NUMERICAL SIMULATION OF THE THERMAL FRONT PROPAGATION INDUCED BY THE ACCIDENTAL OVERFLOW OF A MOLTEN ALLOY IN A CLOSED SPACE

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Lucrarea prezintă simularea numerică a propagării temperaturii în sectorul de turnare provocată de deversarea accidentală a unei cantităţi de aliaj lichid. Motivaţia lucrării a constituit-o ponderea mare a incendiilor produse în turnătoriile din România datorită contactului aliajului lichid cu materialele combustibile.

Procesul de simulare a generat grafice şi temograme care pun în evidenţă evoluţia şi variaţia temperaturii în plan orizontal (axele X şi Y) şi în plan vertical (axa Z) în diferite puncte ale spaţiului analizat. Modelarea matematică s-a efectuat prin metoda elementului finit (FEM), iar procesul de simulare a fost realizat cu programul Ansys CFX .

This paper presents the numerical simulation of the propagation of thermal front in a foundry floor caused by accidental discharge of a quantity of liquid alloy. The motivation of this paper was the large number of fires in foundries in Romania due to liquid alloy contact with combustible materials.

Process simulation generated graphics and thermograms that reveal the evolution and temperature variation in the horizontal plane (X and Y axes) and vertical plane (Z axis) in different parts of the volume of space considered. Mathematical modeling was performed by finite element method (FEM) and the simulation was conducted with ANSYS CFX.

Keywords: accidental fire, preliminary condition, focus, heat transfer, liquid alloy, casting sector

1. Introduction

During 2003-2009, in the metal alloys foundries from Romania (19 counties), a total of 66 fires caused by various causes were recorded [1].

To identify vulnerabilities that caused and/or promoted the initiation, increase and/or spread of fires in metal alloys foundries the study and analysis of these incidents was necessary, regarding several aspects:

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a) the type of alloy and event data (Table 1, Fig. 1 and 2).

Table 1

Fire Statistics compiled by year, type of alloy and their share

Year	**Number of fires/type of alloy**			**Total fires**	**%/ year**
	iron	steel	nonferrous		
2003	3	5	-	**8**	**12,12**
2004	3	8	2	**13**	**19,69**
2005	2	4	-	**6**	**9,09**
2006	1	3	-	**4**	**6,06**
2007	-	11	2	**13**	**19,69**
2008	2	4	6	**12**	**18,18**
2009	2	5	3	**10**	**15,15**
TOTAL	**13**	**40**	**13**	**66**	**-**
%/tip alloy	**19,69**	**60,61**	**19,69**	**-**	**99,99**

The data in Table 1 show:

- a triple number of fires in the steel foundries (60,61%) given the iron foundries and the nonferrous alloys (19,69%) because of the much higher temperatures of processing of the liquid steel;
- high vulnerability to fire in some years (2004, 2007);
- a random distribution of the fires along the analyzed period.

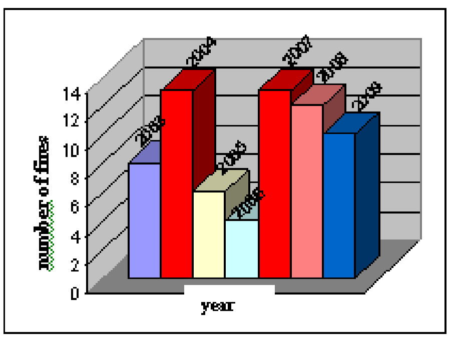


Fig. 1 Dynamics of foundry fires between 2003-2009

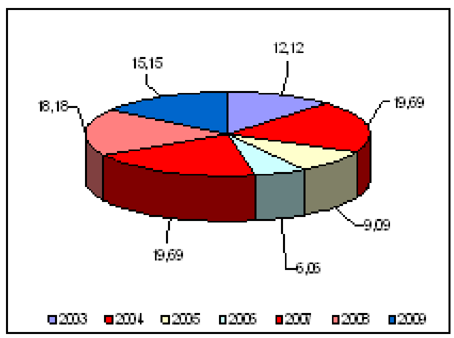


Fig. 2 The share of foundry fires between 2003-2009

b) the causes of fire (Table 2)

As the data presented in Table 2 show, the metallic melts, the most common causes of the foundry fires, accounts for a share of 24.24%. This observation requires a more extensive research of the dangers that could be brought about by the liquid alloys processing. If for the fires caused by liquid alloys processing the combustible materials firing, typical fire-fighting procedures and techniques were involved, using extinguishing substances and products in the well established intervention procedures in the event of a technical accident (overflow of a large amount of liquid alloy), management intervention can not meet the standard procedures; management of the intervention is more difficult and with a much higher risk.

Table 2

Causes of fire in the foundries in the period 2003-2009

The cause of fire	Type alloy			Total fires	%
	iron	steel	Non-ferrous		
Metallic melts	3	10	3	**16**	**24,24**
Wiring defects	-	7	3	**10**	**15,15**
Welding	4	4	1	**9**	**13,63**
Technical malfunction of operation	1	4	1	**6**	**9,09**
Smoking	3	3	-	**6**	**9,09**
Followed by fire accident	2	2	-	**4**	**6,06**
Open fire	-	2	-	**2**	**3,03**
Improvised electric equipment	-	2	-	**2**	**3,03**
Ignition or chemical reactions	-	1	1	**2**	**3,03**
Intentional action (arson)	-	1	1	**2**	**3,03**
Organizational deficiencies	-	2	-	**2**	**3,03**
Defective heating systems	-	-	1	**1**	**1,51**
Heating means unsupervised	-	-	1	**1**	**1,51**
Funnel defects or unpeeled	-	-	1	**1**	**1,51**
Explosion followed by fire	-	1	-	**1**	**1,51**
Being established	-	1	-	**1**	**1,51**
TOTAL	**13**	**40**	**13**	**66**	**100**

