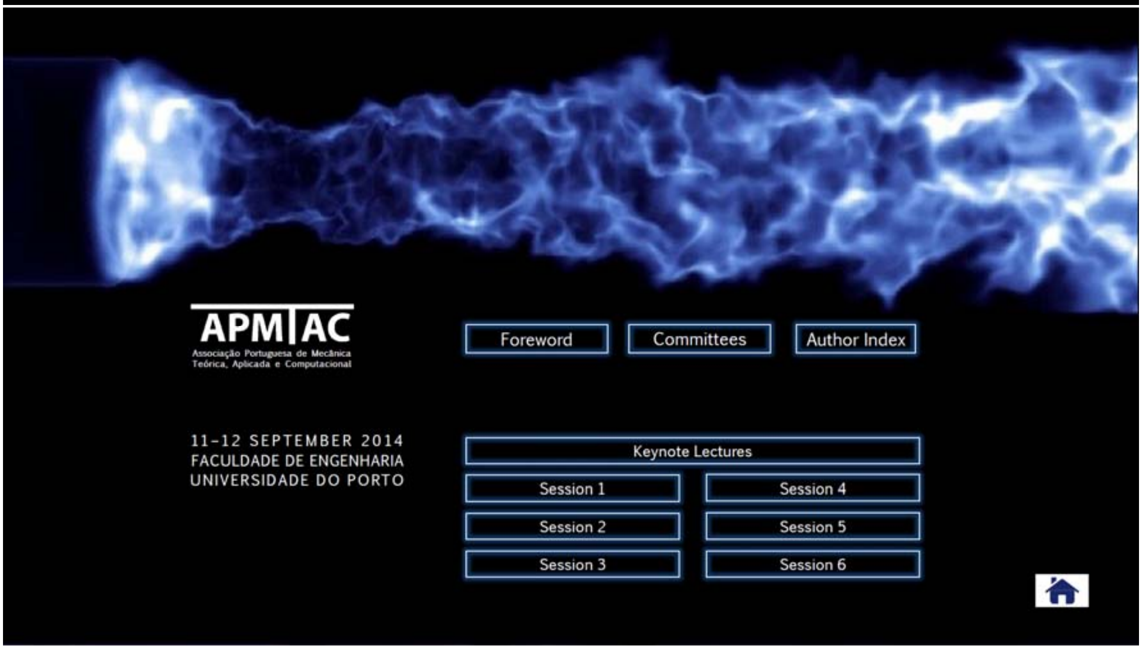

MEFTE 2014
V Conferência Nacional de Mecânica dos Fluidos, Termodinâmica e Energia
PORTO, Portugal, 11–12 SET 2014
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO
www.fe.up.pt/mefte2014
U.PORTO
climar
TÉCNICO LISBOA
APMTAC


APMTAC
Associação Portuguesa de Mecânica Teórica, Aplicada e Computacional
Foreword
Committees
Author Index
11–12 SEPTEMBER 2014
FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO
Keynote Lectures
Session 1
Session 4
Session 2
Session 5
Session 3
Session 6

MEFTE 2014

V Conferência Nacional de Mecânica dos Fluidos, Termodinâmica e Energia

PORTO, Portugal, 11–12 SET 2014

FOREWORD

This e-book is a compilation of the papers presented at the 5th MEFTE conference—V Conferência Nacional de Mecânica dos Fluidos, Termodinâmica e Energia, MEFTE 2014—which took place at the Faculdade de Engenharia da Universidade do Porto (FEUP), Portugal, from 11 to 12 September 2014.

MEFTE 2014 was jointly promoted and organized by the Faculdade de Engenharia da Universidade do Porto (FEUP), the Centro Interdisciplinar de Investigação Marinha e Ambiental (CIIMAR-UP), the Instituto Superior Técnico da Universidade de Lisboa (IST-UL), the Faculdade de Ciências e Tecnologia da Universidade de Coimbra (FCTUC), the Escola de Engenharia da Universidade do Minho (EEUM) and the Laboratório Nacional de Engenharia Civil (LNEC), under the auspices of the Associação Portuguesa de Mecânica Teórica, Aplicada e Computacional (APMTAC).

