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The problems connected with the solidification parameters estimation

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Abstract

In the article results of thermo-physical properties estimation are presented. Thermo-physical properties estimation was carried out with trial-and-error method on the base of the model computer simulations results. In the first step the computer simulations of self-cooling and heating processes for different thermo-physical properties of specimen alloy and for proposed two testers geometry was carried out. Thermo-physical properties of specimen alloy were artificial, assumed by author. The results of simulation in the form of self-cooling and heating curves were used in the second step of work. In the second step the computer simulations to thermo-physical properties estimation by trial-and-error method was carried out. In these simulations only thermo-physical properties of specimen alloy were estimated, thermo-physical properties of others materials and boundary conditions were exactly the same as in model simulations. Finally thermo-physical properties assumed in first step were compared to estimated in second step.

Keywords: Application of information technology to the foundry industry, Thermo-physical properties, Computer simulation solidification

1. Introduction

The knowledge about thermo-physical properties is crucial element of designing process with use CAD and CAE software, designing manufacturing technology of products made of metal alloys. Technologies where shaping of products properties, right for environment of work, take place on the way of right conducted thermal processes [1]. Applying in foundry engineering different alloys creates necessity to work out methods to determination physical properties, which might be used in CAE software. It is essential problem, because data available in literature concerns only common materials, however there is no data for many alloys, moreover these data sometimes are differ in dependence of their determination method.

Determination of physical properties changeable in temperature and first of all specific heat, thermal conductivity and latent heat of crystallization might be carried out with calculating or experimental methods [2,4]. Often the experimental methods are used to verification of mathematical analysis [5].

There is still lack of comprehensive and universal method for determination the thermo-physical properties of metal alloys. Method with the help of which might be quick and accurately determined set of thermo-physical properties for CAE type software that are common and common in foundry engineering [1,3].

2. Aim and scope of research

The main aim of work was comparison thermo-physical properties estimated with trial-and-error method on the base of self-cooling and heating curves generated in model computer simulations with thermo-physical properties used in these model simulations. Model simulations were made instead real experiment to avoid influence of unknown precisely thermo-physical properties additional material (e.g. sand mould, boundary conditions etc.) on results of estimation. Only thermo-physical properties of “specimen” material were estimated.

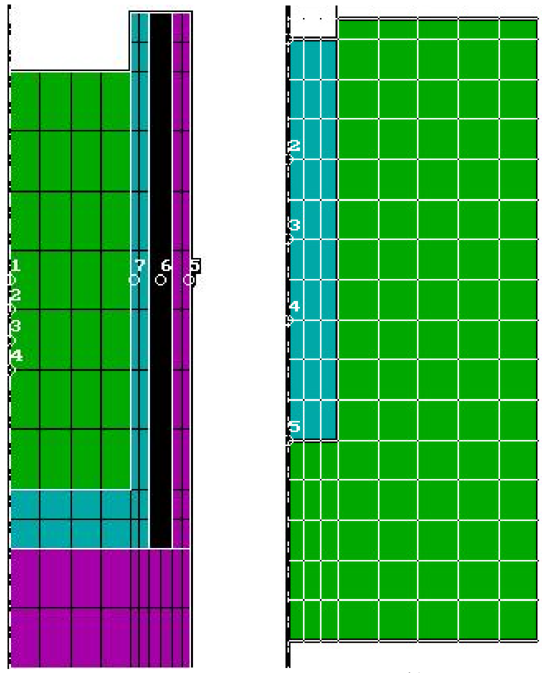
In the first stage of work was carried out model computer simulations of self-cooling and heating processes for different thermo-physical properties of specimen and for proposed two geometries. Two significantly different geometry of virtual tester was proposed to avoid accidental favorable conditions. Proposed geometries are presented in figure 1.

In geometry no 1, presented in figure 1a, specimen was in shape of cylinder diameter 40mm and height 70mm. Specimen was surrounded with layer of ceramic material and next layer of metal that imitating heating elements of resistance furnace and next another layer of ceramic material. The whole set was placed on base thickness 20mm also made of ceramic material. Temperature of specimen was measured and recorded in four points (P1-P4) placed on specimen axis of symmetry. To control also additional three measuring points was placed (P5-P7)

In geometry no2, presented in figure 1b, specimen was in shape of cylinder, diameter 25mm and height 100mm. Specimen was placed in mould made of thermo-insulating material. The mould surrounded side surface of specimen and one of head surface; thanks this heat flow was similar to unidirectional flow along to specimen axis. The second head surface was a surface of the heat exchange between specimen and gas burner during heating process and surroundings during self-cooling process. Temperature of specimen was measured and recorded in five points (P1-P5), first point was placed on heat exchanging surface the next were placed in distance 30, 50, 70 and 100mm from it.

The following physical properties changeable in temperature have been artificially assumed:

Thermal conductivity – λ [W/m·K],
Specific heat – Cp [J/kg·K],
Latent heat of crystallization – Qk [J/kg·K],
Density – ρ [kg/m^3].



a) b)

Fig. 1. Geometry of testers with differential mesh

In case of geometry no 1, model simulations were carried out for two different artificially assumed by author thermo-physical properties of specimen that are presented in figures 2 and 3.

In case of geometry no 2, model simulations were carried out for four different artificially assumed by author thermo-physical properties of specimen that are presented in figures 2 and 4- 6.

