundary conditions generates errors in these calculations. In our work, we will show that, in order to define these convection exchanges, the characteristic temperature difference must absolutely take into consideration the average air temperature in the centre of cavities. We determine a law of exchange which introduces the effect of the other walls constituting the boundary conditions and to determine the level of the instability beginning

Key-words : modelling, thermal exchanges, convection, enclosure, slope

Introduction

The numerical studies have showed their deficiency at least currently, because they cannot provide reliable and consistent results for values of Rayleigh number higher than 10^8 to10^9. This limitation imposes the experimental method to determine the exchanges by convection on the faces of these cavities. Besides, these experimental studies provide a necessary database to validate the numerical techniques to get solutions around this interval of the Rayleigh number.

Many correlations of the Nusselt-Rayleigh type (or Nusselt-Grashoff type) have previously been proposed to characterize exchanges by convection [2,3,4 and 5], on the basis of the temperature difference between the two faces (hot-cold; Ts-Tf). This difference does not take in to account the temperature of the other faces of the cavity which are considered by numerical modellers as adiabatic or submitted to a linear evolution of temperature, and supposed by scientists as being near to the adiabatic conditions.

On the other hand, very few correlations contain the effect of the elongation on the transfer of heat. The correlations proposing an evolution of the type $Ra^{1/3}$ lead to an independence of the exchange coefficient on elongation.

The specificity of our study and our experiences holds on firstly the fact that they relate to two cavities possessing an important height of 2.5 m and complex different elongations (0,81 and 6,3) [1,6,7,8 and 9] secondly the conditions on these faces of cavities can be complex thermal distributions (temperature or flux) , but known with precision. Finally we remedy the problem of the representative temperature difference by the association all faces In the global exchange process.

2. Experimental conditions and description of the two installations

The experimental tests that we did for this study have been achieved in two enclosures of different shapes: the first of approximately cubic shape, is a cavity whose dimensions are equal to those of a dwelling room and the second test cell, of parallelepiped shape and is elongated in the vertical direction. For these two cavities we conceived an original method of a generalized fluxmeter type [6],[9]. This technique permitted us to impose on walls that were divided into in elementary surfaces either a flux, a temperature and to measure. This also allows the control of these quantities; it permits to master the two sizes.

2-1 Description of the cavity :

This cavity of elongated type (height 2.46m, width O.72m and depth O.385rn) has a shape aspect ratio of A=6.3. On the opposite to the preceding enclosure, only one a vertical face (2.46xO.72m) is flux metrical, with 162 independent heating elements distributed in three identical vertical strips each having 54 elements. The readings of temperature are done in the centre of each of the 54 heating elements except for the central strip where one also finds three more finely zones discredited, The first, where we tripled the number of thermocouples, is situated to mid-height and spreads over six heating elements. We can realise in this zone, flux discontinuities and measure with precision the evolution of convective fluxes. The two other zones are localized in the immediate neighbourhood of the two low and high end that are often submitted to important temperature difference due to the nature of the flow and the thermal conditions imposed on horizontal walls.

Because of limitation in which exquisites means, flux measurements are only done on the central strip. The two lateral strips serve, as safe guards elements to avoid sides phenomenon due to the conduction between the hot flux meter walls and the lateral walls. We dispose in this cavity of a comb with 10 thermocouples permitting to measure the mean temperature of air in front of flux meter walls, at distances comprised between O.5 and 20 cm. With the help of a pulley device, we can displace this comb vertically along of the face and can determine the behaviour of air in the boundary layer as well as the stratification in the central core of the cavity. A more complete description of this installation appears in references [7],[8] and [9].

2-2 Configurations of temperature studied

Table 1 Flux convected in order of Rayleigh number Flux Conv/(Ts-Tms)

	C: hot wall F: cold wall	$C.(Ra)^{0,25}$	$C.(Ra)^{0,33}$	$C.(Ra)^{B}$	Constant: B and C
Cas	configuration	C	C	C	B
C_1	cCcffc	1,09	0,172	0,21	0,322
C_2	fCfffc	1,01	0,15	0,631	0,27
C_5	cCcfcc	0,887	0,143	1,124	0,24
C_4	mCmfff	Insuf	ficient	point	nbr
C_5	fCffff	0,824	0,122	0,14	0,324
C_6	cCcfcf	0,817	0,122	0,82	0,25
C_7 8	Floor very cold	xxxx	xxxx	0,0015	0,52

Results that we present in this study are relative to the very varied configurations that we regrouped in five categories . Table 1

-the first category represents the configurations where walls are heated of way to get the isothermal faces. Wanted goal is to get some relatively simple results to analyse and can serve data for the validation of certain codes of calculation.

