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Computer simulation of carburizers particles heating in liquid metal

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Abstract

In this article are introduced the problems of computer simulation of carburizers particles heating (anthracite, graphite and petroleum coke), which are present in liquid metal. The diameter of particles, their quantity, relative velocity of particles and liquid metal and the thermophysical properties of materials (thermal conductivity, specific heat and thermal diffusivity) have been taken into account in calculations. The analysis has been carried out in the aspect of liquid metal carburization in metallurgical furnaces.

Keywords: Liquid metal carburization, Computer simulation

1. Introduction

Nowadays in the process of cast iron melt the deficiency of carbon in liquid metal is more often completed by addition of carburizer. It can be added to charge in solid, on the surface of metal bath or in the stream of carrier gas.

In Department of Foundry, Silesian University of Technology, carburization process in analyzed in some aspects. The researches enclose implementation of synthetic cast iron melts with carburization by variety of carburizes and with using different methods of carburization [1,2,3,4].

Next considered problem is analysis of carburizers properties and types and their influence on structure and properties of obtained cast iron [5,6,7]. Third aspect is the process operation of computer simulation concerning particles heating and dissolution [8,9]. By addition of carburizers there is proceed a process of carburizer particles heating, which caused the change of carburizer temperature: from environment temperature (usually) to metal bath temperature. This process will depend on the diameter of particles, thermophysical properties of added carburizer and liquid metal as well as mutual movement of particles and metal bath. Time of particles carburization certainly has significant influence on carburization course and obtained indicators.

In that article there has been undertaken a test, which concerned analysis of carburization of the most often applied carburizers added to liquid metal (e.g. anthracite, graphite, petroleum coke). The particular attention has been drawn to the time of particles heating and the comparison between that time and the time of particles floating on surface of metal bath has been done. Higher indicators can be obtained while particle heats to the temperature of liquid metal, before its floating on the surface. Calculation presented in that article has been carried out by using FLUENT program [10,11].

2. Computer simulation

In GAMBIT program had been modelled some geometries, which has been used in computer simulations. With FLUENT program there have been made simulations of carburization particles. It has been supposed, that carburization process would be implemented in the cube with dimensions 12x12x12 mm,

fulfilled with liquid cast iron, which temperature would be 1723 K.

Particles of graphite, anthracite and petroleum coke have been placed in that cube. The quantity of particles has been assumed correspondingly 1, 8, 27. On the basis of that assumptions, there have been carried out some calculations of the particles diameter in dependence to assumed carbon increment in liquid metal. The diameter of particles has been well-suited so as to weighed part of added carburizer amounts to 3,1%. It comes from the fact, that in synthetic cast iron melt, carried out on the basis of steel scrap, carbon deficiency, which should be completed through carburization, amounts to 3,1%. As the result of calculations, the following particles' diameters have been selected: 7 mm for single particle, 3,5 mm for eight particles and 2,3 mm for twenty seven particles. In consideration of system symmetry, two-dimensional system has been applied in calculations, in which 1, 4 and 9 particles are visible. Suggested systems are shown on Fig. 1.

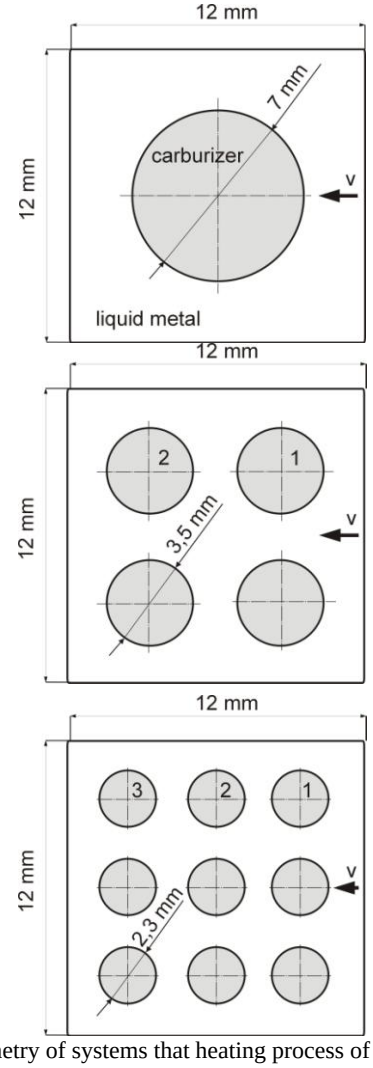

Fig. 1. Geometry of systems that heating process of particles have been simulated for

Origin temperature of particles has been supposed about 300 K. Calculations have been carried out for three materials: anthracite, graphite and petroleum coke. In the process of analysis, knowledge of thermal conductivity (λ), specific heat (c_p) and thermal diffusivity (a) is significant problem. Relationship between these parameters is following: $\lambda = c_p\ \rho a$, where ρ is substance density.