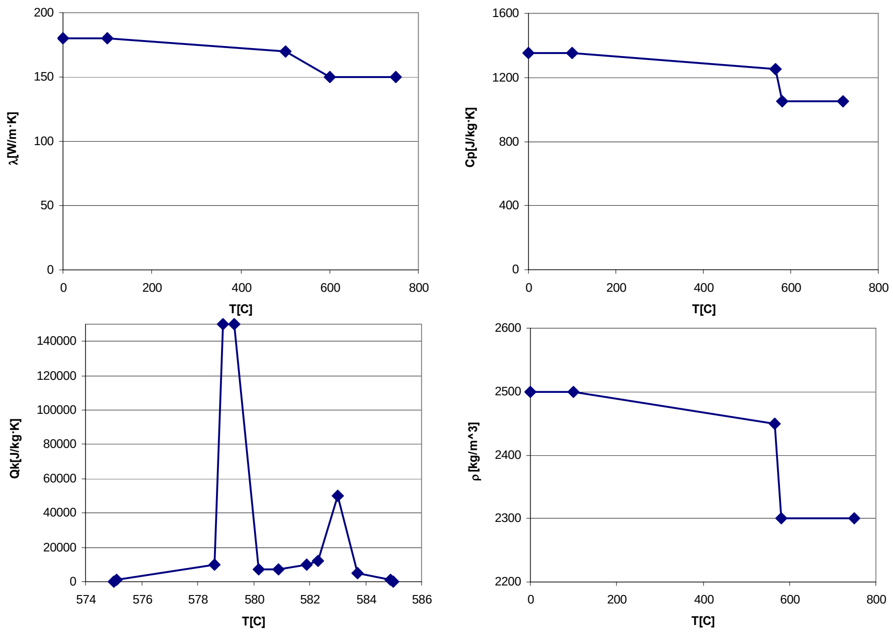


Fig. 2. Assumed thermo-physical properties – geometry no 1, data no 1 (1.1); and – geometry no 2, data no 1 (2.1)

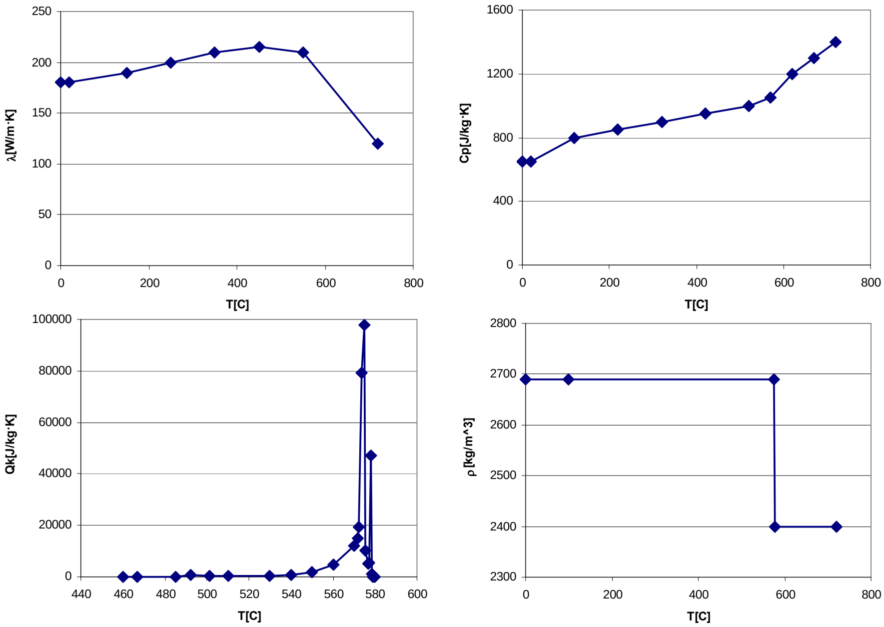


Fig. 3. Assumed thermo-physical properties – geometry no 1, data no 2 (1.2)

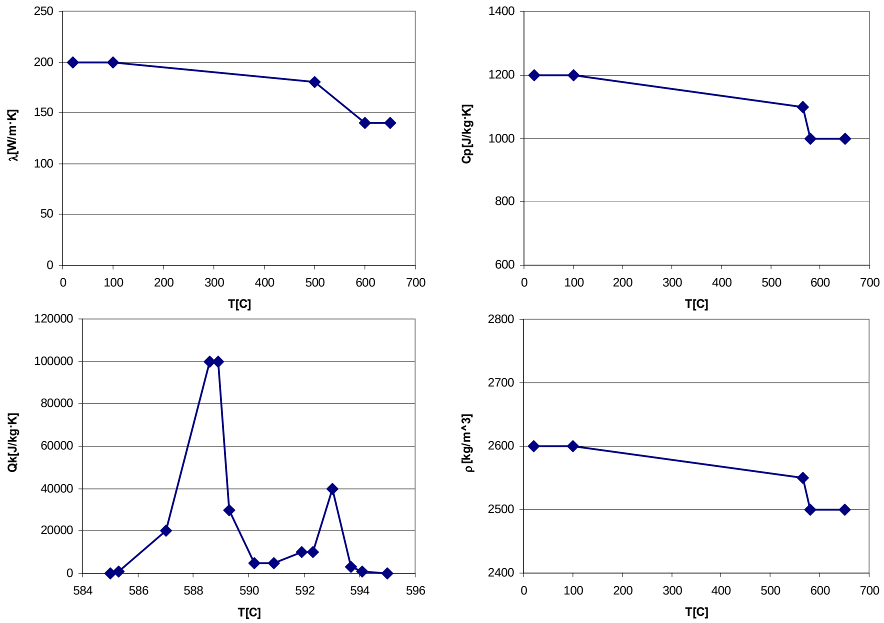


Fig. 4. Assumed thermo-physical properties – geometry no 2, data no 2 (2.2)