The APMTAC biennially promotes this national scientific event, which aims to provide a discussion forum for researchers working in the fields of fluid dynamics, thermodynamics and energy. The previous four venues were held in Caparica in 2006, Aveiro in 2008, Bragança in 2009, and Lisbon in 2012. The Conference has, since its first edition, promoted the participation of young researchers and students, contributing to the dissemination of their work and fostering their links with other researchers and research groups.

MEFTE 2014 had three keynote lectures, and six sessions where 40 papers were orally presented, from a total of 63 abstracts submitted for evaluation. From these, a total of 41 papers or extended abstracts have been compiled into this e-book. The Organizing Committee expresses its appreciation and thanks all those who contributed to this event, in particular, the members of the Scientific Committee, as well as all authors and participants for their effort and dedication.

Finally, we thank the invited speakers for the keynote lectures for their contribution, making this conference a place to share knowledge and the state-of-the-art in fluid mechanics, thermodynamics and energy.

Porto, December 2014

The Organizing Committee

MEFTE 2014

V Conferência Nacional de Mecânica dos Fluidos, Termodinâmica e Energia

PORTO, Portugal, 11–12 SET 2014

SCIENTIFIC COMMITTEE

Alejandro Crespo	U.Vigo | EPHYSLAB	João Peças Lopes	U.Porto | FEUP
António F. Miguel	U.Évora	José Conde	UNL | FCT
A. Heitor Reis	U.Évora	José Leonel M. Fernandes	U.Lisboa | Técnico
Abel Rouboa	UTAD	José Laginha Palma	U.Porto | FEUP
Almerindo Domingues Ferreira	U.Coimbra | FCTUC	Luís Adriano Oliveira	U.Coimbra | FCTUC
André Fortunato	LNEC	Luís Eça	U.Lisboa | Técnico
António Carlos Mendes	UBI	Maria Graça Neves	LNEC
António Moreira	U.Lisboa | Técnico	Mário Costa	U.Lisboa | Técnico
António Sarmento	U.Lisboa | Técnico	Miguel Teixeira	U.Reading
Carlos Pinho	U.Porto | FEUP	Paulo Oliveira	UBI
Celestino R. Ruivo	U.Algarve | ISE	Paulo Piloto	I.P.Bragança
Domingos Xavier Viegas	U.Coimbra | FCTUC	Pedro Coelho	U.Lisboa | Técnico
Eric Didier	UNL | FCT	Roger Moreira	U.Federal Fluminense
Fernando Tavares de Pinho	U.Porto | FEUP	Sílvio Gama	U.Porto | FCUP
Helena Ramos	U.Lisboa | Técnico	Toste Azevedo	U.Lisboa | Técnico
Jerónimo Puertas Agudo	U.Coruña	Vicente Pérez-Muñuziri	U.Santiago de Compostela
João Alfredo Santos	I.P.Lisboa | ISEL	Viriato Semião	U.Lisboa | Técnico
João Campos	U.Porto | FEUP	Vitor Costa	U.Aveiro
João Melo de Sousa	U.Lisboa | Técnico		

Numerical simulation of the thermal effects of localized fires

C Balsa[1,2], B Béjannin[3], S Mouysset[4], P Piloto[1,5]

[1]Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253 Bragança, Portugal.
[2]Centro de Estudos de Energia Eólica e Escoamentos Atmosféricos (CEsA), FEUP, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
[3]Universitée de Toulouse, INP(ENSEEIHT)-IRIT, 2, rue Charles Camichel, B.P. 7122, 31071 Toulouse Cedex 7, France
[4]University of Toulouse, IRIT-UPS, 2, rue Charles Camichel, B.P. 7122, 31071 Toulouse Cedex 7, France
[5]Instituto de Engenharia Mecânica (IDMEC), FEUP, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal
email: balsa@ipb.pt, baptiste.bejannin@etu.enseeiht.fr, Sandrine.Mouysset@irit.fr, ppiloto@ipb.pt

ABSTRACT: The thermal effects of a localized fire bellow a concrete slab with the length of 10 m and the thickness of 30 cm is simulated. The nonlinear equation of heat transfer was solved by finite differences using an implicit scheme. The appropriate mesh size in the direction corresponding to the heat flux resulting from the fire was defined. The temperature results of the two dimensional simulation does not depend on the dimension of the mesh size in the horizontal direction (perpendicular to the heat flux).