-the second, to more fundamental character corresponds to configurations where the two vertical faces (situated in screw to screw) are isotherms and the four other faces are adiabatic with the condition:

$$\varphi_{cv}=0 \;\; , \varphi_{cv}+\varphi_{rd}=0$$

It allows a better comprehension of convective flows.

-the third corresponds to an elongated cavity where the vertical face is uniformly heated. The strong insulation behind this wall and the weak irradiative losses at its front (weak emissivity) leads in this case to a condition of nearly uniform convected flux.

-the fourth category is that where that wall is subject to quite varied flux distributions along its height (hotter areas or non-heated areas).

Finally, several experiments with different temperature gradients have been carried out in each category.

3. Choices of the reference for modelling the average convective flux on the vertical faces

In established thermal regime and with the hypothesis of air that is transparent to infrared radiation, the equilibrium of convective transfers on the six faces must be nil and can be written as follows:

$$\sum_{i=1}^{6} Qcvi=0 \qquad (1)$$

In case we simply model the convective transfers by the means of average transfer coefficients on each face and a unique reference temperature, we can write that equilibrium as follows:

$$\sum_{i=1}^{6} hi.Si.(Tpi-Tref)=0 \qquad (2)$$

Supposing that the transfer coefficients have the same value on each face, we can define a reference temperature

$$Tref=\frac{1}{St}\sum_{i=1}^{6} Tpi.Si=Tms \qquad (3)$$

These appears to be a good correlation in figure 4 where then cavity's central air temperature (Tc) is given as a function of the average surface temperature (Tp) of the six faces (Tms). We have tried to better define experimentally equation (3) by characterizing distinctly transfers on the ceiling, the flooring, both motive vertical faces and both lateral ones. We have established for the elongated cavity the best correlation (least squares method) between the measured central cavity's air temperature and the faces temperatures. We obtained :

$$Tc=0.5*Tvm+0.4*Tl+0.08*Tpd+0.04*Tpr \qquad (5)$$

Where Tvm is the motive vertical faces temperature, Tl is the lateral faces temperature, Tpd is ceiling temperature, Tpl is the flooring temperature according to the relation (2):

$$Tref = \frac{1}{h_{glob}.St}(h_{vm}.S_{vm}T_{vm} + hl*Sl*Tl + h_{pd}*S_{pd}*T_{pd} + h_{pr}*S_{pr}*T_{pr}) \qquad (6)$$

of the experimental results, one gets for coefficients of exchanges the following reports:

$$h_{vm}/h_{glob}=0.85 \, , hl/h_{glob}=1.24 \, ,$$
$$h_{pd}/h_{glob}=0.70 \, , h_{pr}/h_{glob}=0.32$$

These ratios are close to 1, which justifies the use of the simplified hypothesis that we made to establish equation (3). We can see, however, in this cavity, an influence on the cavity's central temperature; this influence is more important on the lateral faces and is weaker on the ceiling and the motive vertical faces. We can see all that in figure 4 because the most distant points of the bisecting line correspond to settings where temperature of horizontal faces are peculiar.

The mean surface temperature is a very good modelling of the temperature at the centre of the cavity and therefore of the air equilibrium if differences are weak (as in the case of construction) or if the intermediate walls have nearly adiabatic behaviour. This temperature can easily be obtained numerically because it depends directly on the boundary conditions of the problem. That is why it was considered as a reference temperature.

A similar approach was adopted in references [4] and. Their results concern a small cavity pilled with water. They defined a temperature of reference as being the mean surface temperature of the four vertical faces.

This is not adequate in certain configurations they didn't study. These points correspond to a variety of different situations, a hot face with five cold faces, five hot faces with a cold face, a hot face and a cold face with four faces at intermediate temperatures, the flooring and the ceiling maybe hot or cold. The nature of the flow induced by these configurations is appreciably different. Results described in detail in the reference [10] showed the very complex influence of temperature configurations on the flow characteristics (level of turbulence, localization of the transition zone, etc...), and that there doesn't exist a simple regrouping.

4. Stratification

One drew the evolution of the middle temperature outside of the layer boundary, according to the height for all experiences. This middle temperature is determined on the 9 levels of measure the long of the hot plate, while doing the average of all values recorded on the last three thermocouples of the comb. These last three thermocouples are located with certainty outside of the layer boundary. Fig.1

In all cases that we studied, the evolution is appreciably linear on a higher height. In the high part and bass of the cavity the evolution is disturbed by the horizontal wall presence (i.e Fig.2). In the case of a very hot flooring this disruption is appreciable. It intervenes on the first two or three levels, the temperature being then appreciably constant.