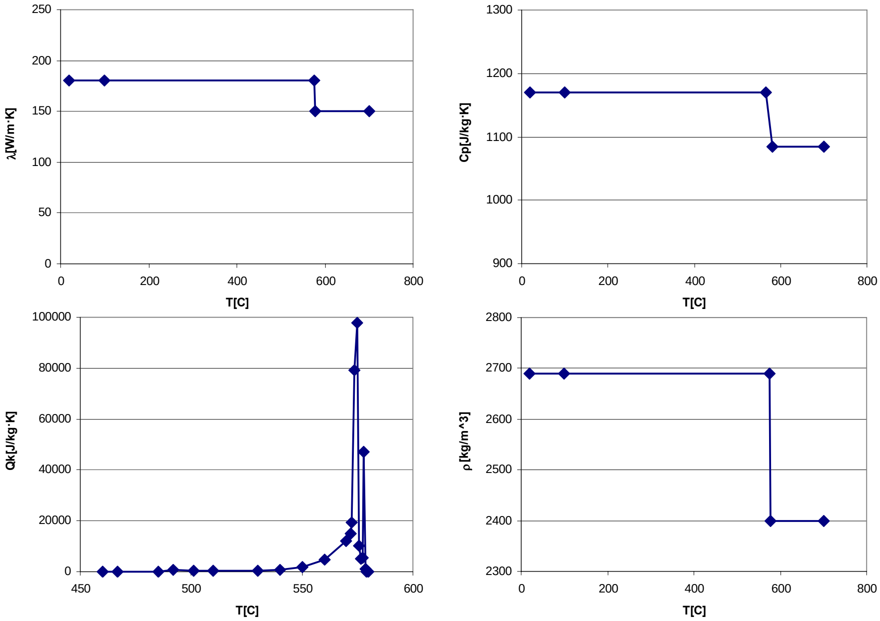


Fig. 5. Assumed thermo-physical properties – geometry no 2, data no 3 (2.3)

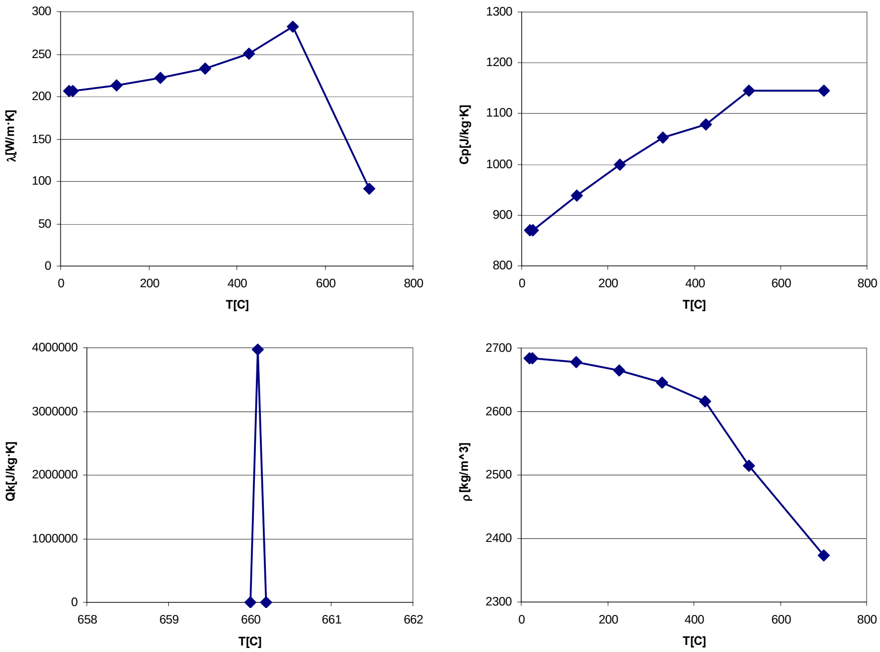


Fig. 6. Assumed thermo-physical properties – geometry no 2, data no 4 (2.4)

For such assumptions model computer simulations were carried out. As a result eight sets of heating (designed with N) or self-cooling (designed with S) curves had been obtained. These curves were a base of thermo-physical properties estimation by trial-and-error method. Examples of set of curves for cases 1.1N (geometry no 1, thermo-physical properties of specimen no 1, heating process N) and 2.2S (geometry no 2, thermo-physical properties of specimen no 2, self-cooling process S) are presented in figure 7.

All computer simulations i.e. model and made in frame of estimation process were carried out with ColdCAST software moreover with the exactly the same space and time discretisation.