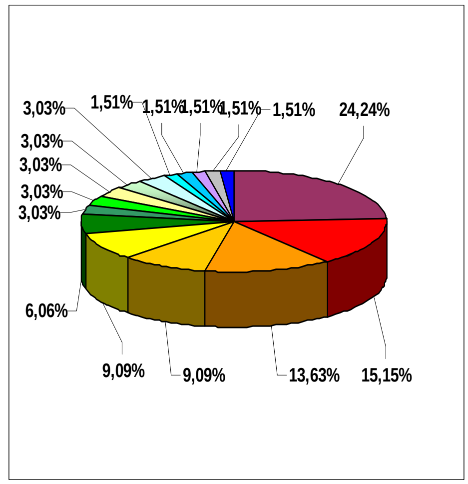


Fig. 3 Share of the causes of fire

For a more precise knowledge of the phenomena that accompany this kind of accident and for adopting both of the most effective intervention procedures and appropriate protective measures the simulation of thermal front propagation in the most severe conditions in overflow of a ladle with liquid alloy is necessary. The proposed objective is to build a scenario of accidental spillage of liquid alloy (steel) and to study the phenomenon of heat transfer from the source (liquid alloy) to the rest of the desktop (the casting sector). The study of heat transfer was possible by using the numerical simulation technique in order to:

a) review the evolution in time (at different times) of:

- convective heat transfer from the focus (liquid alloy mass) to neighborhoods;

- how to change the temperature inside the casting house;

b) a comparative analysis of the temperature variation at certain points set inside the casting house;

c) study, as alternative, of the consequences and effects that the accident could have both on the staff working in the foundry and the construction elements and base structure of the foundry hall. One more reason to consider such accident as an important objective was the European campaign on safe maintenance [2] initiated by the European Agency for Safety and Health at Work launched on

28.4.2010, at World Day for Safety and Health at Work, entitled "Healthy Workplace 2010-2011".

2. Aspects of heat transfer in a confined space

Theoretical background:

To analyze heat transfer in a closed space a cross section through a foundry hall was necessary (Fig. 4).

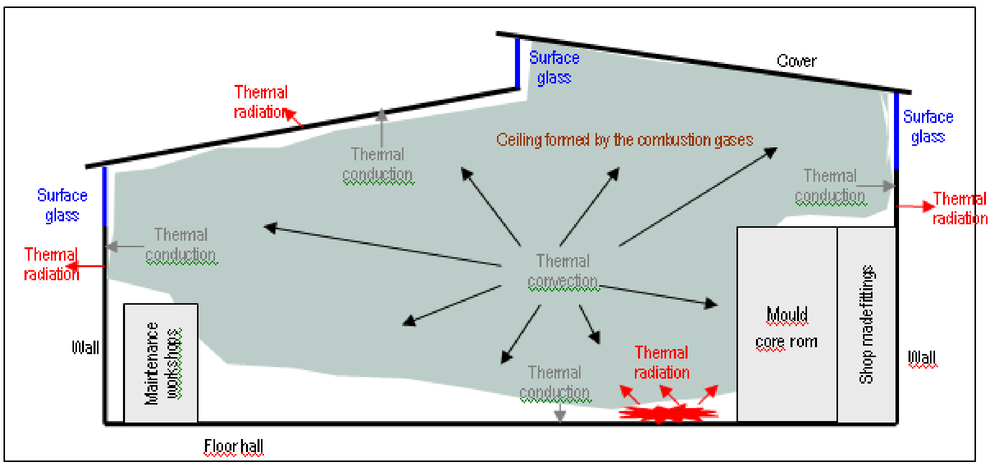


Fig. 4. Heat transfer inside the foundry hall

Heat transfer is a spontaneous process, the irreversible heat spreads in space, providing heat exchange due to the existence of temperature difference (thermal potential) between the source and the environment inside the hall.

When analyzed, the heat transfer is achieved in known fundamental ways:

a) radiative heat transfer (thermal radiation) by means of electromagnetic waves radiating from the source (represented by the focus of liquid alloy) to the fluid represented by hall atmosphere. In the focus area, the mechanism of transformation of radiant energy of the heat is achieved due to the shock between molecules, atoms and free electrons existing within it are removed temporarily from steady state and switched to another energy level. On returning to the initial energy, the energy received from the shock is released as electromagnetic waves that are emitted in place of the discharge space environment.

Heat transfer by radiation from the furnace is expressed by the Stefan - Boltzmann equation of the thermal flux emitted by a body [3] with the relation:

$$Q = \sigma_o ST^4 \ [\mathrm{W}] \quad (1)$$

where: σ_o is the coefficient of radiation of black body ($\sigma_o = 5.67\ 10^{-8}$ W / (m^2 × K^4);

S - the surface, in m^2;

T - temperature in K.

b) heat transfer by conduction (heat conduction) occurs in the floor, walls and roof. Heat transfer by conduction is the mechanism by which heat is transmitted, step by step without apparent movement of particles that compose the system.

