Optimization of the Dehydration Process in the Manufacture of NT Series Compressors

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Abstract— *The article presents the results of optimizing the final production process (the time of required dehydration) of an industrially produced compressor. Optimization is based on simulations carried out that were conducted in ANSYS CFX. Several variants were tested in which the process parameters were varied (the inside diameter of the tube, the flow at the inlet and outlet temperature). The results of the simulations show which the parameters of the compressor speed up the dehydration process and what consequences shortening of process will have for of the whole production of the compressor. Optimization of the compressor manufacturing process was performed for the NT series compressor. The compressor is the largest industrial compressor manufactured in a specialized global company.*

Keywords— compressor, dehydration, heating, optimization, simulation.

I. INTRODUCTION

The study of the dehydration process was designed for a globally operating company, one of whose sites is based in Slovakia. This is a company that is a leader in its field. It specializes in the manufacture of hermetic compressors. In its plants worldwide, the company produces more than 35 million compressors. It also produces devices that function as part of the condensing units of electrical systems to make smart appliances. The company in Slovakia specializes in the production of compressors for commercial refrigeration and production of condensing units. In 2011 it also began to produce the global Mini platform for home cooling.

One of the compressor series includes compressors for commercial refrigeration. This includes compressors from the series NE/NEK, NT, NTU and NJ. These compressors are different from compressors for household refrigeration in terms of design and construction. Compressors for commercial refrigeration have higher cooling capacity and higher resistance to extreme conditions in which operation takes place.

Manufacture of compressors on the production line consists of a number of interlinked processes. Individual processes run with various time-intensities, hence the need for optimization in order to shorten the production time of a compressor unit. One of the longest processes in the manufacture of compressors is dehydration. Since the process currently takes up to 5 hours it needs to be optimized to shorten the overall production time of the compressor and to reduce production costs in manufacturing the compressor.

The process of dehydration can be simulated in ANSYS CFX. The simulation shows how the process runs, either under the current state or under changed conditions. The results of the simulations also show under what conditions the process would accelerate, thus reducing the consumption of electricity necessary to observe the process.

II. DESCRIPTION OF THE NT SERIES COMPRESSOR

This is a compressor manufactured for industrial purposes in the area of refrigeration equipment (refrigerators and freezers). The NT series (Fig. 1) is developed to meet the growing demand for commercial refrigeration equipment with lower energy consumption and noise. The compact shape and displacement of 27.8 cm3 offer multiple advantages in terms of efficiency, noise, size and price compared to large compressors with similar displacement.

FIG. 1 – NT SERIES COMPRESSOR

NT series compressors are characterized by:

- Low noise and vibration,
- High reliability in various operating conditions,
- Wide range of voltages including standard voltages 220-240 V/50 Hz, 115 V/60 Hz, 208–230 V/60 Hz
- Wide range of applications with double voltage 200-240 V/50 Hz (230 V/60 Hz). Possible use as a global platform for all voltages with dual frequency range 200-240 V/50 Hz (230 V/60 Hz),
- usability for all refrigeration applications (refrigerators, freezers, dehumidifiers, etc.) and for R134a, R404A, R407C and R290 coolants,
- availability in versions with low and high starting torque.

III. ANALYSIS OF THE CURRENT STATE OF THE DEHYDRATION PROCESS IN THE PRODUCTION OF COMPRESSORS

In the process of dehydration of the compressor there occurs transient heat conduction, thus the temperature field varies with time. In these processes, there is a notable change in the temperature difference between the central body and the surface of the body where the temperature is changed rapidly. In these processes it is necessary to know the function of the temperature and heat flow in terms of the coordinates and time.

The process of dehydration of NT series compressors takes place in two electric ovens. The capacity of each oven is 12 racks, with up to 60 compressors on each rack. The total capacity of the ovens is 1440 units.

Dry air is injected into the compressor at 150 ° C. The air therefore needs to be warmed from a temperature of 20 ° C to 150 ° C. Consumption of air used for heating the compressor is 500 l h-1. The heating time of one “charge” of compressors is five hours. For the first four hours, the compressors are heated to approximately 130 ° C and during the last hour, the water evaporates from the compressors. The input wetness of a compressor before dehydrating is at the level of 500 mg and the output level is 60 mg. Electricity consumption of one oven is 26 MWh per month.