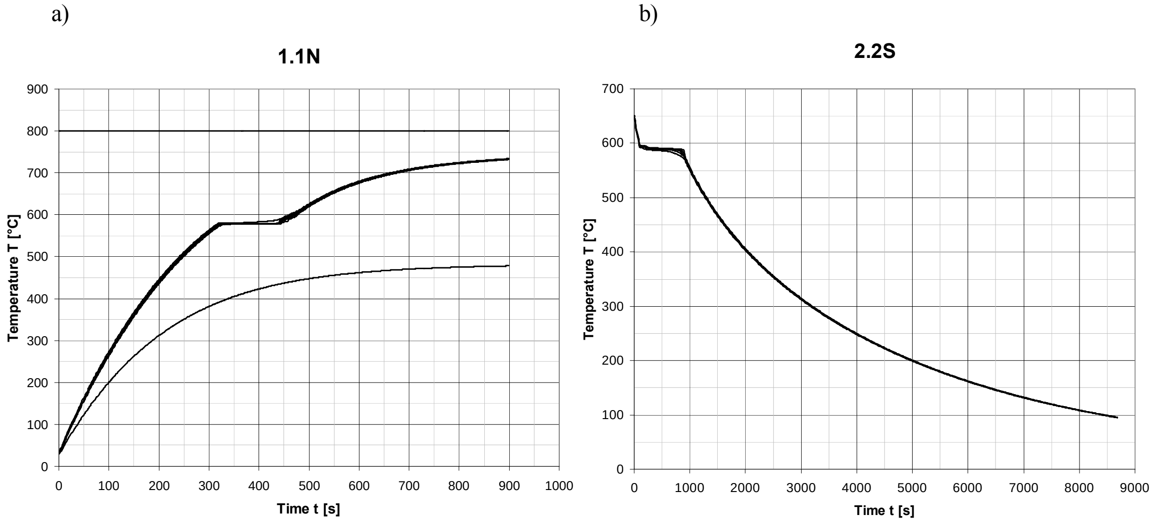


Fig. 7. Change of temperature; a) geometry no 1, data no 1, heating process N; b) geometry no 2, data no 2, self-cooling process S

IN the second stage of work was carried out estimation process with trial-and-error method. Thermo-physical properties estimation process consisted in making simulations for modifying thermo-physical data of specimen until satisfactory matching of curves, for model and estimating data, was obtained. Persons (Students from Department of Foundry, Silesian University of Technology) who were caring out estimation process did not know what thermo-physical data of specimen had been used in model simulations. Examples of satisfactory matching are presented in figure 8 and 9. Additionally to evaluate degree of this matching following parameter was calculated according to equation (1) it might be called relative difference. If the value of relative difference decrease below 2% estimation was ended. Values of this parameter calculated for each considered cases of geometry and thermo-physical data are presented in table 1.

$$\Delta T' = \frac{\sum \left| \dfrac{Tzo_i - Tp_i}{Tp_i} \right|}{n} \cdot 100\% \tag{1}$$

where:

Tzo_i – temperature in measuring point for „i" time step of simulation making in frame of estimation process[˚C],

Tp_i – temperature in measuring point for „i" time step of model simulation [˚C],

n – number of time step in simulation,

$\Delta T'$ – relative difference of temperature value in measuring point [%].

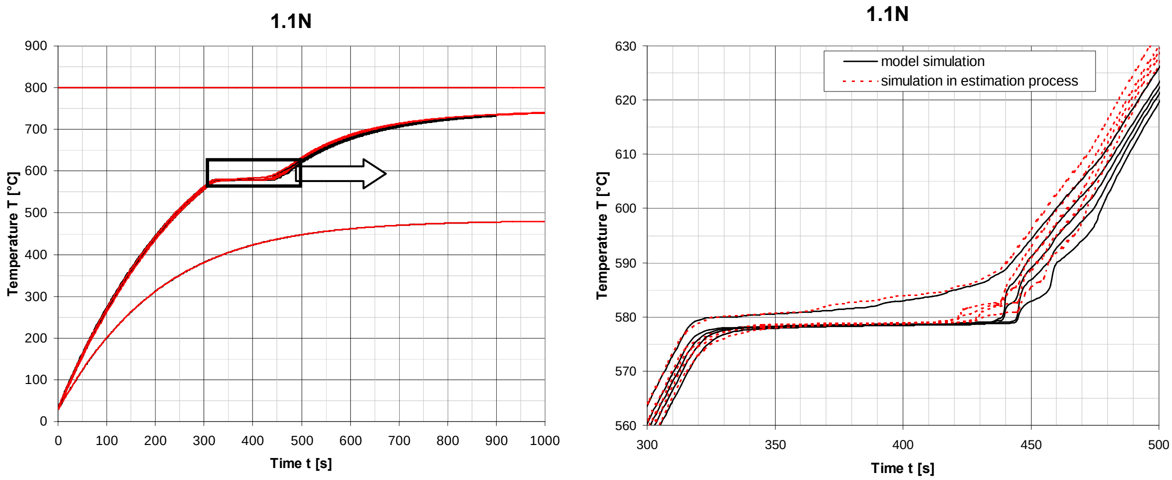


Fig. 8. Satisfactory matching of temperature curves – geometry no 1, data no 1, heating process N