Thermal conductivity of carbon materials and graphitoidal materials differs considerably. Graphitoidal materials conduct heat good, occupying intermediate place between aluminum and ordinary steel, in respect of thermal conductivity coefficient. Whereas carbon materials are characterized by thermal conductivity coefficient lesser than graphitoidal materials to hundred times. Thermal conductivity coefficient (λ) of different carbon and graphitoidal materials might oscillate in wide range and depends on such factors as type of raw materials, production technology, density, size and orientation of graphite crystals and so on. Thermophysical properties used to calculations of materials are presented in tables 1 to 3.

Table 1.
Thermophysical properties of graphite

T [^{o}C]	0	200	600	1000	1600	2000
λ [W/(mK)]	135	103	79	47	21	12
c_p [J/(kgK)]	600	1170	1470	1930	2060	2170
a [mm^2/s]	118,4	46,33	28,28	12,82	5,37	2,91

Table 2.
Thermophysical properties of petroleum coke KN1

T [^{o}C]	16	499	1001	1499
λ [W/(m K)]	2,152	5,145	6,869	9,632
c_p [J/(kg K)	780	1705	1970	2005
a [mm^2/s]	1,678	1,839	2,121	2,922

Table 3.
Thermophysical properties of anthracite A1

T [^{o}C]	16	499	999	1499
λ [W/(m K)]	1,663	3,011	3,299	3,875
c_p [J/(kg K)	753	1635	1897	1913
a [mm^2/s]	1,319	1,100	1,039	1,210

The following densities have been supposed for these materials: for graphite – 1900 kg/m^3, for petroleum coke - 1644 kg/m^3 and for anthracite 1674 kg/m^3. Mutual movement of liquid metal and added carburizers has been supposed in the calculations. It comes from the fact that operation of carburization in induction furnaces or insertion of carburization in stream of compressed air has been assumed. Both in first and especially in second case intensive movement of metal bath occurs. Three levels of velocity have been supposed: 0,01 m/s, 0,1 m/s and 0,5 m/s.

Obtained images of temperature profile for specified amount of particles at given time by different velocity of metal flow is presented on figures from 2 to 7.

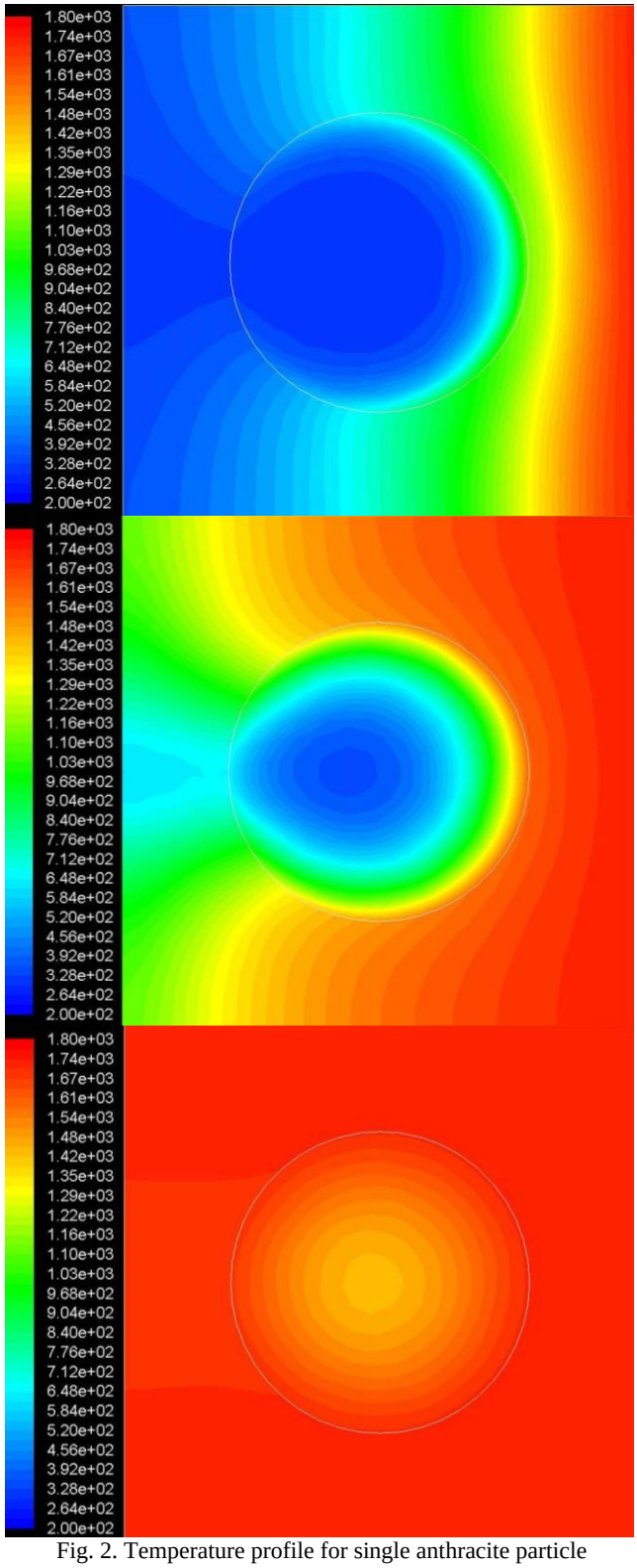

Fig. 2. Temperature profile for single anthracite particle in time t=0,3s, t=0,8s and t=4,5s for v=0,01m/s

