Control and track of melting process by QVI

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Abstract

This paper is occupied by track and control of single component raw materials melting process. Experiments were performed in an electric-resistance furnace with a horizontally placed movable graphite electrode (heater). Used raw material was floated quartz sand, while obtained material was electrofused SiO_2, also called quartz glass. Height of the electrode elevation and total melting time were varied. The process is considered as non-stationary process due to existence of captured gas bubbles in the viscous melt and many accompanying effects, as well. Tracking of processing parameters was enabled by thermovision as the source of information. In that regard, infrared camera was used. On the basis of these measurements, temperature profiles in the system during the melting process were obtained. Working models of the process were defined by correlation of the temperature changes with time at distances of 1, 3 and 5 cm from the heater. The "black box" method that correlates temperature and time in a model was applied. Powered functions are obtained as models of proposed system. These models were the base for processing control. Namely, based on virtual process defined by different models, sets of parameters for the process control are determined.

Keywords: non-stationary process, ThV camera, working models, process control

1. Introduction

In case of single-component raw material melting with clearly defined composition, focus of analysis is transferred to the process parameters analysis, while the properties of raw materials can be considered as a constant of the process. In this approach, this research is not focused on material related phenomenon that occur during the melting process, but on the control of processing factors and their relation to product quality. That approach is called model of "black box", where the optimization is occupied with definition of control processing algorithm presenting feedback of the system. Therefore, preference was given to the application of a method that enabled visual tracking of process, i.e., quantification of visual information (QVI). Method used as the source of technological process information was thermovision. Therefore, temperature distribution was tracked. It should be highlighted that the process is considered as non-stationary process due to existence of captured gas bubbles in the viscous melt and many accompanying effects.

2. Materials and methods

Electro-thermal melting for obtaining quartz glass was performed in the electro-resistance furnace with horizontally placed movable graphite heater. Numerous experiments with the same raw material, floated quartz sand with 99 % of SiO_2, were realized while the heights of electrode elevating and total time of melting durations (velocities of electrode elevating) were variable. Voltage and amperage were increased to the maximal power for each melting. The step of electrode elevating was 2cm. Existence of caught gaseous bubbles into the viscous melt during the process causes non-stationary process inside of reactive volume, so the process itself was analyzed as a non-stationary. Since the melting and cooling are considered as non-stationary processes, the temperature distribution in the rector space was the main parameter that needed to be observed and usage of thermocouples would not provide reliable results, so the preference was given to the application of method that enabled visual tracking of the process i.e., quantification of visual information (QVI). Thermovisual (ThV) method was selected to record temperature fields and dissipations. On the basis of these visual and thermal images, isotherms and temperature distribution in relation to time were obtained. Modified camera AGEMA, type 9000, was used during the research. Non-contact temperature measurements are enabled in the range from –40 to 2000^{o}C, with average measurement accuracy of ±2^{o}C. Analysis of obtained thermograms is processed by the program package of “Explorer” type. There are two temperature measurement modes: analysis of particular area for obtaining an average temperature on defined area; and measurements at a location. The former was applied in this research.

3. Results and discussion

Typical ThV image of reactive area after reaching maximal furnace power is presented in Figure 1.

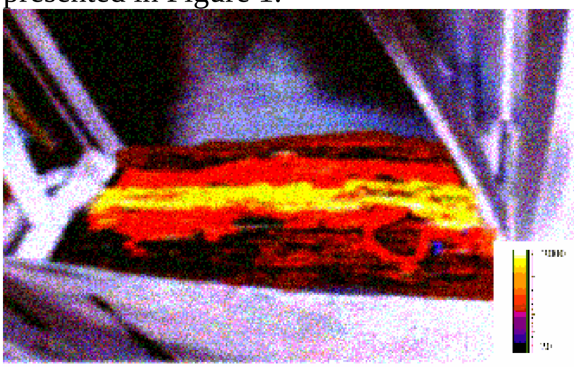

Figure 1: ThV camera image recording after reaching maximal furnace power

On the basis of the images, countered diagrams of isothermal curves in the reaction space were obtained. More precisely, they were obtained by extrapolation of measured values for particular locations at the distances from the electrode elevation axis of 1, 3 and 5 cm. It was assumed that the electrode temperature was 1900°C. Measurement error was ~5 %. The diagrams presented images at various time intervals and, therefore, for various powers of the furnace. Temperature measurements at the distances of 1, 3 and 5 cm from the electrode elevation axis during experimental recording were prepared as 3-D diagrams of time-distance from the electrode axis-temperature, Figure 2.