Thermal conduction mechanism is related to the kinetic molecular energy of interaction between bodies forming microparticles (molecules, atoms, electrons), as follows:

- the floor and walls, conduction is achieved by energy transfer to the phonon vibrations of atoms;
- for the metal structure supporting the roof, thermal conduction is done mainly by free electrons that have a share of 10 to 30 times higher than the phonon;

The mathematical expression for the Fourier law of heat conduction is given by [4]:

$$Q_{S,x} = -\lambda A\ dT/dx \quad [\mathrm{W}] \tag{2}$$

to:

$$q_s = -\lambda\ gradT \quad [\mathrm{W/m^2}] \tag{3}$$

where: Q is the heat flow in W;

λ - thermal conductivity in W / mK;

A - surface, in m^2;

T - temperature in K;

q_s - unitary surface heat flux in W/m^2.

The minus sign in equation (2) and (3) takes into account that spreads heat flow from a higher temperature to a lower one with reverse temperature gradient.

For the internal environment of the foundry hall where the temperature varies spatially, Fourier's equation (3) becomes:

$$q_x = -\lambda dT/dx; \quad q_y = -\lambda dT/dy; \quad q_z = -\lambda dT/dz; \tag{4}$$

to:

$$q = -\lambda\ (dT/dx + dT/dy + dT/dz) = -\ \lambda T \tag{5}$$

c) convective heat transfer (heat convection) is the process of the heat transfer into the moving air, caused by the difference in temperature between the focus center and the surrounding space [5, 6]. In the situation shown in Fig. 4, the convection involves the combined action of the thermal conduction in the boundary layer of air from the focus center to adjacent particles. The effect of this phenomenon is the rise both of temperature and internal energy of these particles. Heat from the firebox determines both the heating and expansion of air, while its density decreases. It becomes easier and forms ascending currents (convective currents) moving upward to the upper areas of the hall. Heated air is replaced by cooler air from the hall volume, the particles with higher energy more to areas with lower temperatures, where mixing with each other, gives up some of their energy.

Colder zones (external walls, glazing or closed elements) have a reverse direction of heat transfer forming downward convective currents that contribute to fluid motion (swirls formation).

The mechanism of free movement of air in the foundry volume because of the density gradient caused by changes in air mass temperature, is called free or natural convection. The basic equation of heat convection is given by Newton's formula [5]:

$$Q = \alpha A (t_p - t_f) \tau \ [\mathrm{W}] \quad (6)$$

to:

$$q_s = \alpha \ \Delta T \ [\mathrm{W/m^2}] \quad (7)$$

where: α - convection coefficient in W / (m^2 K);

t_p, t_f - wall and fluid temperature, respectively, in K;

A - surface, in m^2;

τ - time, in s.

In the heat conduction equation for a moving fluid, the temperature depends not only on time, according to Fourier's equation, but also on space. Kirchhoff changes the equations by introducing a temperature variation, as follows [5]:

$$Dt/d\tau = \delta t/\delta\tau + w_x \, \delta t/\delta x + w_y \delta t/\delta y + w_z \delta t/\delta z = \alpha \, (\delta^2 t/\delta x^2 + \delta^2 t/\delta y^2 + \delta^2 t/\delta z^2) \quad (8)$$

3. Research method

The mathematical model [7, 8] was constructed using the finite element method, the working mechanism which consists in:

a) the decomposition of the analyzed field (volume of casting sector space) in a number of subdomains (see Fig. 5) or portions of relatively simple geometric shape called finite elements using the following formula [9]:

$$V = \sum_{i=1}^{NE} V^e \quad (9)$$

where:

V - the analyzed field (space volume);

NE - number of subdomains the domain V was divided, each V^e volume;

^{e} superscript for a certain element.

Each item is numbered / identified by a number, usually from 1 to the total number of finite elements, which are highlighted by means of points called nodes. Finite elements interact with each other through common nodes so that the analysis is a finite number of nodes. Similar elements, nodes are numbered from 1 to total number of nodes NN.

b) the analysis of subdomains;

c) the compliance with certain requirements recompose mathematical field.

The computer program used for finite element analysis [10] does not solve the real structure, but a model of it

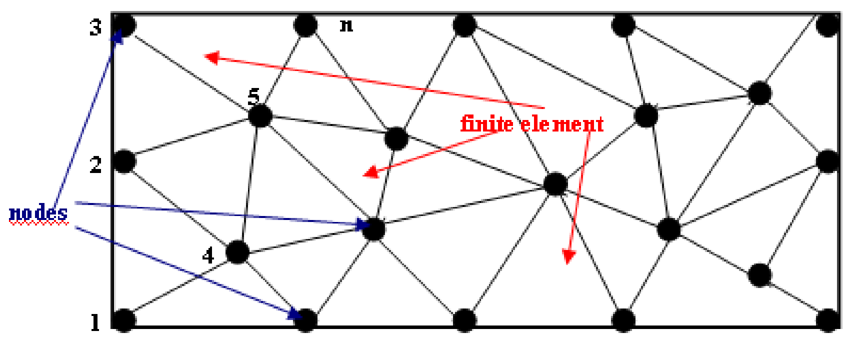


Fig. 5 Meshing domain

To carry out finite element analysis we consider:

➢ the thermal field is variable (non-stationary or transient) because:

- it allows to determine the amount of heat distribution in the temperature range conditions for a pre-established period of time;

- the temperature obtained by transient thermal analysis can be used as input in structure analyses for future evaluations;

➢ the process takes place in an isolated system (see Fig. 4), excluding heat exchange with surroundings of the analyzed domain (heat transfer analysis was performed up to the floor, walls and roof without taking into account the heat exchange at their level);

➢ heat transfer is a convective type [4, 5] since it holds the largest share in the global heat transfer, determining the mechanism of heat transfer. In this regard:

- natural and mechanical ventilation airflows existing in the analyzed space were ignored;

- analysis was conducted under single-phase convection, free, in large areas (hot air movement is determined only by differences in density of its mass, arising from the temperature differences existing in different parts of the fluid and the fluid flow is predominantly produced in vertical direction);

- the flow is turbulent (heat exchange between hot air and wall mass is more pronounced than in laminar flow);

➢ both the heat resulted from the fires which, in reality, would have been certainly and the effluents resulting from the combustion products of fires were not taken into account.

