Experimental researches of temperature distribution in an electrically heated protective gas tight industrial furnace with gas revolution

The following report describes the extent to which temperature homogenization can be achieved in a Type KS 80 S single-zone chamber furnace by means of combinations of parameters and forced gas recirculation. Temperature profile was measured at five measuring levels in the downstream direction in the rectangular cross-section muffle. In addition, velocity was measured at room temperature, in order to permit subsequent quantitative interpretation of flow distribution. Finally, a numerical method was used for determination of temperature distribution in the furnace. These results were then utilized for optimization of gas circulation in the furnace system under examination and an attempt made to apply this to a whole series of inert-gas muffle furnaces of up to 500 l effective capacity.

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Introduction

In many areas of technique, material and heating exchange processes play an important role. To achieve homogenious temperature division in chamber furnace, the theoretic as well as the experimental registration of decreasing processes is of big interest. In the metal working industry, the chamber furnace is an important heat technical furnace for heat treatment of e.g. wrapped metal belts, - wires, small parts, soldering etc. The chamber furnaces KS/S is a insert furnace. This fact requires a periodical operation: loading, heating up, holding and cooling down.

Increasing demands on chamber furnaces concerning quality of products and the obligation to minimize specific energy consumption as well as the cycle time lead to the need to homogenize the heating of insert goods over the whole cross section and depth of insert goods during heating and heat treatment of ribbon or copper alloys. One important operation area is e.g. the recry-stallisation annealing of cold rolled belts. During this process, textures and strengthening accelerated during rolling are removed by grain growth during annealing. The heat treatment has to effected over the recrystallisation, which are important for the material.

The heat treatment of alumina and copper alloys is done in a protective gas atmosphere in order to keep a largely blank surface. A high convective heat transmission can be achieved by big velocity of flow on the surface. These high velocities of flow can be achieved by flow machines, which revolute the gas in the treatment room. Therefore it is used a pseudo radial ventilator. Compact constructions limit the room, which is necessary for the fully mixing process of gases, so that the demand for a possible homogenous as well as low-loss mixture get more and more important. Inflow technique ventilators in the chamber furnace construction, pressure loss rich velocity of flow concerning returning and distribution of revolution material, are also effecting against the mixture process.

The presented problem with the temperature comparison in chamber furnaces makes a detailed research very suitable.

Therefore advices for optimal tem-perature distribution in indirect heated chamber furnaces with forced revolution and furnaces with similar velocity of flow are prepared.

Positioning and dimensioning of measuring grid

The auxiliary grid in **Fig. 1** with the dimensions 300x325x500 mm is divided 100x100x125 mm segments, that means 36 subdivisions are possible. With this

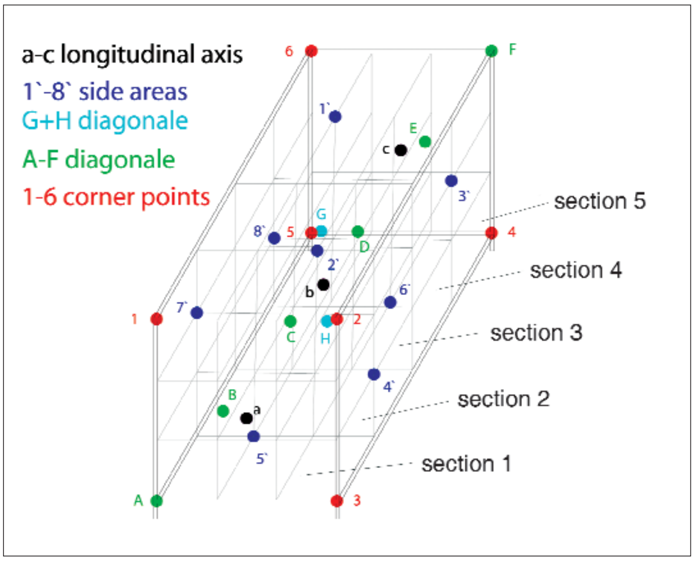

Fig. 1: Auxiliary grid with measuring points

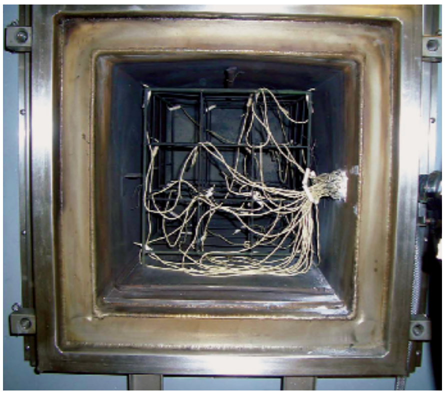

Fig. 2: Symetrical installation of auxilary grid in the chamber

auxiliary grid are spatial temperature measurements possible. The measuring points are equipped with fixed numeration to be able to gauge the temperature processes on every measuring point during and after the researches. To give a detailed statement about temperature division, the auxiliary grid has been placed symmetrical in the chamber. The viewing direction is from the door insight the chamber (**Fig. 2**).