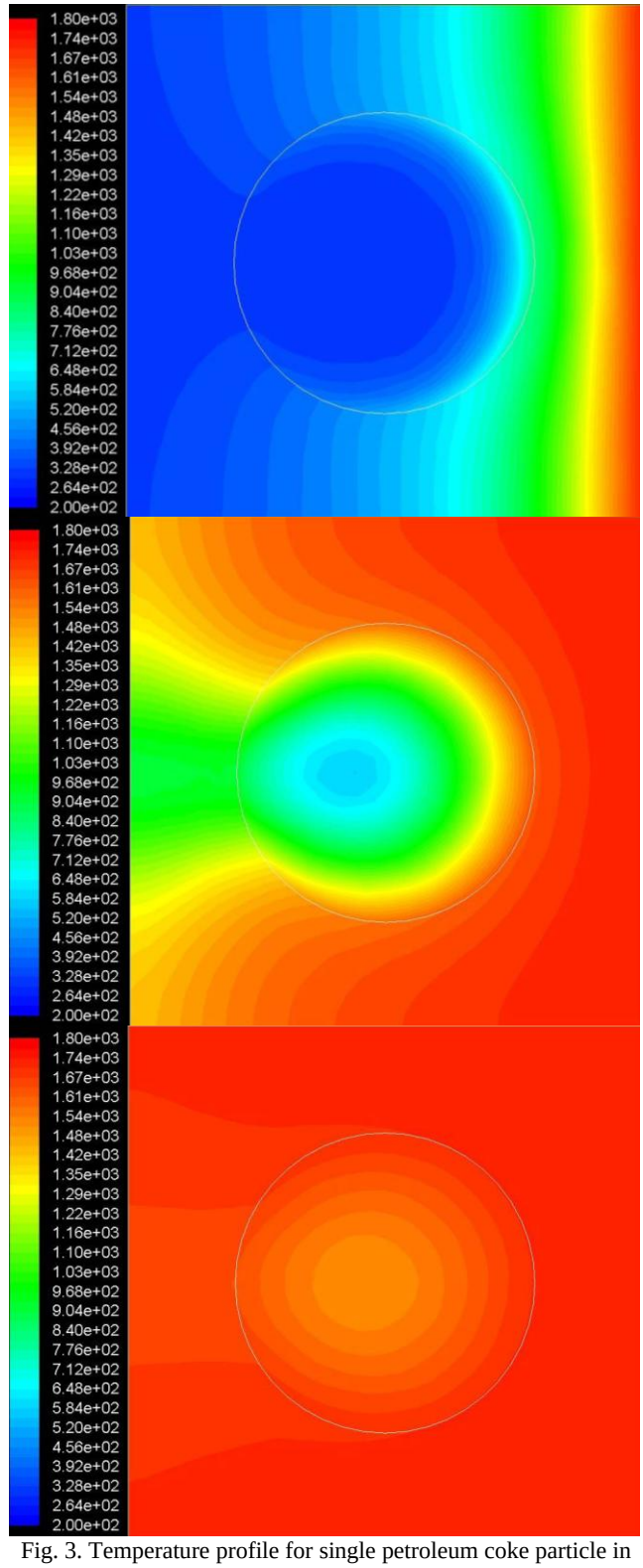

Fig. 3. Temperature profile for single petroleum coke particle in time t=0,2s, t=1,1s and t=3,1s for v=0,01m/s