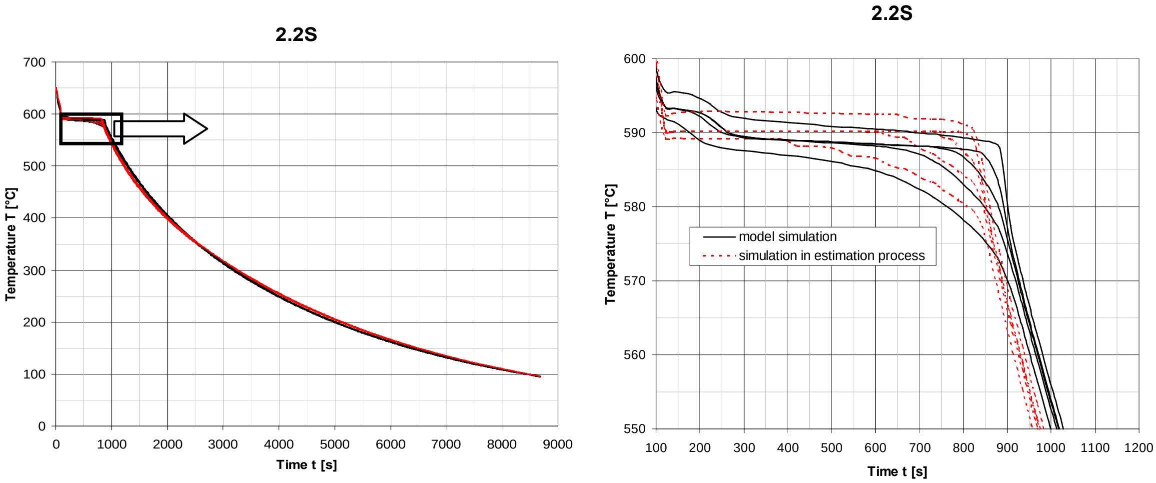


Fig.9. Satisfactory matching of temperature curves – geometry no 2, alloy no 2, self-cooling process S

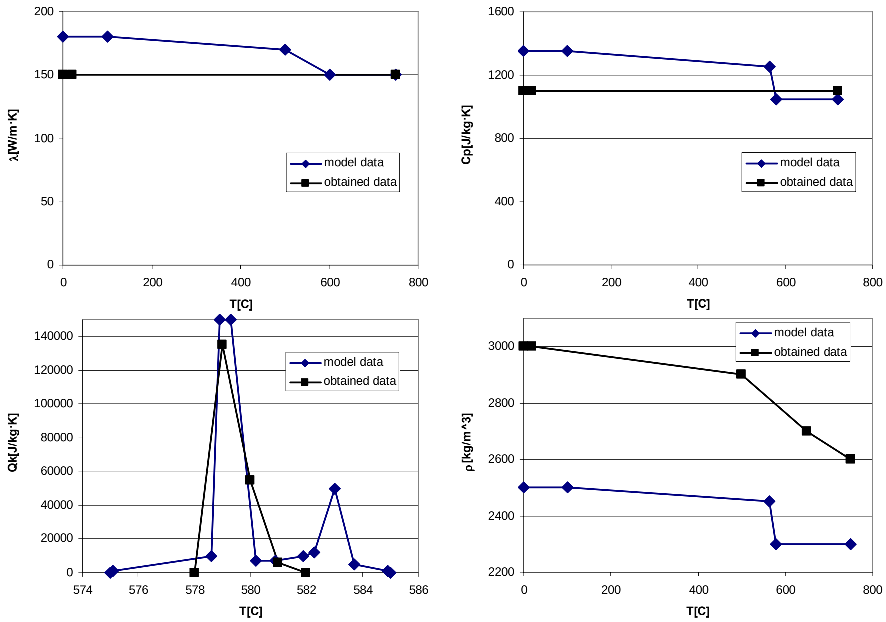


Fig. 10. Comparison of thermo-physical data used in model simulation with estimated – geometry no 1, data no 1, heating N (1.1N)

Table 1.
Values of relative difference of temperature in measuring points

	ΔT' [%]						
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
1.1N	0,49	0,48	0,47	0,46	0,0007	0	0,54
1.2N	0,57	0,57	0,58	0,58	0,001	0	0,55
1.1S	0,33	0,32	0,32	0,31	0,25	0,28	0,32
1.2S	0,89	0,89	0,91	0,91	0,71	0,79	0,87
2.1N	0,75	0,75	0,76	0,77	0,75		
2.2S	1,53	1,55	1,56	1,57	1,57		
2.3N	1,72	1,14	0,99	0,91	0,89		
2.4S	0,75	0,74	0,74	0,74	0,75		

3. Results

As a result of thermo-physical properties estimation with trial-and-error method carried out for each considered cases, estimated thermo-physical data of specimen material has been obtained. In order to comparison model thermo-physical data and obtained within estimation process are presented in figures 10 – 17 in form of diagrams. For the sake of too few values that describe change of physical properties in temperature, full evaluation of difference between model data and estimated was hard to carry out. Therefore to show differences between these data in form of one value the equation (2) was applied. Values of relative difference of temperature in measuring points ΔT' and values of relative differences of thermo-physical properties ΔTF for each considered cases are presented as a statement in table 2.

$$\Delta TF = \frac{mTF - eTF}{mTF} \cdot 100\% \tag{2}$$

where:
mTF – surface area under diagram of model thermo-physical property,
eTF – surface area under diagram of estimated thermo-physical property,
ΔTF – relative difference of thermo-physical property [%].