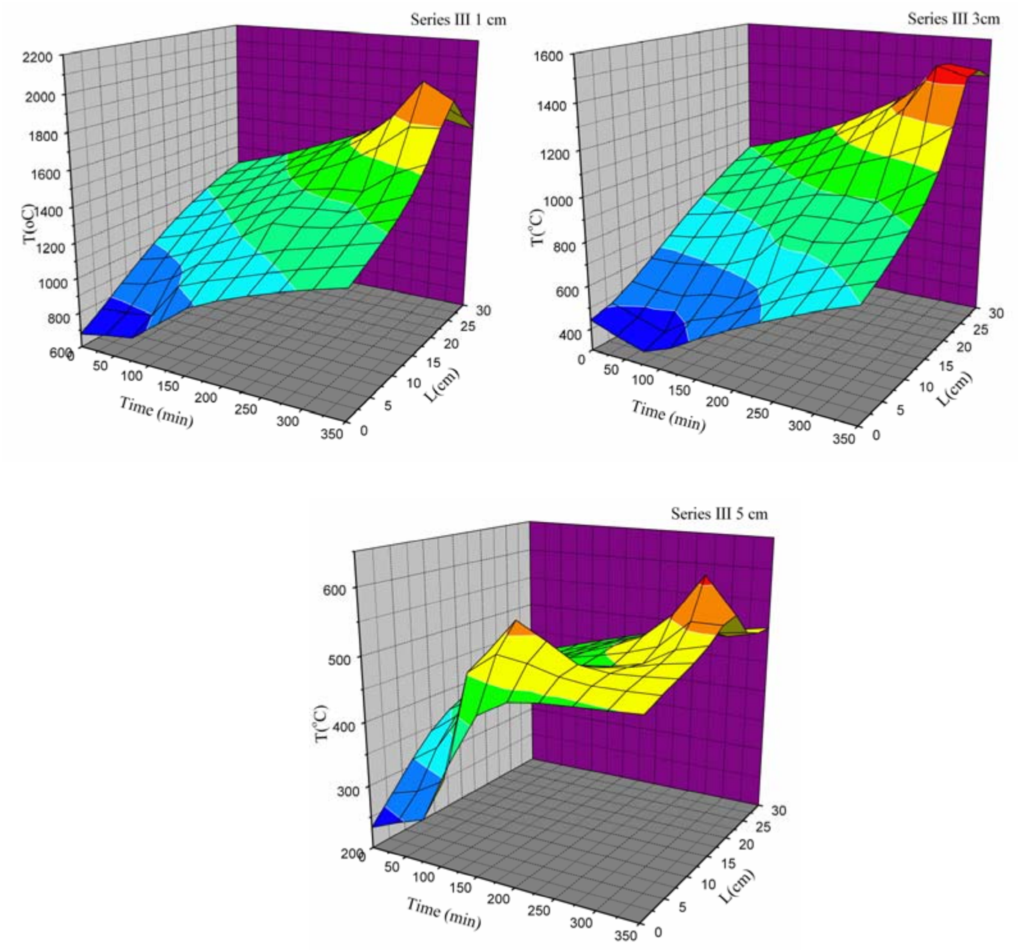

Figure 2: 3-D diagram of time-distance-temperature dependences

Because little temperature dissipation occured at distances from the electrode axix of 1 and 3 cm, it was estimated that similar mechanisms of formation and cooling of the melt existed. At the distance of 5 cm, a completely different mechanism of melt formation and its solidification was observed.
To compare temperature profile and dissipation of temperature, classical temperature profiles (temperature-time) are presented in Figure 3.

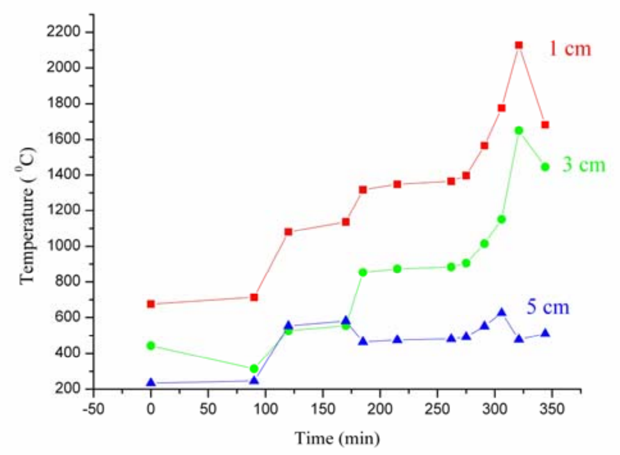

Figure 3: Classical temperature profile at distances of 1, 3 and 5 cm from the heater axes