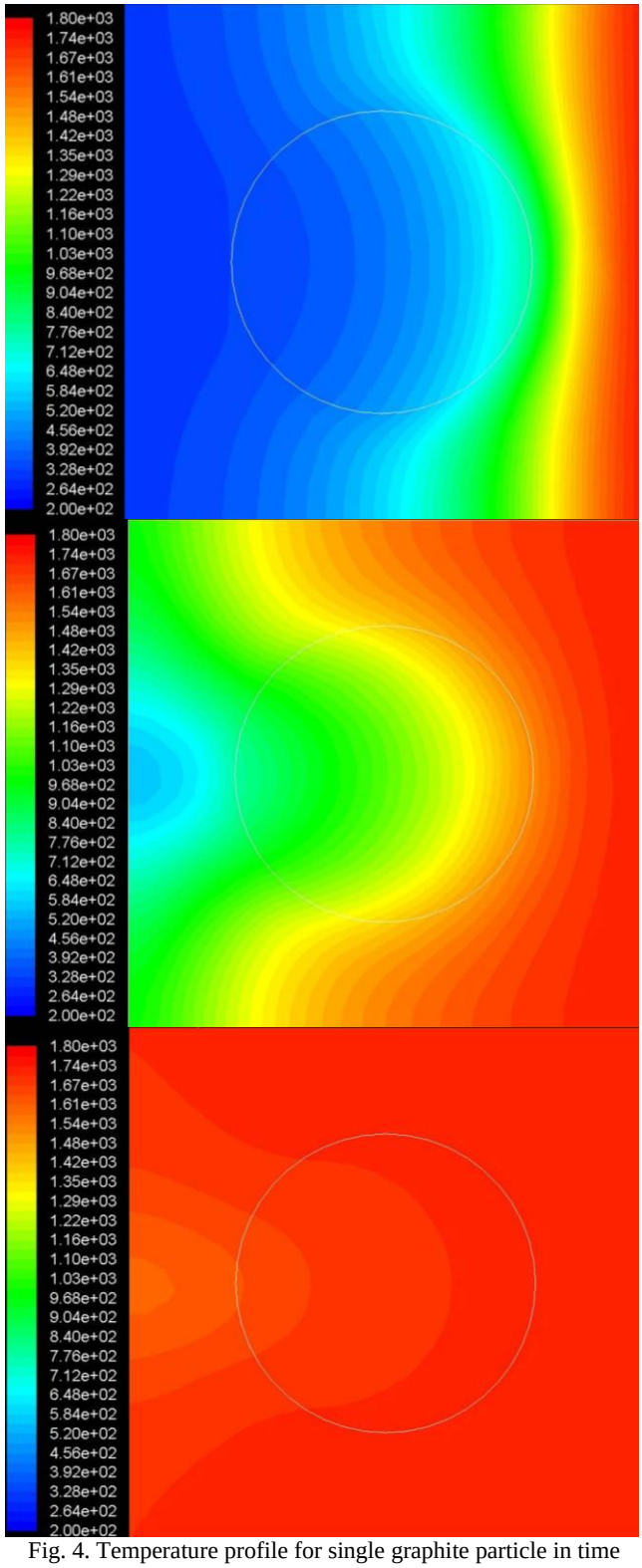

Fig. 4. Temperature profile for single graphite particle in time t=0,25s, t=0,75s and t=2s for v=0,01m/s