KEY-WORDS: Fire; Heat transfer; Concrete slab; Eurocode; Finite differences; Mesh size.

1 STATEMENT OF THE PROBLEM

The main objective of this work is the development of a scientific programming tool that allows modelling the temperature distribution inside a concrete slab subjected to a localized fire. This paper intends to analyse the effect of a car fire accident inside a compartment, made of concrete. When flash-over is unlikely to occur, thermal effects of a localised fire should be taken into account [1].

To obtain the thermal effect of the localized fire, the heat released rate of a utilitarian car was used. The net heat flux incident on the exposed surface of concrete slab was also calculated according to the simplified formulas of Eurocode [1].

The slab has a length of 10 m and a thickness of 30 cm, but the problem is reduced to the vertical section of the slab that is positioned above the axis of the flame. In this way we obtain a two dimensional domain, corresponding to a very flat rectangular area. Figure 1 represents the section of the compartment where the analysed area is at the top, where r corresponds to the horizontal distance to the vertical axe of the flame.

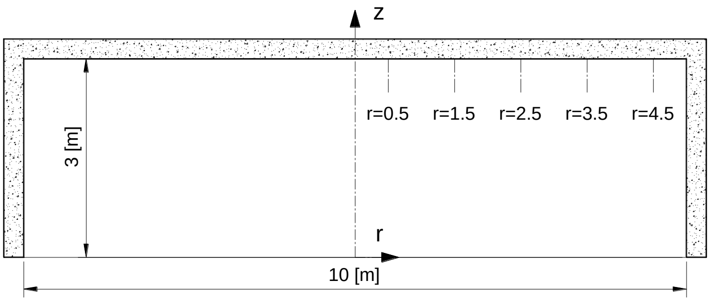


Figure 1: Geometry of the compartment.

The temperature inside the plate is governed by the equation of heat transfer:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)=\rho c\frac{\partial T}{\partial t} \qquad (1)$$

where k, ρ and c are, respectively, the thermal conductivity, the specific mass and the specific heat of the concrete. The solution is nonlinear, because the material properties varies with temperature. Inside the slab we consider that x is the vertical direction, coincident with the main axis of the flame (z-axis in Figure 1), y is the horizontal direction, perpendicular to the axis of the flame.

The numerical solution of equation (1) is obtained by finite difference using implicit discretization schemes. The code is implemented in Matlab. This work follows a previous publication [2] which was addressed to solve the same problem using an explicit scheme.

Section 2 is devoted to the description of the boundary conditions of the slab. Its definition is extremely important because it is through the boundary conditions that the effects of fire are transmitted to the slab. Thereafter, in section 3, we analyse the effect of mesh size in the parallel direction to the axis of the flame, where there is a large temperature gradient on the exposed surface. Section 4 shows the results of simulation in two dimensions covering the vertical section of the slab immediately above the axis of the flame. Section 6 finishes with some observations about the results obtained.

2 BOUNDARY CONDITIONS

The boundary conditions allow transfer to the slab the heat released by the localised fire. The Gasemi method was considered to setup the boundary conditions [1]. This method is applied when the flame is impacting the ceiling. The resulting heat flux ($\dot{h}$) depends on the parameters illustrated in Figure 2 [1]. *H* (m) is the height of the compartment. *D* (m) is the is the diameter of the fire, *r* (m) is the horizontal distance between the vertical axis of the fire and the ceiling point where the heat flux is calculated, L_h (m) is the horizontal flame length that depends on *H* and on *Q*, the rate of heat release of the fire.