Obtained profiles showed minor differences in heating/cooling mechanisms at distances of 1 and 3 cm from the heater axes. Significant differences in heating/cooling mechanisms were observed at distances of 3 and 5 cm from the heater axes. It can be explained by faster cooling at larger distances due to heat loss through the walls of reactor and reduced “influence” of heater on process tendency. It indicates that it is not important to track temperature changes at the distance more than 5 cm according to the process control. “Correlation factor” in mathematical analysis shows agreement of the model with the experimental data. However, in case of process observing where the measurements present physical values, analysis must include simple models (equations). Therefore, this analysis was restricted on usage of linear models. As a measure of quality, “correlation factor” was applied.
At the distance from the electrode axis of 1 cm, model of power three-parameters function with the greatest correlation coefficient is obtained, Equation 1.

$$y=a+bx^c \qquad \text{(Eq. 1)}$$

with parameter values of: a=35.78; b=40.73; c=0.64

At the distance from the electrode axis of 3 cm, following model of three parameters exponential function with the greatest correlation coefficient is obtained:

$$y=a+b\ \exp(x/c) \qquad \text{(Eq. 2)}$$

Values of parameters are: a=378.720; b=60.550; c=116.341

At last, at the distance from the electrode axis of 5 cm, 5-th degree polynomial function with six parameters as a model is obtained:

$$y=a+bx+cx^2+dx^3+ex^4+fx^5 \qquad \text{(Eq. 3)}$$

Models for the observed temperature range are presented graphically in the Figure 8