The arrangement of the thermocouples in auxiliary grid (Fig. 1):

- The diagonal A-F (green marking) with 6 measuring points from in front left to behind right at the top.
- One diagonal G-H (turquoise marking) with 2 measuring points from in front right to behind left beyond.
- All 6 remaining edges 1-6 (red marking), which are not included in the diagonal.
- In the middle of the longitudinal axis a-c (black marking), that means in the medium square in front, middle, behind.
- Lateral face 1'-8' (blue marking) at the top, beyond, left and right, in the middle of the each 2 squares with

Structure and performance of revolution ventilator

In the chamber furnace construction, revolution ventilator are often used. The revolution wheels are directly coupled with the flow drive, which is installed in the door in order to assure a fast exchange. The flow and heat technical efficiency of the furnace depends on in and out flow conditions before installation in the flow circulation. The pseudo radial ventilator has advantages compared to the axial ventilator. The transforming of the flow off cross section to the rectangle cross section of the flow lead through, can be designed more easy with the radial ventilator than with the axial ventilator. The deflection by 90 °C in the radial ventilator additionally allows a more reasonable installation in the furnace. The type of operation of the revolution ventilator can be described in **Fig. 3**. The material is sucked on the suction side and then flowed through radial with high circumference speed. This principal is valid for the radial ventilator. The radial flowed through material is deflected by 90 °C on the furnace diffusion in longitudinal direction of the furnace. During this process, losses arise in the meaning of pressure losses. The order of and the positioning of the screen shields can be recognized. These screen shields serves for radiation insulating.

In order to minimize the losses of gas volume flows, the protective gas is insert beyond the first three tight adjoining screen shields, which pre-heat the gases before inlet in the chamber. The tight adjoining screen shields are mounted in distances of x = 10 mm from each other, so that the enough radiation energy can be released to the gases and to achieve as less as possible energy loss.

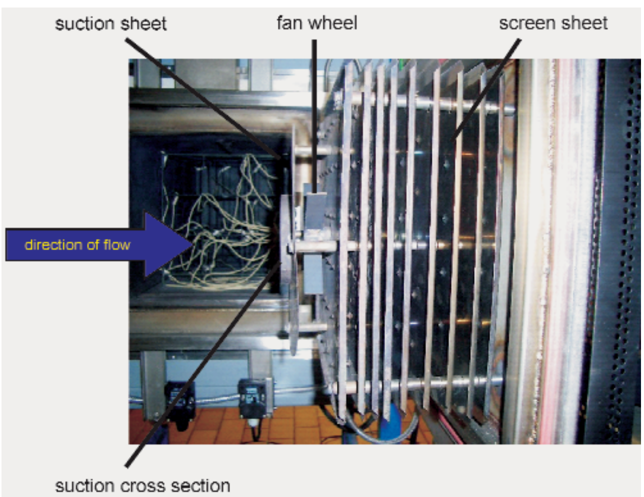

Fig. 3: Structure of revolution ventilator

Heat transmission

The temperature profile is a result of balance between the recourses and released heat power in stationary condition. The mathematical replica of the process is ordinary complex as it is a plurality of coupled filed problems. Therefore results the need for limitation on the essential mechanism. The heat transmission mechanism is divided in heat conduction, radiation and convection.