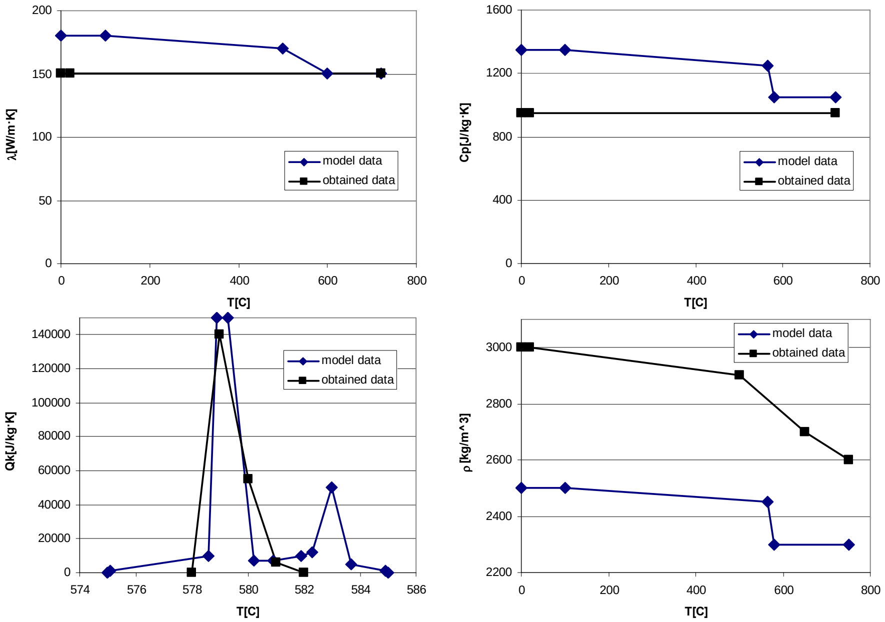


Fig. 11. Comparison of thermo-physical data used in model simulation with estimated – geometry no 1, data no 1, self-cooling S (1.1S)

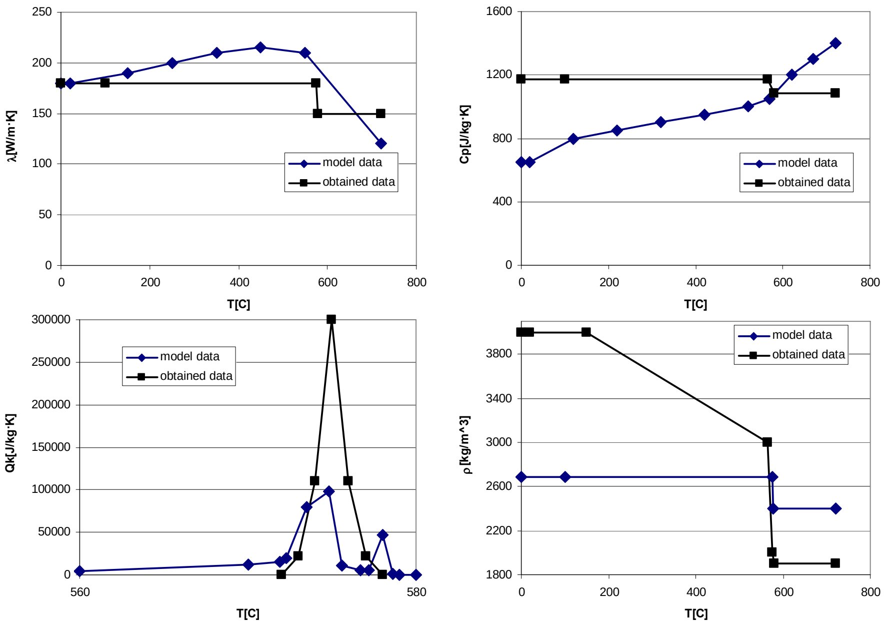


Fig. 12. Comparison of thermo-physical data used in model simulation with estimated – geometry no 1, data no 2, heating N (1.2N)

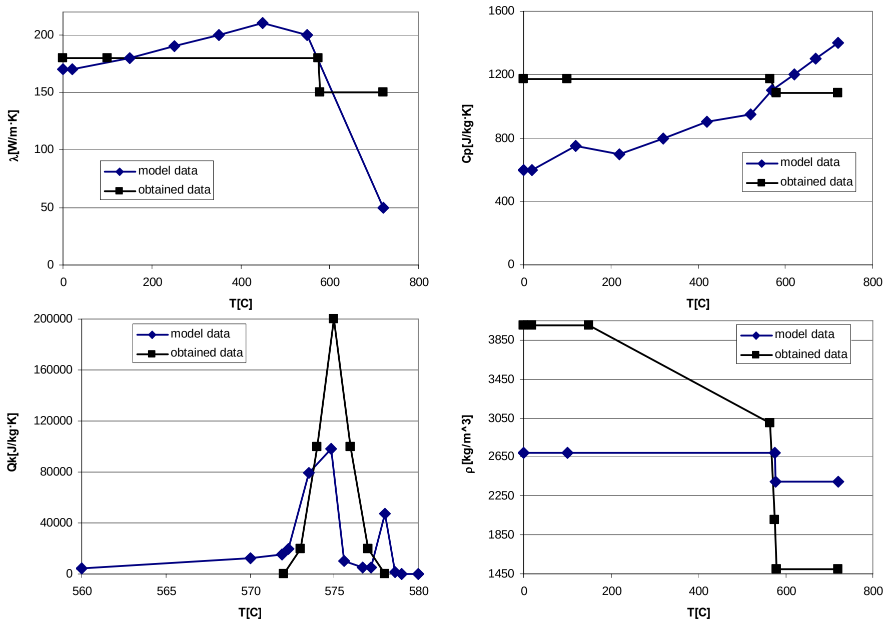


Fig. 13. Comparison of thermo-physical data used in model simulation with estimated – geometry no 1, data no 2, self-cooling S (1.2S)