4. Study of thermal front propagation through the numerical simulation method

4.1. Carry out numerical simulation conditions

The numerical simulation program at the temperature evolution arising from the discharge of liquid alloy ladle was run assuming the following conditions [11]:

➢ contact between mesh elements is constant throughout the running process;

➢ the duration of the running process was set at 10 minutes;

➢ heat transfer is achieved by convection in the hall space;

➢ heat source (focus) represented by the liquid alloy was placed at ground level and near a building component (bracket wall);

➢ the following phenomena are neglected:

- the heat transfer towards plants and technological equipment and existing utilities in the casting sector (they were excluded from the system);
- indoor air speed (it was considered mechanical ventilation does not work);
- heat loss (temperature differences) that may occur through natural ventilation intakes or scales;
- the heat transfer from different fire focuses and combustion gases which may occur simultaneously with the process.

4.2. Accident scenario and assumptions

A technical accident consisting of liquid alloy discharge is always possible. Among the causes contributing to the production of this type of accident the following can be mentioned:

a) failure to follow instructions and carry out technological malfunction or incorrect operation of the hardware technology;

b) mechanical failure during the transport of ladles;

c) poor performance or failure of the program maintenance schedules (maintenance, repairs, etc.) of all facilities and technological equipment;

d) natural causes by earthquakes events can be also considered possible.

In the accident scenario the following sequence of events were considered:

➢ the full ladle is filled with liquid steel from the furnace;

➢ the full ladle is transported by crane to the casting place;

- security system that provides vertical positioning ladles yields and a tipping phenomenon occurs;
- the accident occurs before starting the operation of filling the mold;
- discharge of the entire volume of liquid steel on the foundry floor is complete and instantaneous;
- the liquid steel is assumed spread over an area about 100 m^2, the focus created manning an irregular shape and about 2 cm thick.

4.3. Moments considered in the simulation

The start of simulation was considered at time, M = 0 s (spills total liquid alloy and its contact with the hall floor).

The analysis of temperature variation was performed at the moments:

- M = 60 s, after the accident;
- M = 300 s, after the accident occurred (the middle of the simulation);
- M = 600 s, ten minutes after the accident occurred (the end of simulation).

4.4. Critical areas considered in the simulation

The following dimensions of the casting sector has been adopted as shown in Fig. 6: length, L = 95 m, width l = 50 m and height h = 14 m. The points considered relevant to achieve a comparative analysis temperatures evolution are noted as follows:

a) "F" called the focus;

b) "B" and "D" are collinear with point "F" on the X axis (casting sector length) and the origin of the coordinate system (point "a") common to point "B";

c) "A" and "C" are also collinear with point "F" on the Y axis (casting sector width) and the origin of coordinates at point "o^1".

Spatial coordinates of points determined on the axes X, Y and Z are presented in Table 3, and their location is shown in Fig. 6.

The temperature analysis was performed at the points mentioned, on the horizontal direction (X and Y axes at intervals of 10 m) at a height of 1.7 m, corresponding to a worker's average height and on the vertical direction (Z axis) at heights of 0 to 14 m, at intervals of 1 m.

Table 3

Coordinates analysis

Point analysis	**Symbol**	**Coordinates / axis**			
		X [m]	**Y** [m]	**Z** [m]	
				horiz.	vert.
Focus	**F**	45	50	1,7	0÷14
Mould cores sector wall	**A**	45	40	1,7	0÷14
Boundary between the melting and the casting sectors	**B**	0	50	1,7	0÷14
Maintenance workshops wall	**C**	45	90	1,7	0÷14
Debate - cleaning - heat treatment - remedy-defective spare parts quality control district	**D**	95	50	1,7	0÷14

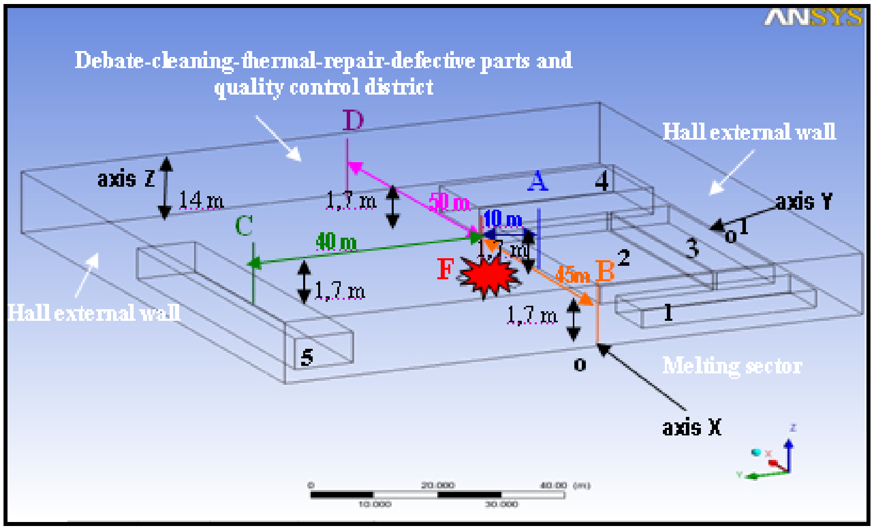


Fig. 6. Points where temperature measurements were made:**1**- District of moulding mixture preparation and core training, **2**- District of cores manufacture (drying, assembly and painting cores), **3**- Shop fittings manufacturing cores, **4**- Storage models, **5**- Maintenance Workshops (mechanical, electrical, mechanical processing etc.).