The energy balancing for heat transmission mechanism per volume unit is [1]:

$$-\left\{\frac{\partial \dot{q}_x}{\partial x}+\frac{\partial \dot{q}_y}{\partial y}+\frac{\partial \dot{q}_z}{\partial z}\right\}= \rho \cdot c_p\left\{\frac{\partial \vartheta}{\partial t}+w_x\frac{\partial \vartheta}{\partial x}+w_y\frac{\partial \vartheta}{\partial y}+w_z\frac{\partial \vartheta}{\partial z}\right\} - Str - \ddot{q} \quad (1)$$

Heat conduction

The result of this equation (1) without consideration of the flow, under neglect of radiation rate and under the condition homogeny and stationary proportion for the volume power density:

$$\frac{\dot{Q}}{A} \equiv \dot{q} = -\lambda \cdot \frac{dT}{dx} \quad (2)$$

tridemensional in vectorial form

$$\vec{\dot{q}} = -\lambda_i \cdot \mathrm{grad}T \quad (3)$$

Radiation

A lot of gases emit in form electromagnetically waves. The radiations are absorbed or reflected if the abut against a body [2].

$$\dot{Q}_i = \varphi_{ij} \cdot \sigma \cdot \varepsilon_i \cdot A_i \left(T_i^4 - T_j^4\right) \quad (4)$$

Convection

The heat transmission in gases by conduction and convection are connected with each other are described therefore together [2]. The convective heat transmission contains the heat exchange between a solid body and a gas. On the boundary surface

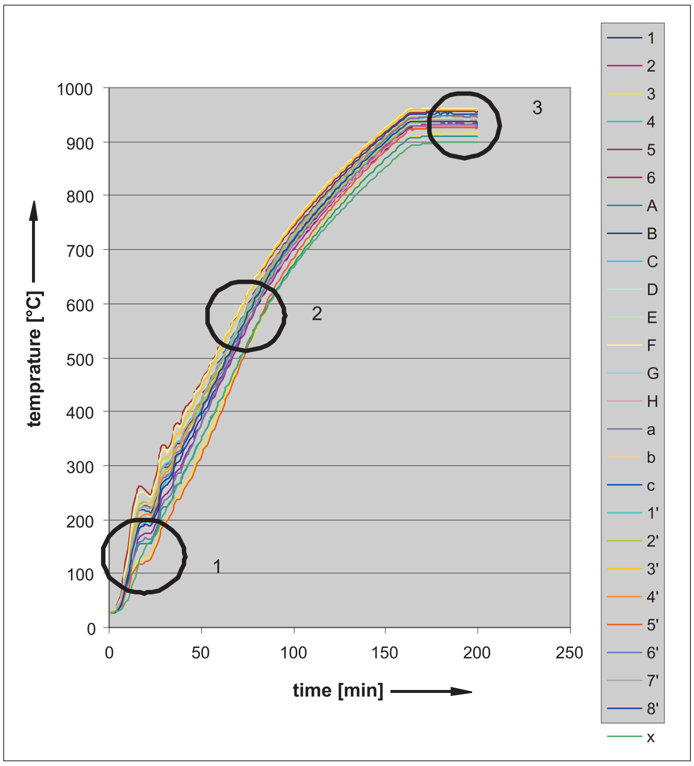

Fig. 4: Heating-up curve under Argon atmosphere

between both materials, the heating power is transferred by conductions, while the transport inside the gas is mainly effected by movement of these materials.

$$q = \alpha_k \cdot A \cdot \left(T_0 - T_f\right) \qquad (5)$$

The flow process can be calculated by solving of the equation [3], [4]:

- mass balance
- energy balance, see equation (1)
- impulse balance

Partial results

The heating up curve under Argon atmosphere (**Fig. 4**) makes clear the process of the single measuring points in the chamber, while a stationary value is adjusted in the area of app. 10 min (marking 1). One presumable reason is, that there is a energy storage of the insert in this area. During On closes examination it can be seen that a small oscillating process of the control thermocouple (numbering x), which effects the rough behaviour of the furnace. The stationary condition always adjusts during turning point of control thermocouple process. This oscillating temperature process depends on the heating-up rhythm. This can be recognized up to T = 300 °C. In this stationary phase, it can be seen a very high temperature difference between the uppermost and lowest curve.

As already mentioned it was selected Argon atmosphere in this example. On the marking 2 and 3, see Fig. 4, it has been compared to judge the influence of the gas during heating and stationary condition, the range of temperature as well as possible changes. The result of $\Delta\vartheta$ = 34 K shows no difference, that means that is does not change anything in both cases. With the estimation of the maximal deviation from measurement, it is possible to include the magnitude, which can appear under disadvantageous circumstances. These are ± 3,7 K at T = 900 °C, that means in the worst case the range would be $\Delta\vartheta$ = 34 K ± 3,7 K. The graphs, which are out of the range, have not been considered during this judgment as the measuring points joints do not tower into the furnace that means the experimentee do not tower until the measuring points.