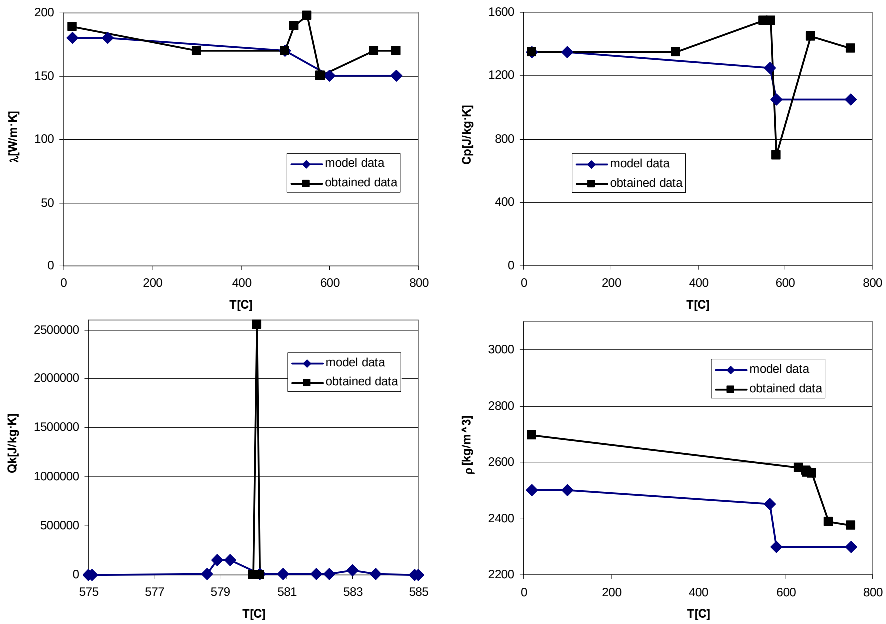


Fig. 14. Comparison of thermo-physical data used in model simulation with estimated – geometry no 2, data no 1, heating N (2.1N)

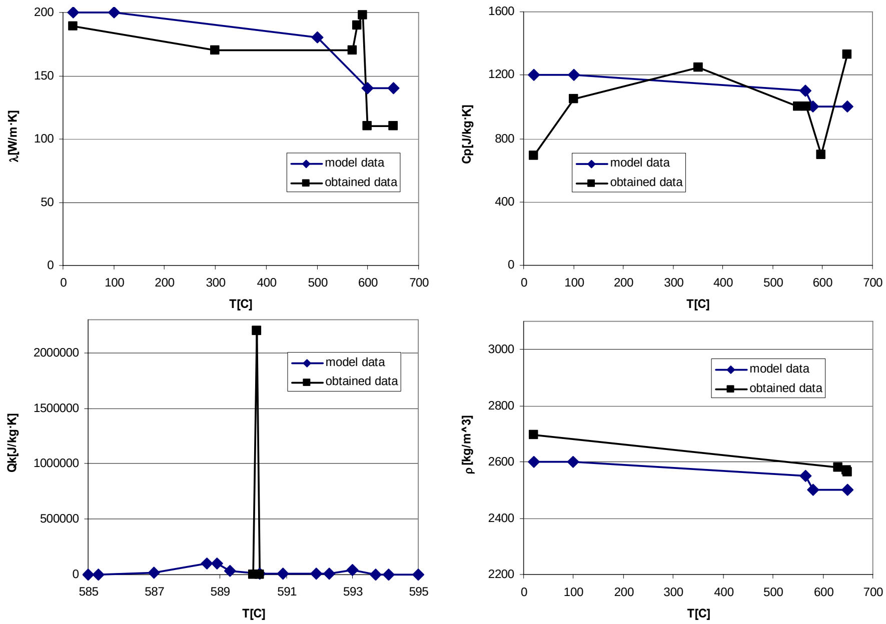


Fig. 15. Comparison of thermo-physical data used in model simulation with estimated – geometry no 2, data no 2, self-cooling S (2.2S)