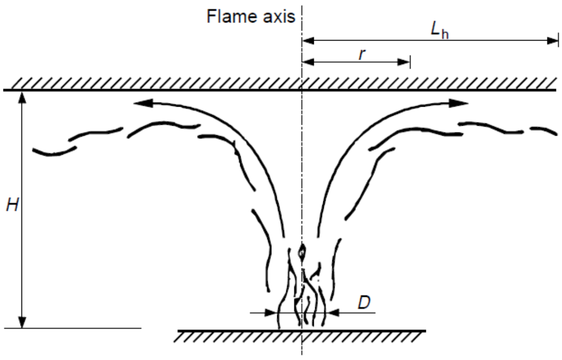


Figure 2: Geometry of the compartment [1].

The heat flux $\dot{h}$ [W/m²] received by the exposed surface area at the level of the ceiling is given by:

$$\begin{aligned} \dot{h} &= 100000 && \text{if} \quad y \leq 0.3 \\ \dot{h} &= 136300 - 121000y && \text{if} \quad 0.3 < y \leq 1 \\ \dot{h} &= 15000y^{-3.7} && \text{if} \quad 1 < y \end{aligned} \tag{2}$$

The parameter *y* depends on the diameter *D* and on the heat release rate *Q*. For the heat release of the fire we have choose the typical curve that corresponds to a utility car. This curve as trapezoidal form with a maximum value equal to 18 MW that corresponds to a conservative value for the dimensioning [3].

The net heat flux $\dot{h}$ that affects the exposed surface of the slab along its entire length (from $r = 0$ to $r = 5$), from the beginning ($t = 0$) to the end of the fire duration ($t = 1500$ s). The values of the net heat flux are represented in Figure 3 for different values of *r*. We consider also that he values of the heat flux are symmetric relatively to the axe o of the flame (see Figure 2).

Additionally, the heat of the slab loosed by radiation and convection was also considered. In the exposed surface area the heat flux by radiation is calculated using equation (3),

$$h_r = \phi \varepsilon_m \varepsilon_f \sigma \left[\left(\theta_m + 273 \right)^4 - 293^4 \right] \tag{3}$$

where ϕ represents the configuration factor, ε_m is the surface emissivity of the member, ε_f is the emissivity of the fire, σ is the Stephan Boltzmann constant and θ_m is the surface temperature of the member [°C]. In the unexposed and exposed surfaces of the slab, the convective heat flux is also calculated according to equation (4),

$$h_c = \alpha_c \left(\theta_m - 20 \right) \tag{4}$$

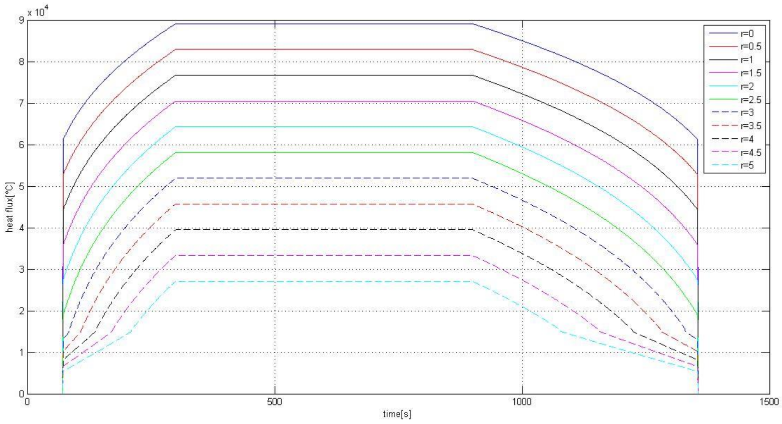


Figure 3: Net heat flux $\dot{h}$ for different values of *r*.

where α_c is the coefficient of heat transfer by convection [W/m^{2}K]. The insulation boundary condition was imposed on the left and right side of the slab.