The first investigation for the ventilation wheel 1 at changing of number of rotaries

It was determined how big the influence of the suction cross section of the measuring metals sheets on the mixture of changed gas volume flow $\dot{V}_{Gas}$ depending of diameter d of the measuring metal sheet series 1. In **Fig. 5** the curve processes of three different volume current proportions. As supposed, the exchanged gas amount increased with increasing cross section d_2. But no better results have been achieved, as a worse temperature distribution was determined with the biggest cross section. The reason therefore could have many aspects. Presumably small significant turbulences evaluated in the chamber, which did not help for the homogenisation of the temperature. The increasing number of rotaries has the effect that temperature difference decreases.

Graphical temperature course of the measuring values with different parameters in the chamber furnace KS 80 S

With the help of the parameter combination and the forced circulation of the gases a homogeneity of the temperature was achieved. In the channel with the rectangular cross-section was the measuring of the temperature profile in 5 measuring areas downstream. Additionally it was recorded a speed-measuring at room temperature on the level 1 to render afterwards a quantitative explication of the stream distribution.

The following parameters were at disposal: Suction sheet metal diameter, speed changes, fan wheels, gases, gas inlet configuration. In **Fig. 6 and 7** the temperature history at T = 800 °C is shown depending on the parameter (the legend with the figure 81 is the time from

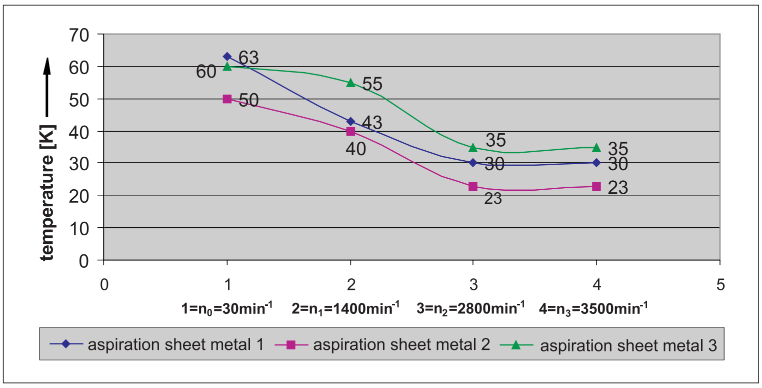

Fig. 5: dT/dt as function of suction metal sheet at various rotaries

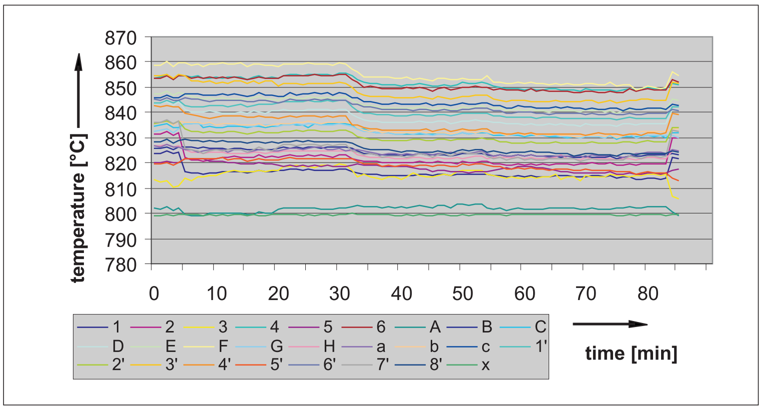

Fig. 6: Argon atmosphere, T = 800 °C, fan impeller 1, diameter 140 mm

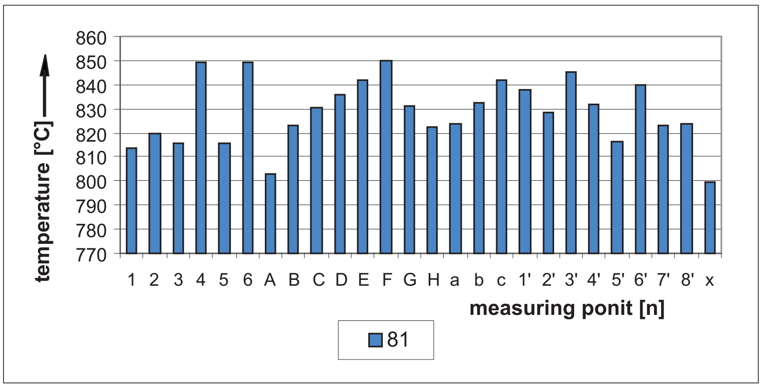

Fig. 7: Instantaneous image at t = 81 min

the upper pic. 6, instantaneous exposure).