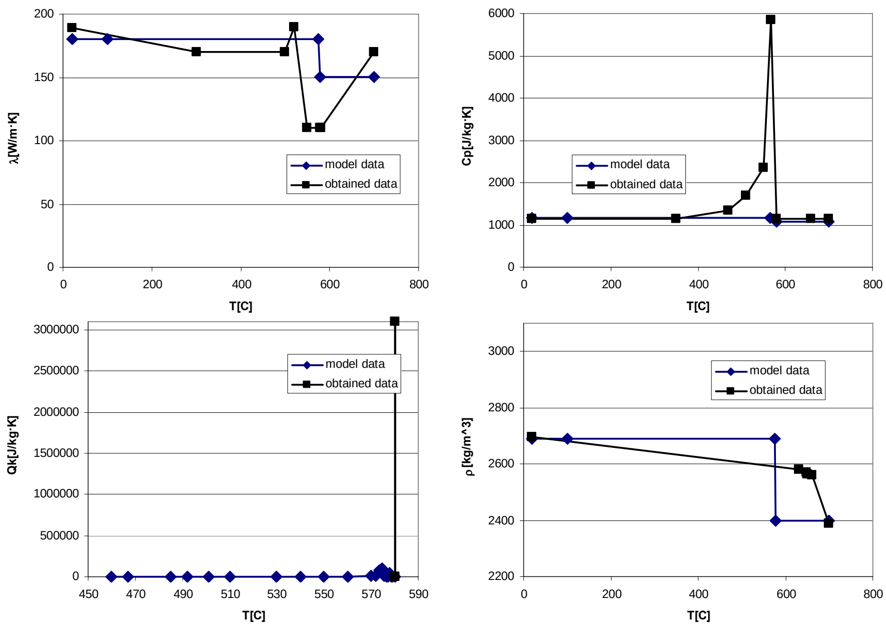


Fig. 16. Comparison of thermo-physical data used in model simulation with estimated – geometry no 2, data no 3, heating N (2.3N)

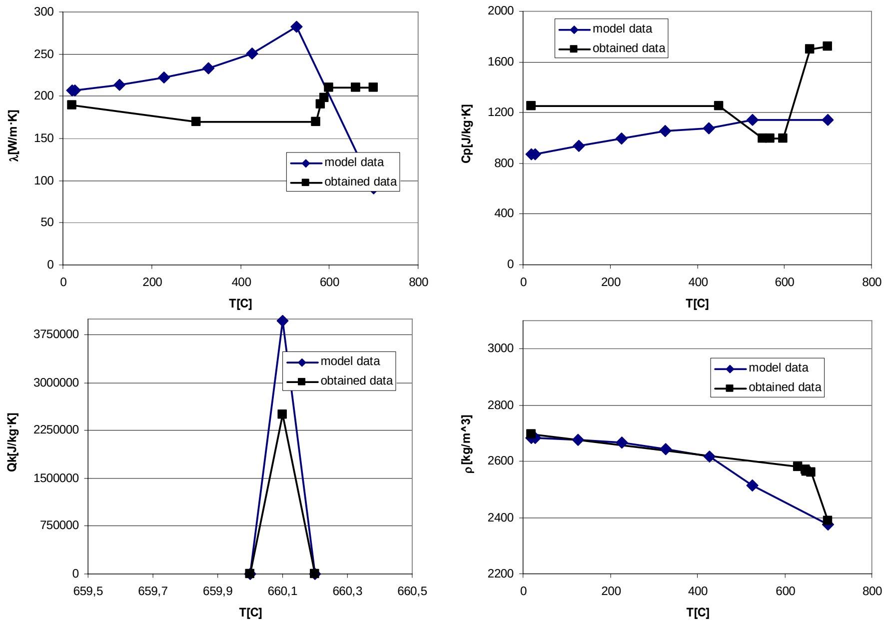


Fig. 17. Comparison of thermo-physical data used in model simulation with estimated – geometry no 2, data no 4, self-cooling S (2.4S)

Table 2.
Values of relative difference of temperature in measuring points and values of relative differences of thermo-physical properties for each considered cases

	ΔTF [%]				ΔT' [%]						
	Cp [J/kg·K]	**ρ [kg/m^3]**	**λ [W/m·K],**	**Qk [J/kg·K]**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
1.1N	12.36	18.24	11.06	17.07	0,49	0,48	0,47	0,46	0,001	0	0,54
1.2N	21.48	24.19	10.29	25.93	0,57	0,57	0,58	0,58	0,002	0	0,55
1.1S	24.31	18.24	11.47	14.95	0,33	0,32	0,32	0,31	0,25	0,28	0,32
1.2S	22.47	21.20	0.88	1.75	0,89	0,89	0,9	0,91	0,71	0,79	0,87
2.1N	8,98	7,11	2,99	7,89	0,75	0,75	0,76	0,77	0,75		
2.2S	5,32	2,58	7,01	6,2	1,53	1,55	1,56	1,57	1,57		
2.3N	17,93	0,48	5,25	30,78	1,72	1,14	0,99	0,91	0,89		
2.4S	19,43	1,29	18,07	36,96	0,75	0,74	0,74	0,74	0,75		

4. Summary and conclusions

In most analyzed cases a big discrepancy of assumed model and estimated thermo-physical properties are observed. It reaches even 36,96%, while matching of change of temperature curves are incomparably good. Such big discrepancy of analyzed thermo-physical properties is a result of that heat flow process depends on a few thermo-physical properties, moreover each thermo-physical property changes in temperature function. From it follows that the same course of change of temperature curves, in measuring points, may be obtained for different assumed thermo-physical properties.

In carried out simulations within the estimation with trial-and-error method exactly the same values of thermo-physical properties of additional materials (mould, insulation etc.) as in model simulation are used, what in case of real experiment is impossible. Therefore differences between model and estimated thermo-physical data in case of real experiment may be probably larger. They additionally were increased by differences follows from differences between thermo-physical properties of additional materials in real experiment and simulations.

Such big difference in thermo-physical properties assumed and estimated disqualifies an application used within of work method to find thermo-physical data on the base of change of temperature curves obtained in real tests.

Carried out within of work analysis show that assumed method is too inaccurate. Probably analysis widen about:

calculation of temperature derivative on time, calculation of gradient - temperature derivative on distance, make possible to significant decrease differences in thermo-physical data assumed and estimated. Moreover as start values of thermo-physical properties in estimation should be apply values calculated on the base of physical equations.

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