4.5. Input

Input data that have been run in the ANSYS CFX simulation program [12, 13] are presented in Table 4.

Table 4

Process input data

Parameter introduced	Value
Type of alloy	steel
Temperature of liquid alloy	1.600^{0}C
The amount of spilled liquid alloy	15.000 kg
Simulation time	10 min
Air speed	0 m/s
The ambient temperature	25 ^{0}C
Focus area	~ 100 m^2

5. Results and Discussion

5.1 Convective heat transfer and temperature variation in the horizontal plane (longitudinal and transverse to the casting sector) at 1.7 m height from ground

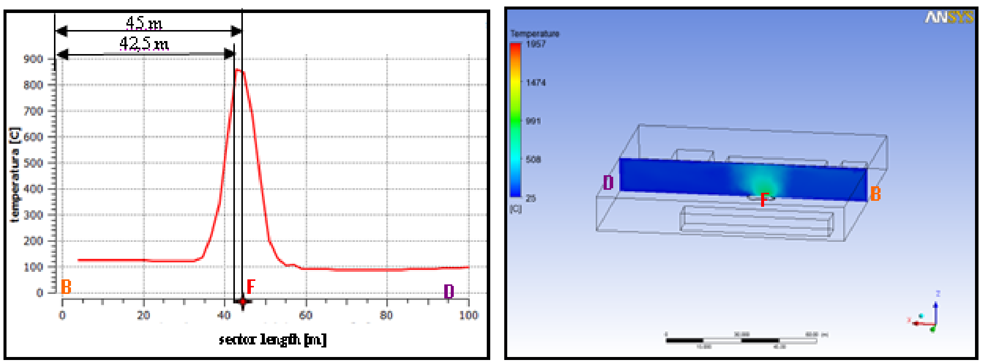
5.1.1. Temperature variation along the length of the casting sector (X axis).

Table 5 shows the variation of temperature, and Fig. 7 shows the evolution of these temperatures.

Table 5

Temperature variation on the X axis

The analyzed plan	**The moment**	The analyzed points and the distance to the focus[m]									
		B	intermediate points			**F**	intermediate points				**D**
		45	30	20	10	focus	10	20	30	40	50
		Temperature [^{0}C]									
the X axis (casting sector length)	M = 60 s	**124**	**124**	**122**	**180**	**836**	**103**	**94**	**91**	**96**	**98**
	M = 300 s	**340**	**299**	**285**	**372**	**470**	**250**	**259**	**268**	**274**	**280**
	M = 600 s	**441**	462	468	472	**677**	472	408	422	413	**427**



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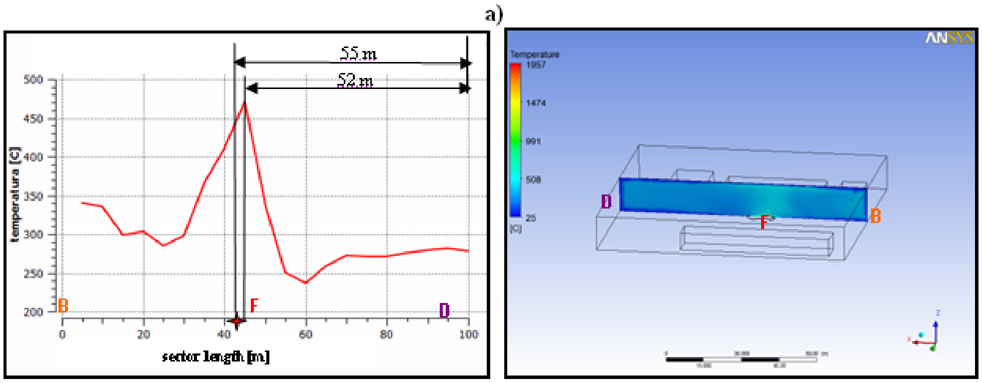

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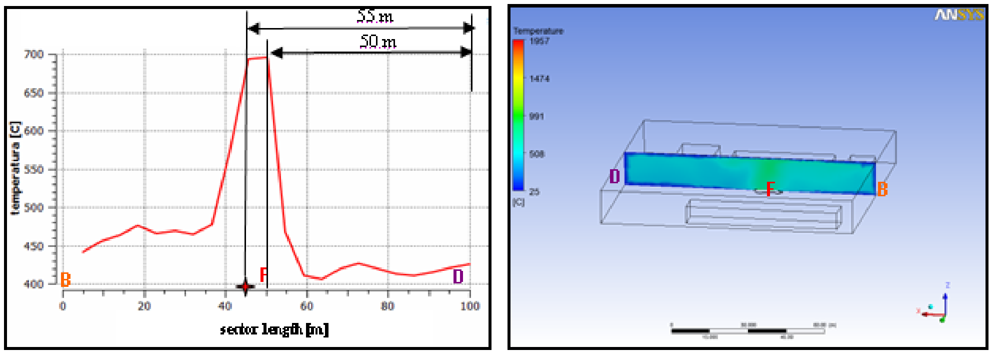


c)