Temperature distribution

The temperature homogeneity is determined of the geometry, the radiation conditions, the convection and the heat conduction of the gas. The heating is made from two sides, bottom and rear. At the unheated door occurs an intense temperature decrease which can reach further into the furnace volume, depending on the size of the door. The heat conduction in the gas (not helium) can be omitted. The main actors are convection and radiation. With natural convection these is the defined factor up to approx. 300 °C. Afterwards the temperature transmission by radiation overweights. If a reinforced convection is forced by gas circulation, it will be significantly valid up to approx. 400 °C. Above this the heat transmission and temperature will be dominated by the radiation. End result: if an exact temperature distribution via huge volumes are necessary, then it shall be used a gas circulation at temperatures up to 400 °C. Above 800 °C a more-zone heating is reasonable and necessary. Between 400 °C and 800 °C the best is to use both possibilities. Gas circulation can be used up to 950 °C. If it is necessary because of the process to use it up to max. 1050 °C, e.g. debinding at 300 °C and pre-sintering at 1100 °C with a good temperature distribution, the ventilator must be able to be lowered with a special wheel to a minimum speed, e.g. 2/s, in order not to be destroyed. But a rotation is necessary as otherwise the axel drive will be deformed.

Studies were made on a more-zone heating with three control paths, distributed over the furnace length (door area, middle part, rear) by the University of Erlangen for FT (**Fig. 8**). With the actions can be achieved temperature derivations of +/- 3 to +/- 7 K over the furnace volume. With a higher effort, e.g. a six-sided heating with trimming possibility, are for special applications also higher accuracies to achieve, but it is often easier to limit the useful chamber (next higher furnace type) in proportion to the muffle dimension in order to achieve a similar good temperature distribution with lower costs.

Temperature compensation in measuring cube (100x100x100) in a VMK 250 S laboratory furnace

Additionally the heat transmission from the furnace chamber to different materials, as to say the soaking of these materials, was studied. The heat transmission is determined by the convection and radiation. The authoritative mechanism in the solid itself is the heat conduction. The heat conuction describes a heat stream dQ/dt through a area A in a material, which is in a temperature gradient dT/dx.