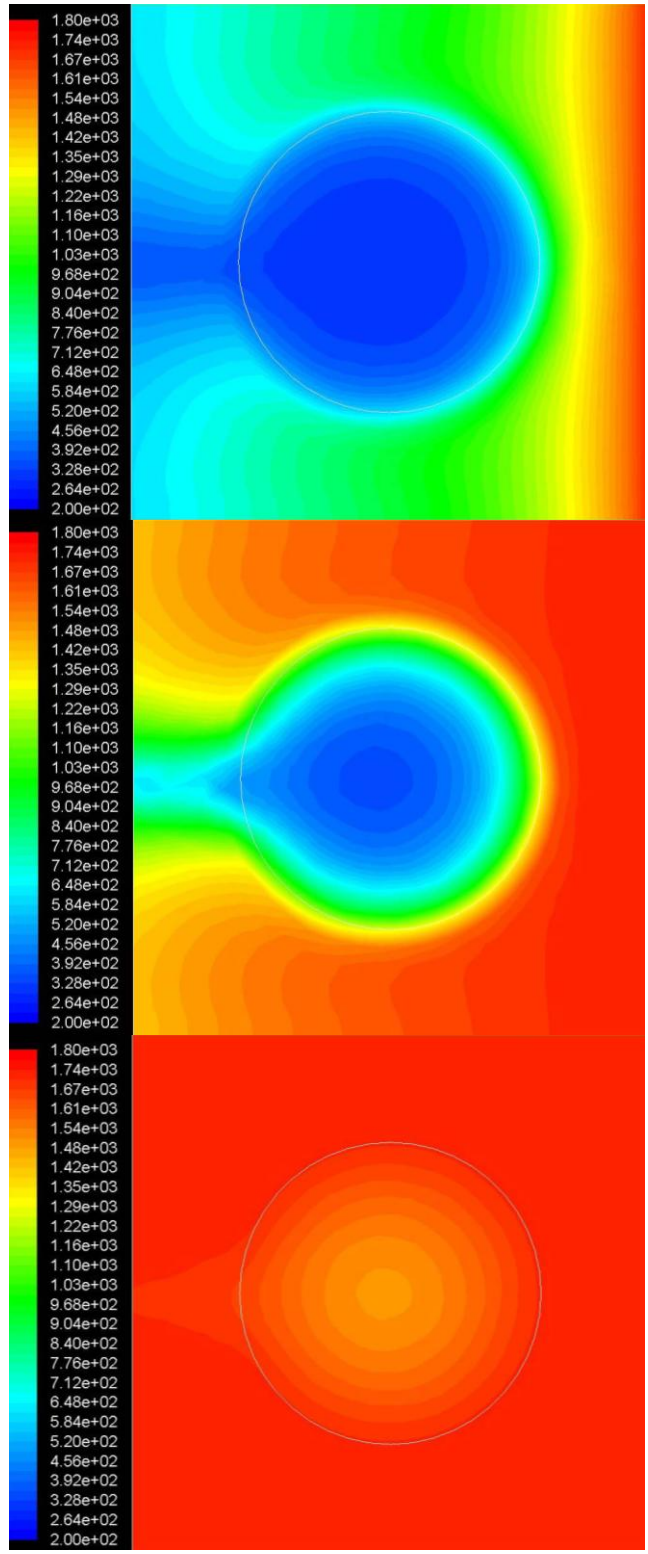

Fig. 5. Temperature profile for single graphite particle in time t=0,01s, t=0,03s and t=0,28s for v=0,5m/s

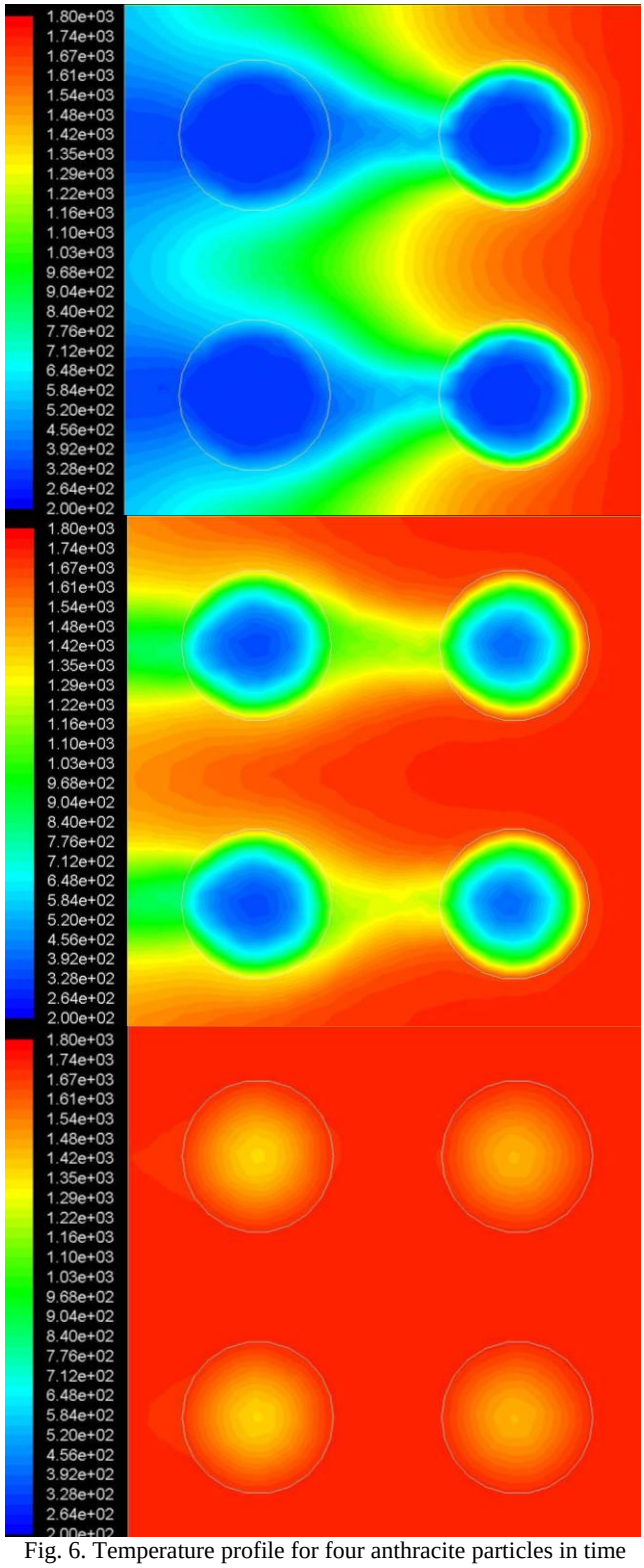

Fig. 6. Temperature profile for four anthracite particles in time t=0,05s, t=0,15s and t=1s for v=0,1m/s