Fig. 7. Temperature variation along the length of the casting sector (X axis) at 1.7 m height at the moments: **a)** M = 60 s, **b)** M = 300 s, **c)** M = 600 s

Graphics analysis from Fig. 7 leads to the following observations:

a) at M = 60 s:

- the highest temperature (880^0 C) is not in the focus area as supposed, but at a distance of 2-3 m from focus to melting sector (see Fig. 7 a);

- the heat dissipates in a circular area, with more pronounced tendency to the casting sector center (this observation is sustained by the temperature variation shown in the thermograms presented in Fig. 7a;

b) at M = 300 s:

- temperature evolution developed mainly in vertical direction, with free distribution to the top of the hall, while the warm air is directed by the formed turbulence of air flow to the hall extremities (Fig. 7 b);

- the ceiling formed by the warm air accumulated in the upper side of the hall is leading down the hall heating the rest of the air volume placed in the middle and the lower parts of the hall and homogenizing the temperatures around 300^0 C;

c) at M = 600 s:

- the focus has still an elevated temperature (about 677^0 C). Because both pressures and concentration increasing and lowering the ceiling of hot air, the temperature "pole" moves towards the center of the casting hall, at a distance of 5 m from the focus where a temperature of about 700^0 C is recorded (see Fig. 7 c);

- the thermal front changes its dissipation form from sphere (M = 60 s) to the cone, while it increases the temperature on both sides of the focus area, with a continued tendency for temperature homogenization (441^0 C in point "B" and 427^0 C in point "D").

5.1.2. Temperature variation across the width of the casting sector (Y axis)

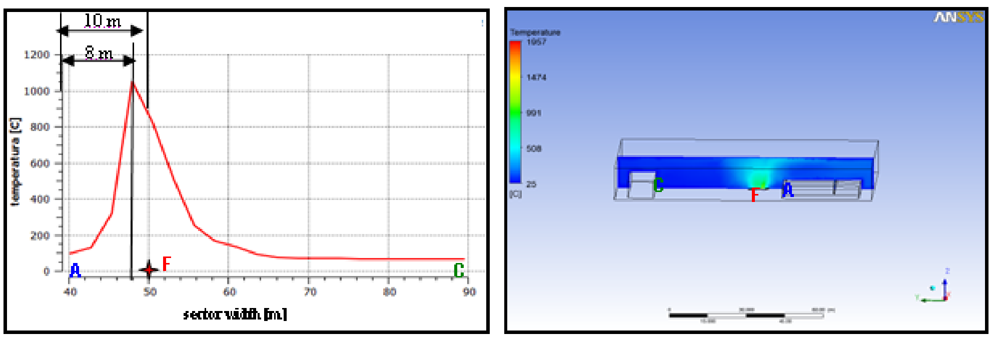
The data in Table 6 shows how the temperature varies across the width of the casting sector.

Table 6

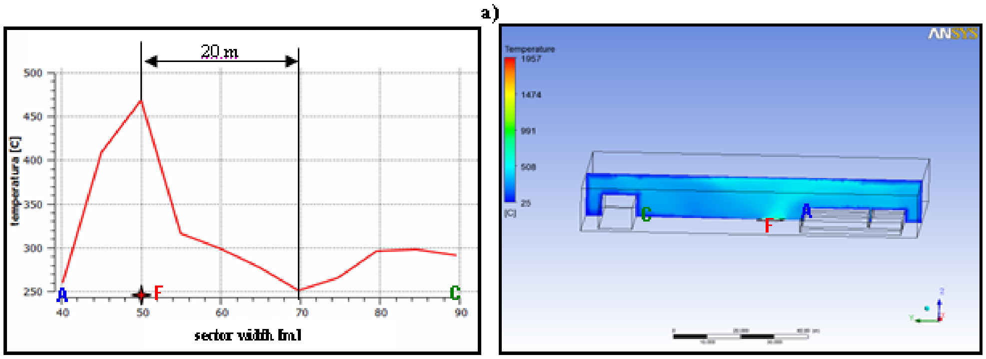
Temperature variation on the Y axis

The analyzed plan	**The moment**	**Points analyzed and the distance to the focus**[m]					
		A	**F**	intermediate points			**C**
		10	focus	10	20	30	40
		Temperature [^{0}C]					
the Y axis (casting sector width)	M = 60 s	**96**	**836**	**145**	**69**	**62**	**56**
	M = 300 s	**260**	**470**	**298**	**252**	**296**	**290**
	M = 600 s	**449**	**677**	**545**	**536**	**480**	**439**

The evolution of temperatures presented in Table 6 is given by graphs and thermograms in Fig. 8.



a)



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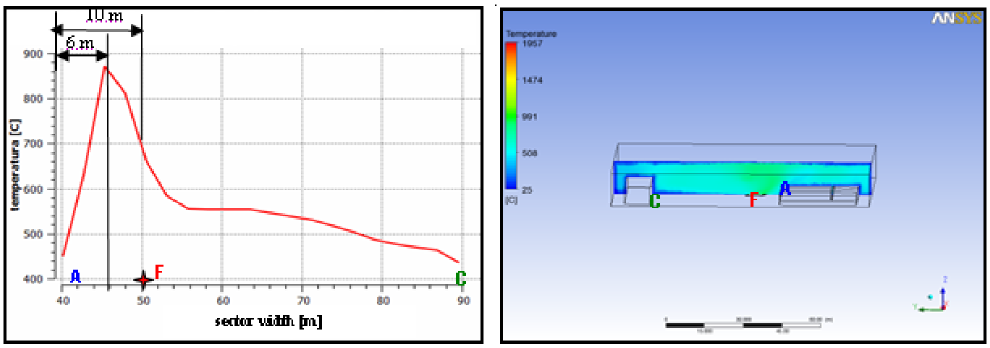


c)