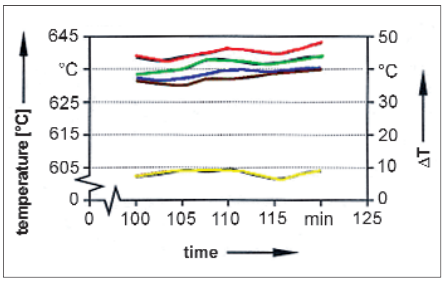

Fig. 8: Temperature distributionn in a three-zone chamber furnace

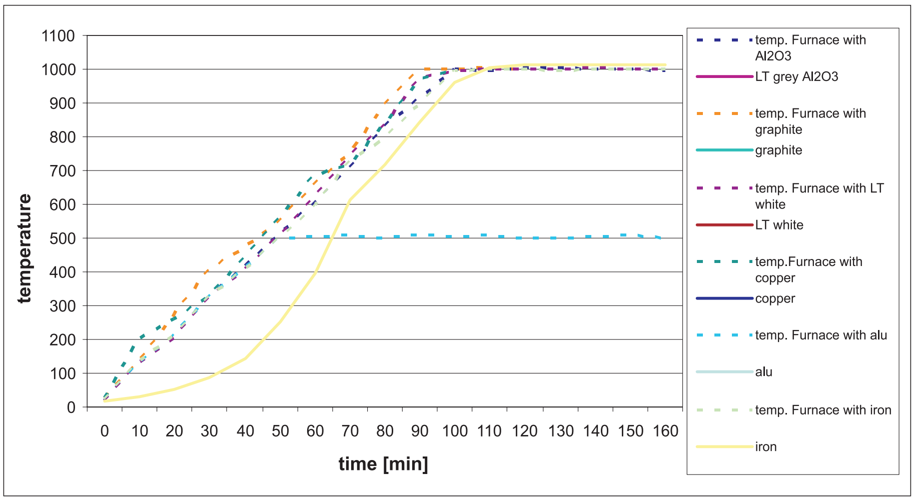

Fig. 9: Temperature process of different materials

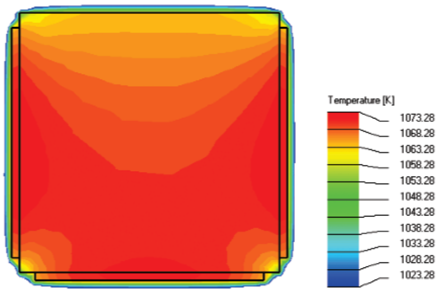

Fig. 10: Temperature distribution in the KS 80 S

Test process

The temperature compensation is determined in this test by means of a stationary measuring method. Cubes with an edge length of 100 mm are used and are placed in the middle of the bottom in the furnace type VMK 250 (250x400x250 – wxdxh). In the top-side of the samples was made a hole for the input of a thermocouple. Then it will be heated up with an approximate constant heating rate to T = 1000 °C. The temperatures can be seen directly on a measuring unit. Therefore now the measuring results and the geometric dimensions of the samples can be taken to calculate the thermal conductivity after the conversion of equation 2.

Measuring results

The temperature history of different materials in **Fig. 9** gives information about the thermal conductivity of individual materials. Graphite achieves the desired value in shortest time and is therefore a very good heat conductor. The radiation is noticeable in graphite over 500 °C, as the graph will become steeper, therefore graphite absorbs nearly all radiation (similar to a black body). Normally copper has the best thermal conductivity characteristic, but the heat transmission through radiation is very dependable of the surface characteristic and on plain metals very low. In the opposite it is to see that the ceramic materials as SiC/Al_2O_3 have a bad thermal conductivity and are therefore good isolators.

Theoretical determination of the temperature distribution in the furnace with the numerical method

Finally the numerical method with a simulation program for the temperature distribution in the furnace was applied. After the input of the furnace geometry and of all material data the software allows the calculation of the temperature distribution in stationary and non-stationary status. Flows are not considered. The listed furnaces in **Table 1** with different rectangular cross-sections were studied. Here only the level 3 was inspected, thus exactly the middle cross-section of the furnace. Linn High Therm offers the KS-series in several sizes. Now it should be shown, in which way the known recognitions of the studied KS 80 S can be applied in bigger units.

Afterwards the calculation of the small -/laboratory furnace lines VMK-S type with minor other heater configuration is made. Fig. 8 shows the temperature distribution for the chamber furnace. A temperature difference of some Kelvin in vertical direction is to note. Also the studied chamber furnace KS 80 S has similar temperature distributions, but at a desired value input of T = 800 °C in the chamber furnace there are significantly higher temperature differences as shown in **Fig. 10**. The temperature in level 3 on the measuring point b is in the stationary status at the same condition T = 836 °C, that means $\Delta\vartheta$ = 36 K higher. These increase of the temperature can originated because the rear wall was not considered in this numerical process.

Also this plot in **Fig. 11** refers to the medium cross section (level 3, centre). One characteristic has to be considered, as the heat insert is affected by four sides. It can be seen that the temperature is almost homogeny over the whole cross section. The furnace type VMK 135 S differs from the desired value T = 800 °C in the centre by app. 2-3 Kelvin. The small furnace types VMK-S reach better temperature homogeneity over the whole cross section compared to KS/S.

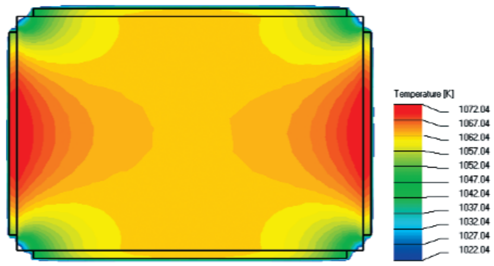

Fig. 11: Temperature distribution in the VMK 135 S

Table 1: Geometrical data for the furnaces

Model Dimensions	KS 80S	KS 160S	KS 240S	KS 480S	VMK 135S	VMK 250S
width [mm]	340	440	490	580	250	250
depth [mm]	600	700	800	950	300	400
height [mm]	340	540	640	840	180	250
litre [l]	69l	166l	245l	462l	13,5l	25,0l

Reference

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