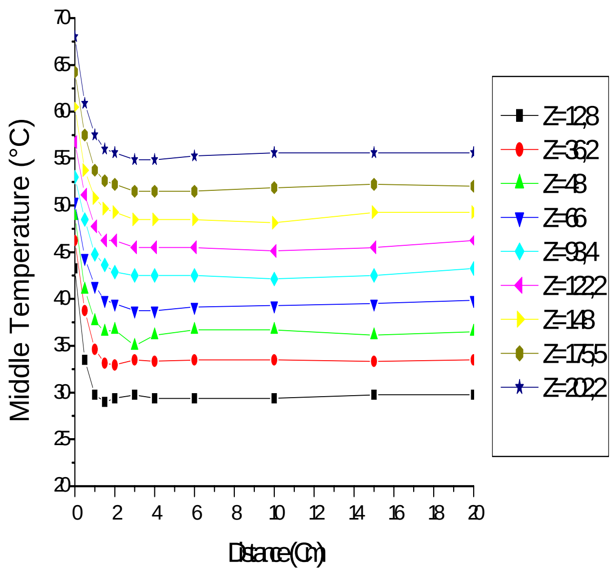

Fig.1 - Profiles temperature and stratification

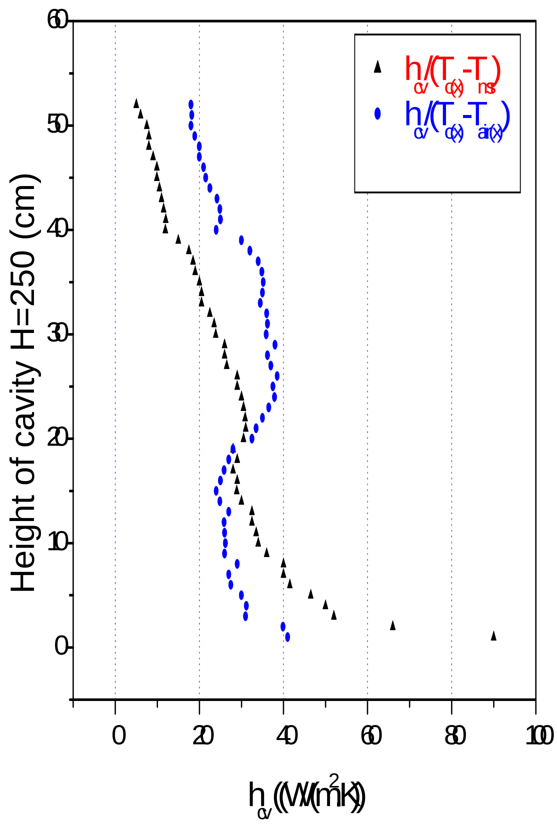

Fig.2 - Convective heat flow for hot wall width heat density constant (case C_5)

In the other cases the disruption limits itself at zones very few extended.

The slope of the stratification $\left(\frac{\partial T}{\partial z}\right)$ has been determined by a linear regression. It is given for all manipulations. To be able to compare the different experiences, one calculated a value definite not dimensioned with regard to the gradient of temperature Δt between hot and cold faces and the height H of the cavity, one can note then:

$$A_c^* = \frac{\partial T}{\partial z} * \frac{H}{\Delta T}$$

5. Conclusion:

The experimental correlation showed one can determine with a good precision the value of the air temperature at the centre when taking the mean surface temperature of all faces (Tms).

The expression of the temperature difference defined with regard to Tms permitted results obtained for all configurations varied (uniform temperatures on faces, faces with imposed flux, vertical faces including some cold or hot zones, etc.) around a law of the type.Fig.3

$$\varphi = C*\left(T_s - T_{ms}\right)^B$$

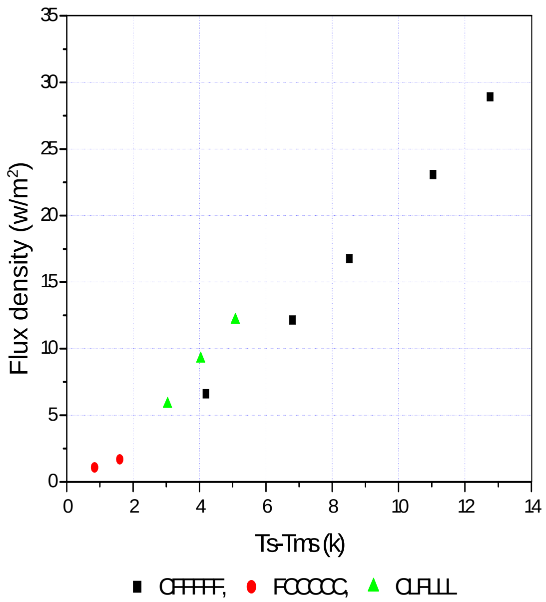

Fig.3 - The density of flux with regard to the gradient (Ts-Tms)

The distribution of temperatures on the six sides of the cavity has a role determining on the average temperature of the center and on the stratification.