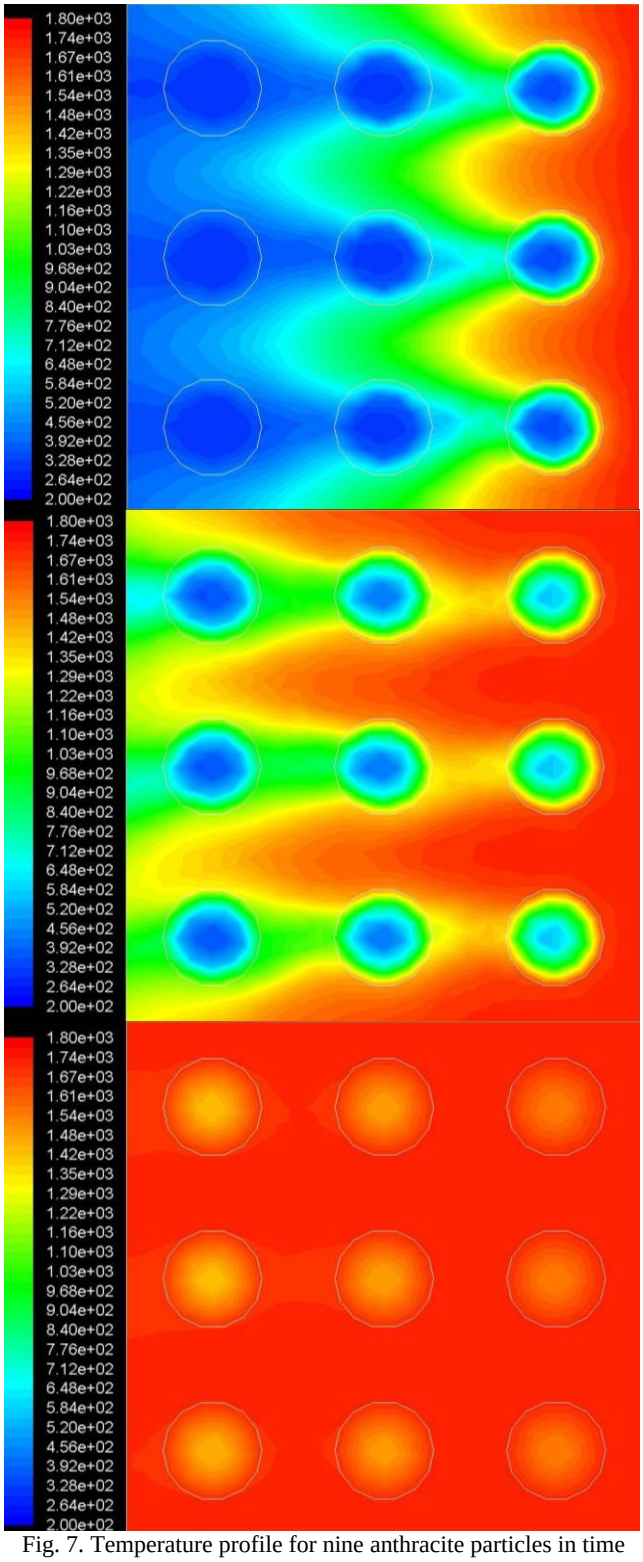

Fig. 7. Temperature profile for nine anthracite particles in time t=0,04 t=0,1s and t=0,5s for v=0,1m/s

3. Analysis of calculations results

The results of carried out computer simulations shows that times of particles heating differ considerably, in dependence of supposed carburizer as well as diameter and mutual velocity of analyzed materials.

Times of single particle heating for three analyzed carburizers by velocity amounts to 0,1 m/s are presented on Fig 8. One can notice from diagram, that graphite becomes heated rapidest, then is petroleum coke and the last is anthracite. Graphite reaches temperature 1721K after 1s time, while petroleum coke reaches after 1s time temperature 904K and anthracite 556K. Petroleum coke becomes heated to temperature 1721K in time of 5,9s and anthracite reaches that temperature after 9,7 s. Obtained results of calculations point out, how significant meaning have thermophysical properties in processes of numerical calculations, because only these data have been changing in considered issue. It means, that in carburization processes the best carburizer should be graphite. Anthracite becomes heated most slowly, what proofed results of experiments, in which obtaining high effectiveness of anthracite carburization demands long time of metal bath heating.