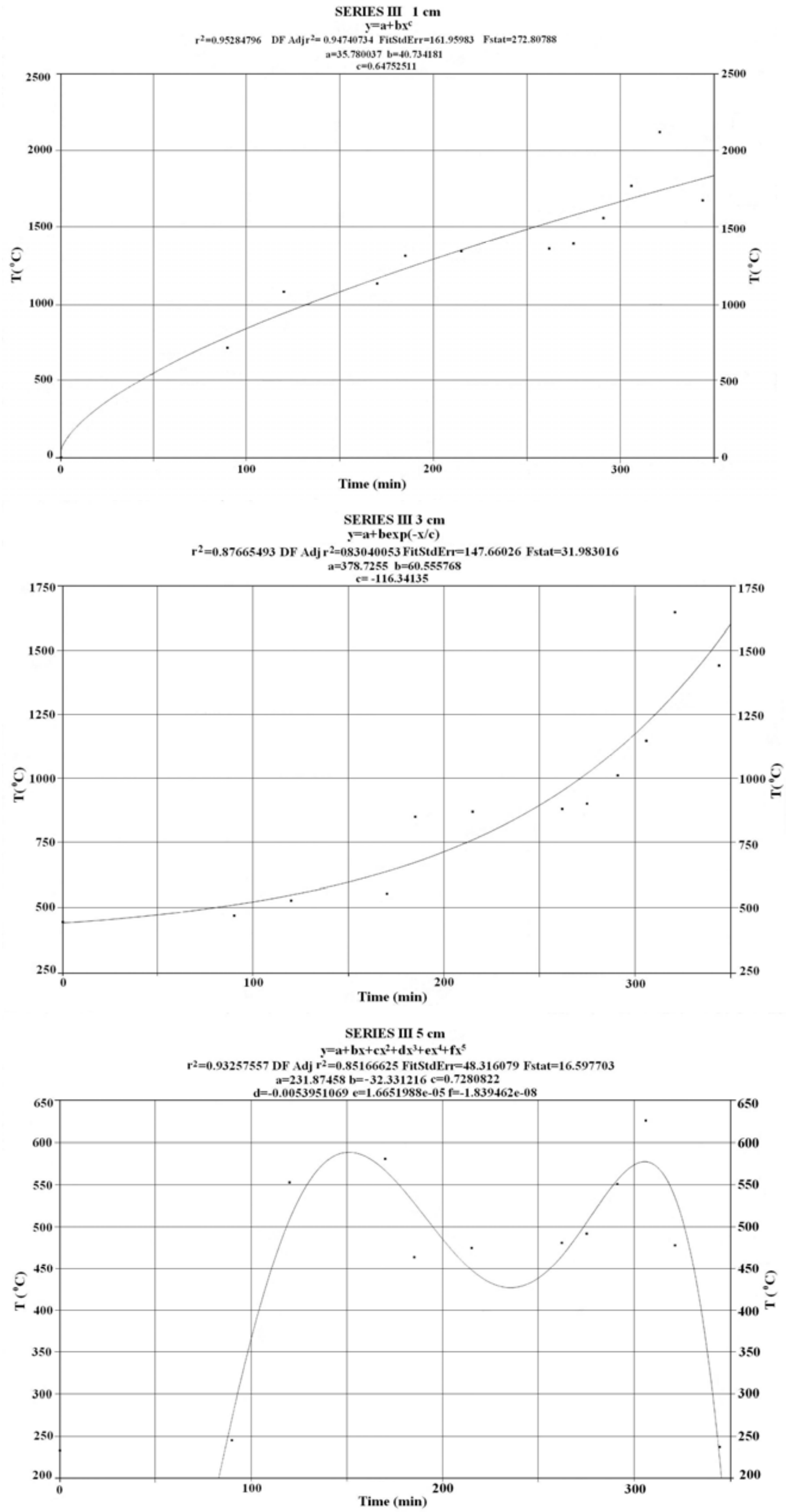

Figure 4: Graphical presentation of time-temperature dependences and differences between calculated and experimental temperatures

Differences between calculated temperatures (model) and experimentally measured temperatures are realized by simulation. It is noticeable that absolute values of differences i.e. errors do not exceed 20 % in case of distances from the electrode axis of 1 and 3 cm. Also, that values increase with the progress of process time. It can be explained by assumption that new secondary interactions in the system that influence to the process itself occur after certain time. Change in character of difference values between model/experiment after 200 minutes of process developing is noticeable. However, considerable difference regarding obtained model is noticed at the distance from the electrode axis of 5 cm. Namely, the first obtained model with the greatest correlation coefficient was 5-th degree polynomial function with six parameters. This model can be used only as a „working model". Since polynomial of n-th degree correlates experimental data in domain with the greatest coefficient, absolute value of difference i.e. error between temperatures of model and experiment was the least.
Changes at the distance of 1, 3, 5 cm from the heater were presented in Figure 1.

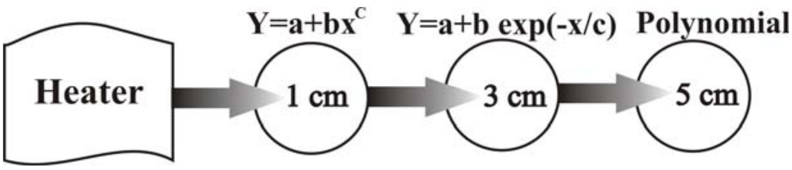

Figure 1: Changes of models at the distances of 1, 3, 5 cm from the heater

Above analysis showed reduced "influence" of heater on process tendency at distances between 3 and 5 cm from the heater axes, while the powder material take the "leading" of process on. It means that it is not important to track temperature changes at the distance more than 5 cm according to the process control.
Processing control implies series of experiments on virtual model to get various sets of processing parameters. It means that model or set of models should be defined as more accurately as possible. Real parts of the system are furnace and measuring and regulating devices, also called executive parts of measuring and regulating system. On the basis of various information obtained from the virtual part of measuring and regulating system, real parts of the system do control of the process. The essence of control system is based on feedback principle with very high level of data processing. In this case, two aspects of process control are proposed. The first one is static model with control elements placed in fixed spots in material. Process control is performed by comparing of response on the control element and values obtained with modelling. Another model, dynamic model, implies moving of measurement system together with heater. This is technically easier and more efficient way for processing control.

4. Conclusion

New approach to analyses of single component nonstationary process melting in the electrical resistance furnace with a movable graphite heater is presented. Working model of time–temperature profile during the process is done on the basis of temperature analyses at the distances of 1, 3 and 5 cm from the electrode axis. It can be concluded that minor differences in heating/cooling mechanisms at distances of 1 and 3 cm from the heater axes occur. However, significant differences were observed at distances of 3 and 5 cm from the heater axes. It indicates that it is not important to track temperature changes at the distance more than 5 cm according to the process control.

References

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