3 SETUP OF THE GRID SIZE IN ONE DIMENSION

The numerical solution of equation (1) in one dimension was solved along the vertical direction that corresponds to the axis of the flame ($r = 0$ in Figure 1). The grid size by finite differences was defined using an implicit scheme as described by Patankar [4].

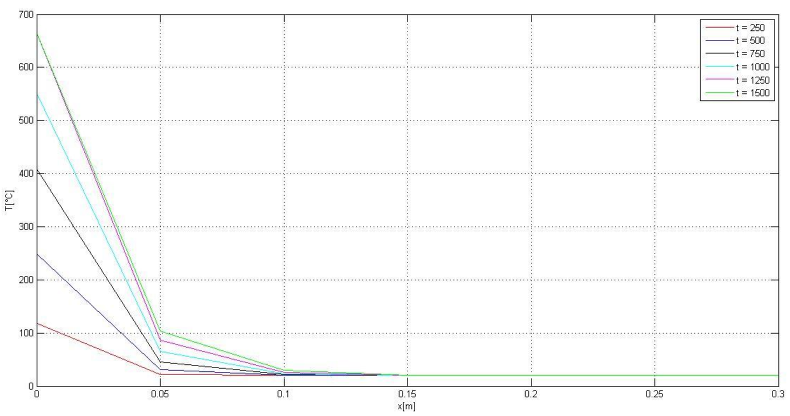


Figure 4: Temperatures across the slab on the axe of the flame obtained with $\Delta x = 0.5 \times 10^{-2}$ m.

The grid size was set up with a uniform value and then the variation effect was analysed. Figure 4 shows the variation of the temperature across the slab on the axis of the flame at different times, obtained with $\Delta x = 0.5 \times 10^{-2}$ m. The maximum temperature is near to 700 ºC and occurs in the exposed side of the slab. During fire development, temperature inside the slab increases as well as the maximum temperature at the exposed side. When fire approaches the end and the incident heat flux is almost zero, the temperature of the exposed surface is lower than the temperature inside the slab. Figure 5 represents the temperature solution with a grid size five times smaller.

Results of Figures 4 and 5 show that the problem is sensitive to the dimension of the spatial grid. If grid size Δx is reduced to 10^{-3} m the temperature curves are shifted to higher values (see Figure 5). This sensitivity is probably due to the high temperature gradient near the exposed side of the slab. Due to the thermal conductivity of the concrete there is a large temperature difference between the exposed side and the neighbouring points. Smaller values of the grid size Δx allows to better capture the temperature variation near the exposed side. As can be seen in Figure 5, this seems to be linear in the beginning of the fire.

Figure 6 shows the temperature evolution of the exposed surface of the slab for different grid size. As we can observe, smaller values of Δx lead to temperature curves with higher values. But values of Δx smaller than 10^{-3} m are responsible just for slight increases in temperature.
The results obtained with $\Delta x = 10^{-3}$ m are satisfactory. However, in order to reduce the computational effort, a grid with variable step was implemented. This grid size was modified by a factor φ higher than 1.0 to increase the grid where there is no significant temperature gradient

$$\Delta x_{i+1} = \varphi\, \Delta x_i . \tag{5}$$

Figure 7 contains the evolution of the temperature at the bottom of the slab resulting from different grid with different values of the step factor φ . As comparison it is also included the curve resulting from the discretization with a constant step $\Delta x = 10^{-3}$ m. The values obtained with $\varphi = 1.4$ are very close to the values obtained with a constant step $\Delta x = 10^{-3}$ m and enables a considerable reduction in terms of computational work because it reduces the total number of operation and the requirements of memory storage. From now on, the grid size will be described by equation (5) using $\varphi = 1.4$.