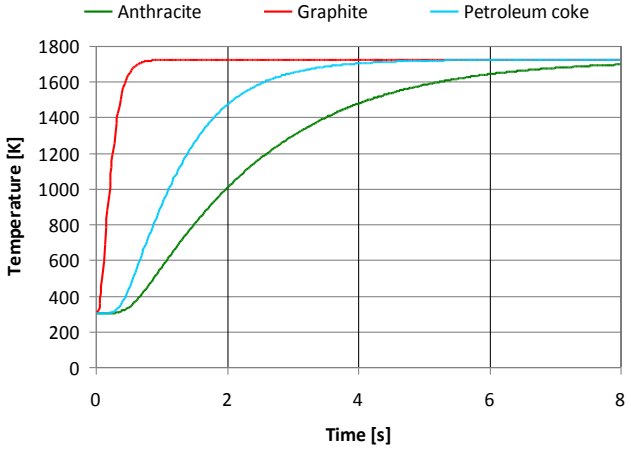

Fig. 8. Statement of simulation results for particle heating of diameter 7mm by velocity 0,1 m/s, made from different materials

Calculations of graphite particles heating time with variable velocity of liquid metal flow are presented on Fig 9. In this case, significant influence of metal movement in regard to particles on heating time is visible. With little mutual movement of carburizer and metal bath (0,01 m/s), heat exchange would progressed very slowly. Velocity increase leads to increase of temperature gradient, which intensifies course of this process considerably. One can notice, that heating of graphite particles to temperature 1721K with mutual movement of carburizers and liquid metal amounts to 0,5 m/s lasts 0,77s. Velocity decrease to 0,1 m/s causes extension of heating time to 1s and with the velocity 0,01 m/s it lasts 3,7s.

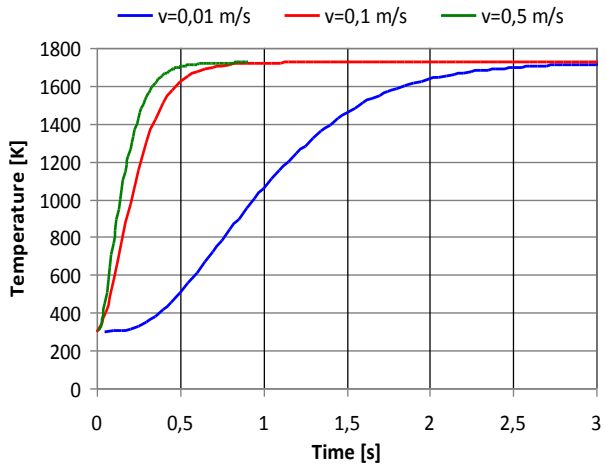

Fig. 9. Statement of simulation results for graphite particle heating of diameter 7 mm and three velocities of flow

Interesting results have been obtained by heating of single anthracite particle for three analyzed velocities of metal movement (Fig 10). In case of anthracite (the material with lesser thermal conductivity), metal movement has considerably lesser meaning than by graphite particles, that follows from calculations. In that case, for all values of relative motion velocity particle becomes heated relatively slowly. After passing 1s time anthracite particle reaches temperature 366K with velocity 0,01 m/s, for velocity 0,1 m/s particle temperature amounts to 554K and for velocity 0,5 m/s it becomes heated after time of 1s to temperature 587K. After passing 10 s time temperatures of anthracite particles practically equalize themselves, reaching correspondingly 1707K, 1714K and 1715K.

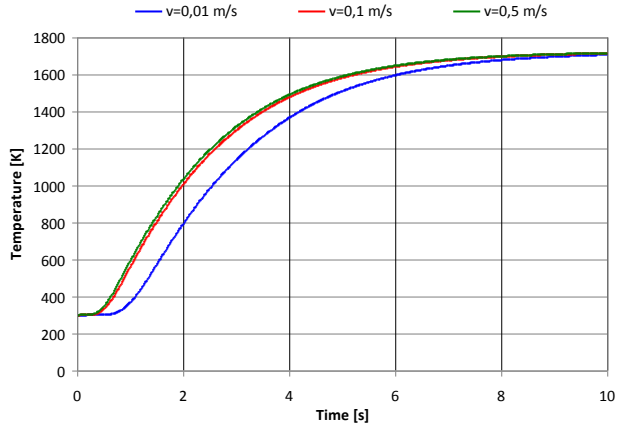

Fig. 10. Statement of simulation results for heating of anthracite particles of the diameter 7mm and three velocities of flow

Next parameter analyzed in the process of particles heating was their diameter. Statement of obtained calculations results for graphite particles, displacing with the velocity 0,1 m/s are presented on Fig 11. It is visible, that heating of particle with diameter 7mm lasts longest period of time and for particles with diameter 2,3 mm – shortest.

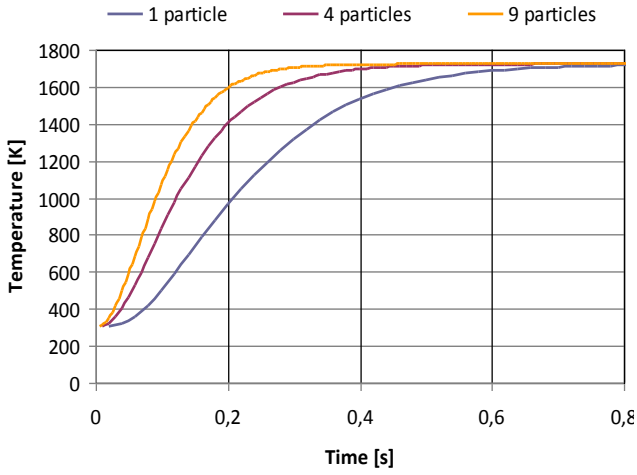

Fig. 11. Statement of simulation results for heating of graphite particles with velocity of metal movement v=0,1 m/s

The statement of heating time for anthracite particles, present in following grades (Fig 1) with velocity of metal flow v=0,01 m/s have been presented on Figure 12. It is obvious, that particles in first grade will become heated most rapidly and particles in third grade - most slowly. Increase of flow velocity will cause decrease of differences between heating times.