The temperature of the geometric center of the cavity can be determined with a satisfactory precision in a lot of cases, while taking the average temperature of surfaces.

By identification of parameters, we established a modeling that for a cavity having a relatively important shape report, led to the following formula:

$$Tc=0.5*Tvm+0.4*Tl+0.08*Tpd+0.04*Tpr$$

This simple modelling permits in the case of the construction to calculate a satisfactory value for the temperature of the center.

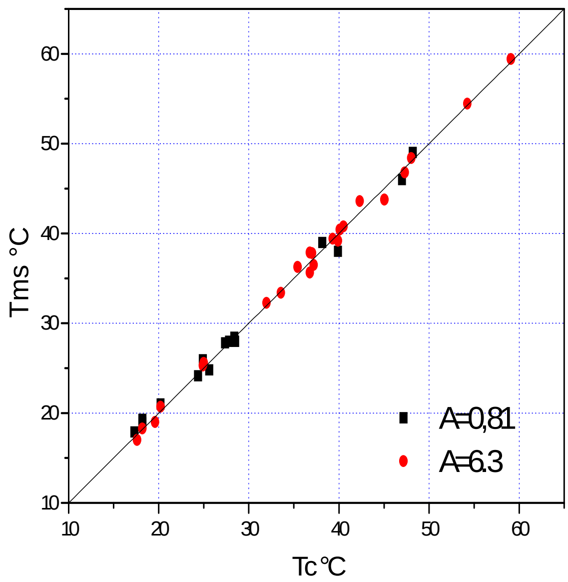

Fig.4 Evolution of the mean surface temperature (Tms) versus the air temperature at the centre (Tc)

Always for this type of elongated cavity, the slope of stratification can be written as

$$A_c^* = \frac{\partial T}{\partial z} * \frac{H}{\Delta T}$$

in three groups according to the gradient of temperature between the flooring and the ceiling.

This representation permits us to note:

- that the not dimensioning permits to become liberated from the influence of the temperature gradient.
- that value not dimensioned doesn't depend on the mode of the heating (constant temperature or constant flux)
- that the studied configurations can regroup around three values of the stratification according to the gradient of temperature between the flooring and the ceiling :

A_c^* = 0,24 for configurations C1 and C2

A_c^* = 0,4 for configurations C3, C4, C5 and C8

A_c^* = 0,75 for the configurations C6 and C7

Nomenklature

A=H/L: elongation of the cavity;
H: height of the cavity ;
L: width of the cavity
Gr: number of Grashoff

$Gr = g\beta(T_{ch} - T_{ms}) H^3 / \vartheta\alpha$

h; h_{glob}; h_l: coefficient of convection exchange; global of the cavity; on the two lateral vertical faces. h_{pd}; h_{pr}; h_{vm}: coefficient of convection exchange on the ceiling; on the flooring; on the two active vertical faces

Φ_{cd}; Φ_{cv}; Φ_{rd}: flux by conduction; convection; radiance

Ra=Gr.Pr: number of Rayleigh.
Pr: number of Prandtl
S_i : surface of each of the six faces
S_l: mean surface of the two lateral vertical faces
S_t: total surface of the six faces of the cavity
S_{vm}; T_{vm}: mean surface and mean temperature of the two vertical generating faces.
Spd: surface of the ceiling; Spr: surface of the flooring
T_c: Temperature of air to the centre
T_s; T_{fr}; T_l: mean temperature of the hot vertical face; of the cold vertical face; of the two lateral vertical faces.
T_{ms}: mean surfacical temperature of all faces of the cavity.
T_{ref}; T_{pd}; T_{pr}: temperature of reference; of the ceiling; of the flooring.
B: thermal expansion coefficient
φ_{cd} ; φ_{cv} ; φ_{rd} : density of flux by conduction; convection; radiation.
υ: kinematics viscosity.
T_{xz}: Middle temperature at level z and distance x.
$\Delta T = T_s - T_{fr}$

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