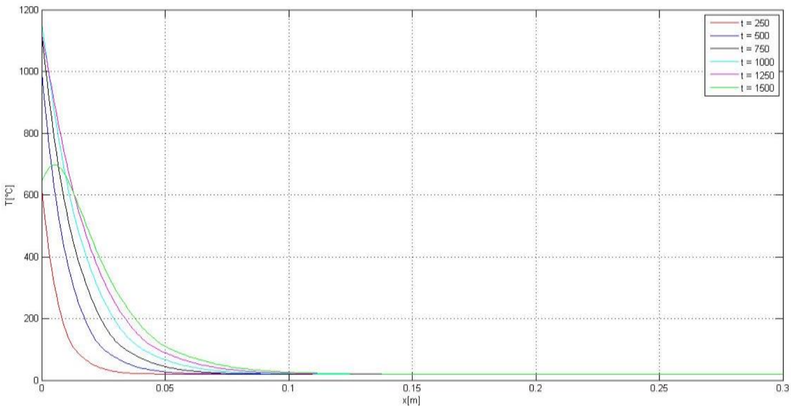


Figure 5: Temperatures across the slab on the axis of the flame obtained with $\Delta x = 10^{-3}$ m.

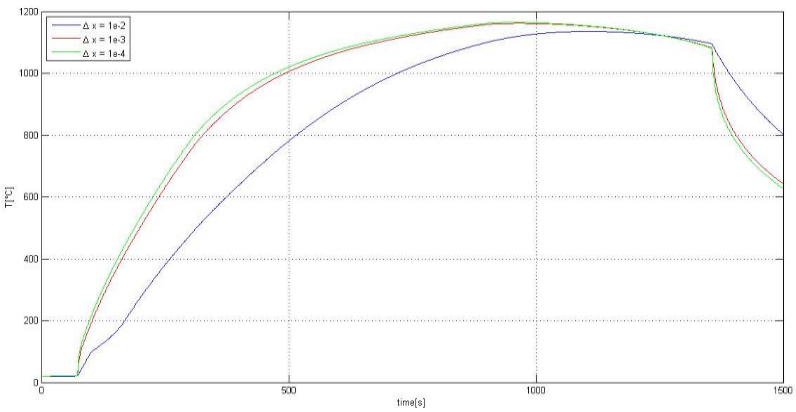


Figure 6: Temperatures at the bottom of the slab on the axis of the flame, for different values of Δx .

4 TWO DIMENSIONAL SIMULATION

To determine the temperature field in the cross section of the slab located on the axis of the flame, an implicit scheme described by Patankar [4] was used. The Cartesian coordinates are *y* as the horizontal direction and *x* as the vertical direction (similarly to the resolution in one dimension).

We verify that the step size in the horizontal direction (Δy) does not affect the results. Figure 8 presents the temperature field inside the slab at *t*=1300 s, obtained with $\Delta y = 0.1$ m and $\Delta y = 0.5$ m. We can observe that the temperature distribution obtained with the two different mesh sizes are very close to each other.

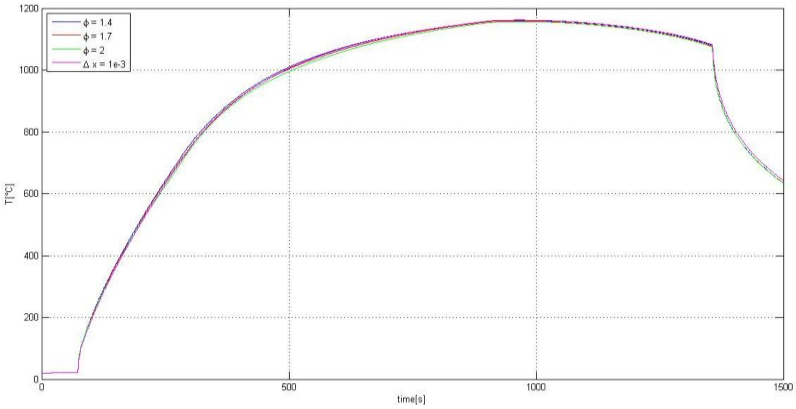
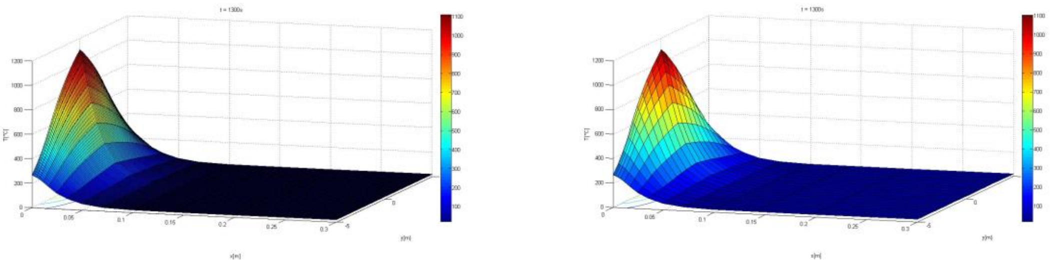