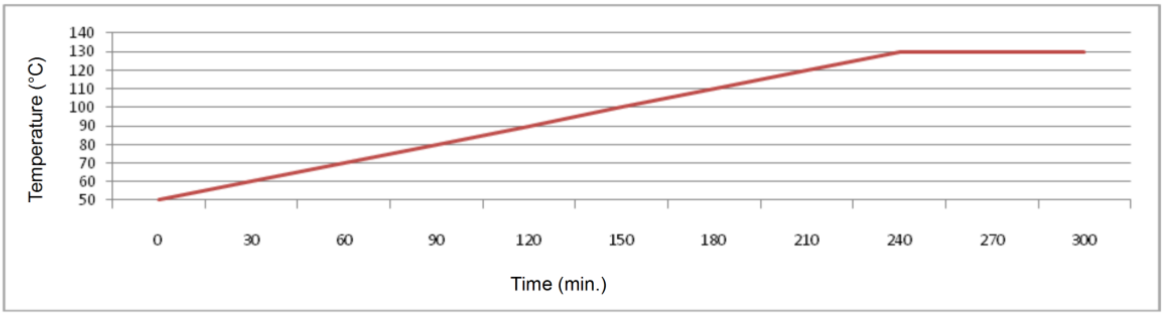

FIG. 2 COURSE OF DEHYDRATION – CURRENT STATE (TIME VERSUS TEMPERATURE)

IV. SIMULATION OF THE DEHYDRATION PROCESS

The dehydration process was simulated in the ANSYS CFX in order to determine the minimum heating time of the compressor to 130 ° C. A numerical calculation was carried out for eight variants, whereby changes were made to internal diameter of the tube bringing air to the compressor, the flow and temperature of the air at the inlet to the compressor. The individual variants are shown in tab. 1.

TABLE 1
VARIANTS OF THE DEHYDRATION PROCESS

Variant	Internal diameter of pipe (mm)	Inlet flow (l·hod-1)	Inlet temperature (°C)
1	6	500	150
2	6	1000	150
3	6	1000	170
4	6	500	170
5	9	1000	150
6	9	500	150
7	9	1000	170
8	9	500	170

The aim of the simulation is to obtain a time diagram showing the course of the increase in temperature in the stator, muffler, support and the average temperature throughout the construction of the compressor in the first four hours of the process, when the required heating of all the components takes place to heat the compressor to the required temperature of 130 °C.

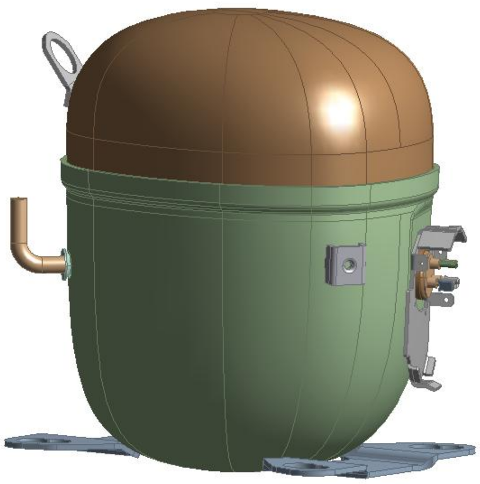

FIG. 3 GEOMETRY OF THE COMPLETE COMPRESSOR

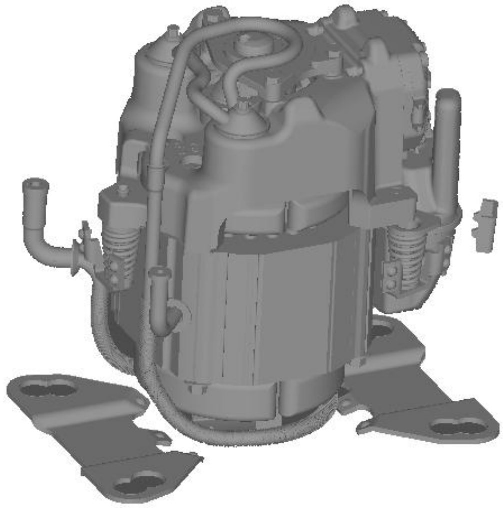

FIG. 4 GEOMETRY OF THE COMPLETE COMPRESSOR WITHOUT COVER

Because of the complicated geometry of the individual parts of the compressor, it has been simplified (Fig. 5 and 6). The geometry is reduced so that in the internal structure of the compressor there remain only the most essential and largest parts.

FIG. 5 REDUCED GEOMETRY OF THE COMPLETE COMPRESSOR

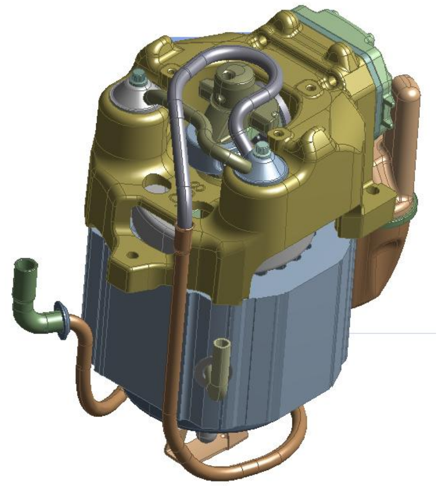

FIG. 6 REDUCED GEOMETRY OF THE COMPLETE COMPRESSOR WITHOUT COVER

After reducing the components of the compressor, it was necessary to simplify the geometry due to the large number of elements (35 000 000) formed by cross-linking. After simplification of the geometry this number of elements was decreased to 3.9 million elements. The simplified geometry is shown in figures 7 and 8.