Fig. 8 The temperature variation across the width of the casting sector (Y axis) at 1.7 m height at moments: **a)** M = 60 s; **b)** M = 300 s; **c)** M = 600 s

Interpretation of graphs and images presented in Fig. 8 reveals the following:

a) at M = 60 s:

- the highest temperature (1050^0 C) was recorded at a distance of 2 m from focus and not in the center of it as was supposed (see Fig. 8 a);

- at the floor level of the hall, the heat dissipates as a circular area. In the upper side of the hall an interesting phenomenon is highlighted. This consists in the heat flow trajectory deviation (mould cores sector) to the hall ceiling, while in the opposite part of the hall where the heat flux has not encountered obstacles it developed as a con;

b) at M = 300 s:

- the temperature is proportionally decreasing, in the focus center, with heat transfer, (470^0 C) which causes the turbulence to decrease, so that it can justify the highest temperature just above the focus;

- at a distance of 20 m from the center of the focus, towards the "C" point, the lowest temperature (252^0 C) was recorded followed by its growth on the extent of partitioning the wall in the proximity maintenance workshops (Fig. 8 c). The phenomenon could be attributed both to the ascending currents and heated air masses that accumulate at the top of the hall, after wards they redirected to the hall roof space, above the maintenance department and the hall floor. The formation of an area with temperatures of 290^0 C near the maintenance workshops as high as 10 m distance about the focus (298^0 C) may be influenced by the wall of the workshops, which acts as a screen which has the effect of returning the warm air currents;

- the trend of heat spreading mainly to the "A" point continues where the formation of areas with higher accumulation of heat in the space formed between the ceiling of pattern deposit, mould cores sector, mould and core mixture preparation and roof underside and, to a smaller extent, to the top of the hall center and the construction where the maintenance workshops are placed;

c) at M = 600 s:

- there is a new repositioning of the area with maximum temperature to the wall that separates the casting sector by mould cores sector at a distance of approximately 6 m from it, where the temperature is approx. 869^0 C (see Fig. 8 c);

- there is a change in the way in which the heat transfer takes place from the circular shape (spherical) to conical shape maintaining the trend of rest spreading to the top of the hall and in the mould cares sector and pattern sector areas;

- the temperatures at the points limit is clear, recording values of 449^0 C at point "A", respectively 439^0 C in point "C".

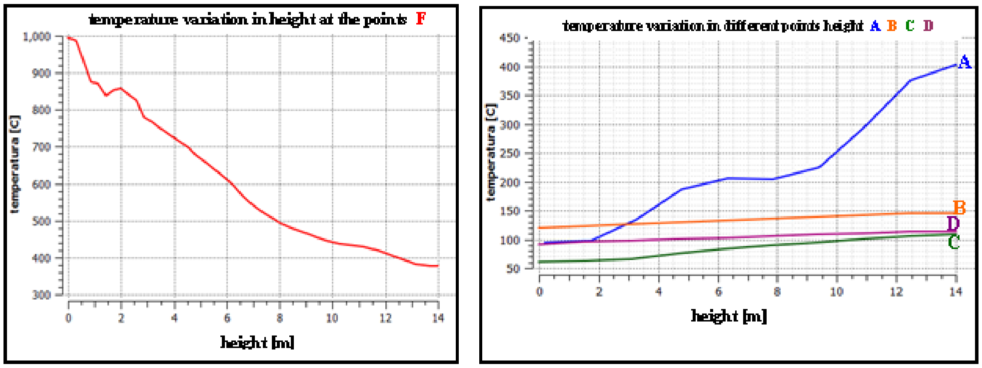
5.2 Transfer of convective heat and temperature variation in the vertical plane (Z axis) from the floor to a height of 14 m

The analysis was conducted on the height of the hall (Z axis), in point "F", "A", "B", "C" and "D" at intervals of 1 m from the top of the focus to the roof underside situated at a height of 14 m (considered the highest rate of construction). How temperature changes is shown in Table 7 and Fig. 9-11.

Table 7

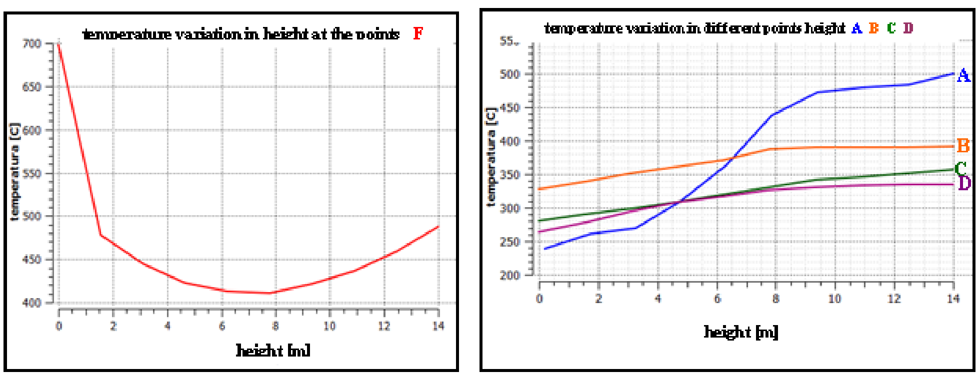
Temperature values (Z axis) over the focus and other established points