Figure 7: Temperatures at the bottom of the slab on the axis of the flame, for different step factor φ .



$\Delta y = 0.1\,\text{m}$ and $t = 1300\,\text{s}$ $\Delta y = 0.5\,\text{m}$ and $t = 1300\,\text{s}$

Figure 8: Temperatures inside the slab at t = 1300 s, for different values of Δy .

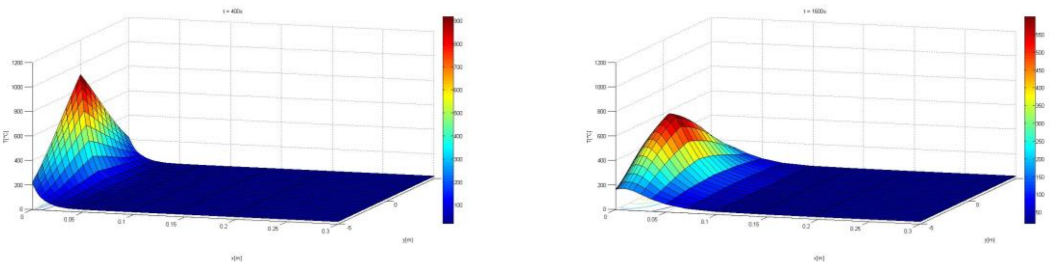


Figure 9: Evolution of the temperature inside the slab.

In Figure 9 we show the temperature distribution within the slab in two different time instants ($t = 400\,\text{s}$ and $t = 1600\,\text{s}$) of the fire. The highest temperatures occur always near the edge in contact with the flames. Most of the slab remains at low temperatures and little affected by heat.

5 CONCLUSIONS

The solution of heat transfer equation in a concrete slab subject to a localized fire is a very sensitive problem due to the high temperature gradients existing in the exposed surface. Because of the low conductivity of the concrete there is a large temperature gradient between the exposed surface boundary of slab and the neighbouring points. Large values of the grid size in this direction can lead to erroneous results.

Due to the geometry of the slab section, with a length much larger than its height, the temperature inside propagates mainly in the vertical direction. The variation of the horizontal discretization step affects very little the results. The problem can be reduced to a set of one-dimensional problems.

REFERENCES

[1] CEN – Comité Europeu de Normalização (2004). *EN1992-1-2 - Eurocódigo 2: Projecto de Estruturas de Betão – Parte 1–2: Regras Gerais – Verificação da Resistência ao Fogo,* Bruxelas.

[2] NGR Caiado (2012). *Simulação Numérica do Comportamento Térmico de Compartimentos Sujeitos a Incêndios Localizados,* Tese de Mestrado, Escola Superior de Tecnologia e Gestão, Instituto Politécnico de Bragança.

[3] C Harmemza, AMC Santiago, LAP Simões da Silva (2011). Metodologias de dimensionamento de parques de estacionamento abertos mistos aço-betão em situação de incêndio. In *VIII Congresso de Construção Metálica e Mista*, Guimarães, Portugal.

[4] SV Patankar (1980). *Numerical Heat Transfer and Fluid Flow*, Taylor & Francis, USA.

[5] L Piegl, W Tiller (1995). *The NURBS Book,* Springer.