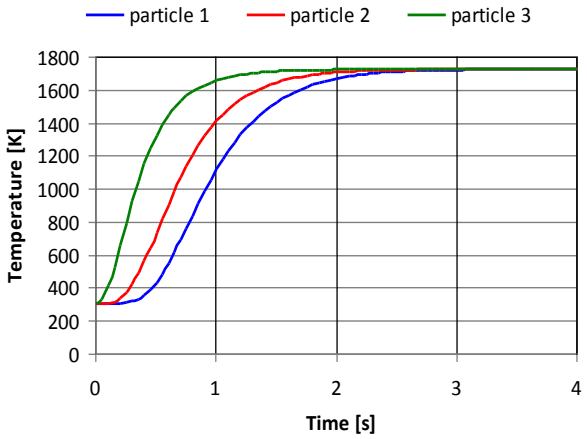

Fig 12. Statement of simulation results for graphite particles heating in following grades with velocity of metal movement v=0,01 m/s

Summarizing the analysis of obtained calculations results of computer simulation considering particles heating one can notice that small graphite particles, moving with high velocity will become heated rapidly, in regard to liquid metal.

4. Particles floating

Significant phenomenon in carburization of metal bath is floating of powder particles on bath surface. First of all it comes from the difference between carburizers density and liquid metal. Velocity of this movement is the dependence resulting from analysis of forces, operative on particle submerged in liquid medium (gravitational force, buoyant force and force of movement resist – Stokes force) [12,13]:

$$v = 0{,}0556 \cdot \left(\frac{\rho_1 - \rho_2}{\eta} \right) \cdot d^2 g \qquad (1)$$

where: g – gravitational acceleration [m/s^2], d – density of suspended particle, ρ_1 – density of liquid metal [g/cm^3], ρ_2 – density of added carburizer particles [g/cm^3], η – coefficient of liquid internal friction (viscosity) [g/cm s].

It is significant, that particle added to metal bath before floating on surface undergoes dissolving. Then degree of carburizer utilization will be the highest. Therefore using presented dependence we can determine the time, in which particle added to liquid metal should dissolve before its floating on surface. On the basis of equation (1) calculations of particles floating time have been carried out in regard to its density and submerge depth by determined temperature and carbon content in metal bath (Table 4). From these two parameters will depend density and viscosity of liquid metal [14,15].

Table 4.
Flow out time of particles for η=5,47 [mPa·s]; T=1400C and for carbon content C=3,18%

depth	diameter of particle [mm]			
[mm]	0,5	2,3	3,5	7
50	0,38	0,018	0,0077	0,0019
100	0,76	0,036	0,0155	0,0039
150	1,14	0,054	0,0232	0,0058
200	1,52	0,072	0,0310	0,0077
250	1,90	0,090	0,0387	0,0097
300	2,28	0,108	0,0465	0,0116
350	2,66	0,126	0,0542	0,0136
400	3,04	0,143	0,0619	0,0155
450	3,41	0,161	0,0697	0,0174
500	3,79	0,179	0,0774	0,0194

Obtained results shows that as of particle diameter increases, velocity of its floating on surface increases as well, which leads for shortening time of particle being in liquid metal. It is visible, that particle with diameter 0,1 mm, submerged on 500 mm depth will float through 94,86 s. For particle of diameter 7 mm this time will amounts to fraction of seconds.

Statement of particles heating time for three analyzed carburizers with different velocities and diameters to temperature 1700 K are presented in Table 5.

Table 5.
Particles heating time to temperature 1700 K

carburizer	velocity [m/s]	diameter of particle [mm]		
		2,3	3,5	7
anthracite	0,01	1,36	2,20	9,3
	0,1	0,50	0,91	2,76
	0,5	0,26	0,55	1,77
petroleum coke	0,01	1,25	1,96	4,40
	0,1	0,34	0,68	2,20
	0,5	0,23	0,50	1,45
graphite	0,01	1,10	1,55	2,61
	0,1	0,19	0,40	0,70
	0,5	0,08	0,14	0,45

Comparing calculations results of particles floating and heating times placed in Table 4 and 5 one can claimed that only graphite particles with 2,3 mm diameter, submerged on min. 500 mm will manage to heat on time before floating on surface.

Acknowledgements

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