Hall height [m]	Time / Analysis point														
	M = 60 s					M = 300 s					M = 600 s				
	F	A	B	C	D	F	A	B	C	D	F	A	B	C	D
	Temperature [^{0}C]														
0	1000	96	120	63	92	700	239	328	280	265	693	449	429	427	414
1	867	98	124	65	94	571	250	335	288	273	698	452	438	432	420
2	860	107	127	67	99	467	264	343	294	282	691	458	443	446	428
3	768	130	129	69	100	443	270	351	299	295	686	475	450	461	436
4	723	162	130	72	102	430	290	358	305	304	688	546	454	480	443
5	667	191	132	78	103	421	329	365	310	310	702	638	460	494	451
6	618	204	134	84	104	413	352	370	320	318	737	702	478	504	458
7	540	208	137	89	106	411	400	380	327	322	768	733	474	510	460
8	496	208	139	92	109	412	442	389	334	328	783	741	482	511	464
9	471	220	140	96	110	421	464	390	340	330	781	748	490	509	468
10	443	254	141	100	112	430	476	390	344	332	785	753	495	505	470
11	432	307	143	103	114	439	480	390	348	334	800	760	500	500	470
12	420	350	145	108	116	454	483	390	351	335	812	767	503	496	469
13	392	387	148	111	118	467	490	391	354	335	718	773	500	488	467
14	378	403	148	113	118	490	500	392	359	335	811	780	498	483	464



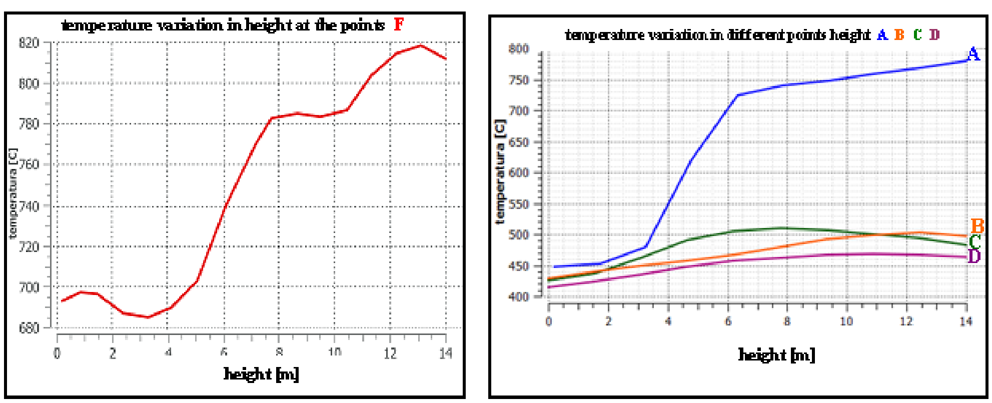
a) b)

Fig. 9 The temperature variation at M = 60 s the hall height (Z axis): **a)** the point "F" (above focus), **b)** the points "A", "B", "C" and "D".



a) b)

Fig.10 The temperature variation at M = 300 s the hall height (Z axis): **a)** the point "F" (above focus), **b)** the points "A", "B", "C" and "D".



a) b)

Fig.11 The temperature variation at the end of simulation (M = 600 s) the hall height (Z axis): **a)** above the focus (point "F"), **b)** above the points "A", "B", "C" and "D".

The analysis of the temperature variation shown in Table 7 and Fig. 9-11 shows that:

- due to the difference of density convection currents, the easier warm air masses determines the formation of a buoyancy phenomenon which explains the trend of increasing the temperature at the top of the hall (14 m height);

- the temperature of hot air masses accumulated in the hall ceiling leads to intense local thermal stress with negative effects on the stability of the metal roof structure (critical temperature of steel - 500^0 C);

- higher temperatures are recorded on the appropriate column of point "A" (on the edge wall of the casting and the mould cores sector) to point "B", "C", "D".

6. Conclusions

The experimental study on the heat transfer inside a closed space can be exploited in the identification and the localization of the places or areas with critical temperature both for the building and the employees. The main conclusions are the following:

1) in the first five minutes of liquid alloy overflow, heat dissipation occurs in circular (spherical) shape, followed by short period when heat transmission is achieved as a sphere –cone shape at the end of ten minutes of simulation a conical shape of heat dissipation is recorded;

2) the ascending direction of the warm air currents is disturbed and influenced by the presence or interposition of leaded or non-leaded bearing elements of construction bearing (partition walls, columns and beams of resistance, etc.). They act as barriers or screens reflecting the heat to the hall roof promoting the formation of zones with dangerous temperature for the metal structures;

3) the zones free of such construction elements allow free distribution of warm air currents and promote a uniform temperature;

4) the areas with a large accumulations of heat have an unstable aspect in the first minutes of heat propagation and the phenomenon of migration of these zones with critical temperatures is present here.

This study can be used in a wide and diversified spectrum of activities, such as:

a) analyzing the behavior and establishing the measures to protect the structural elements of the hall taking into account that:

- reaching the critical temperature of 450^0 C to 550^0 C in prestressed concrete and reinforced concrete leads to unequal expansion and loss of adhesion between the reinforcement and concrete, concrete boom followed by the yielding of the structural elements;

- metal structures are characterized by high thermal conductivity, but low thermal capacity and a temperature of 500^0 C leads to loss of strength, deformation and collapse;

b) identifying alternative strategies used in events such as an accident or fire inside the foundry hall and adopting effective protection measures (passive and active action or emerging fire burning) for the employees and the construction.

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