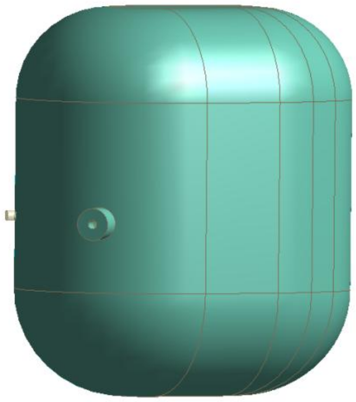

FIG. 7 SIMPLIFIED GEOMETRY OF THE COMPLETE COMPRESSOR

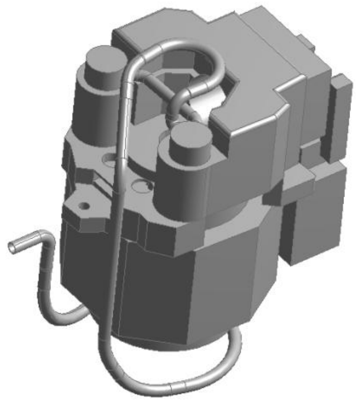

FIG. 8 SIMPLIFIED GEOMETRY OF THE COMPLETE COMPRESSOR WITHOUT COVER

After reducing and simplifying the geometry of the compressor it was necessary to take into account the weight difference of the compressor. The real compressor weighs 19 kg and the simplified compressor 14 kg, for that reason it is necessary to increase the density of the steel from 7850 kg m-3 to 10555 kg m-3 (equation (1)), so that the weight of the simplified compressor reaches the value of the original 19 kg, thus ensuring an approximation of calculation results to real state. To determine the weight, the ANSYS program read the original volume and geometry simplification of the compressor. With the original compressor the volume of the compressor is 2.42 x 10-3 m3, which at a density of steel 7850 kg m-3 corresponds to a weight of the compressor of 19 kg. The simplified geometry reduced the volume of the compressor such that it is 1.8 10-3 m3. The density of the material of the compressor for its reduced volume, was determined according to equation (1).

$$\rho_{\mathrm{f}} = \frac{m_{\mathrm{sk}}}{V_{\mathrm{t}}} = \frac{19}{1{,}8 \cdot 10^{-3}} = 10555\ \mathrm{kg} \cdot \mathrm{m}^{3} \tag{1}$$

where msk is the actual weight of the compressor, Vt is the volume of the reduced construction of the compressor.

For individual variants the time diagram was evaluated with the course of temperature increase in the stator, muffler, support and the average temperature in the whole construction of the compressor. Figure 9 gives the distribution of individual points on the real compressor at which the temperature was measured during the whole course of its heating.

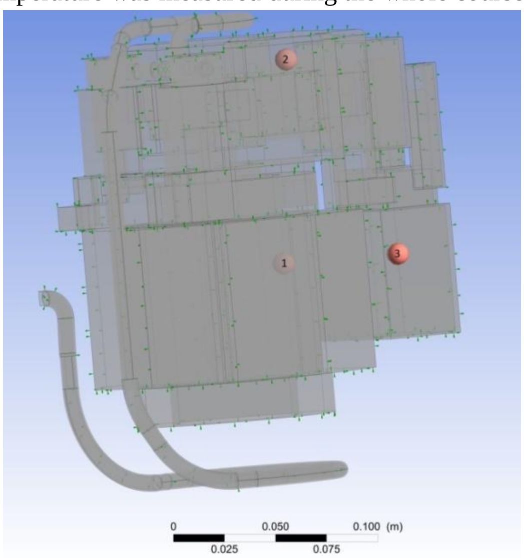

FIG. 9 DISTRIBUTION OF INDIVIDUAL POINTS FOR MEASURING TEMPERATURE DURING THE HEATING OF THE COMPRESSOR

Point no.1 is located in the stator for the reason that it is the largest part of the compressor and therefore also takes the longest to heat up. It is therefore likely that if the stator reaches the desired temperature then the other compressor components should reach maximum temperature. Point No. 2 is located on the support, where it is expected that this part of the compressor will be heated before the stator because of the direct flow of hot air in this part of the compressor. Hot air enters the support directly from the tube which continues to flow into the stator into the plastic muffler.

Point No. 3 is placed on the plastic muffler where greatest amount of H2O is expected. This part of the compressor is quickly heated to its highest temperature as it is a thin-walled element.

An overview of the individual variants of the simulation is shown in table. 2. In figure 10 you can see how temperature on the stator changes under different variants.

TABLE 2
COMPARING NUMERIC CALCULATIONS OF INDIVIDUAL VARIANTS

Variant	Temperature after 240 min. in the simulation (°C)	Temperature after 240 min. in the real compressor (°C)	Required temperature at time (min.)	Shortening of heating by (min.)
1	109.58	130.00	240	0
2	116.2	137.85	195	45
3	129.91	154.11	140	100
4	120.78	143.29	175	65
5	116.33	138.00	195	45
6	108.76	129.03	240	0
7	130.65	155.00	135	105
8	121.22	143,81	175	65

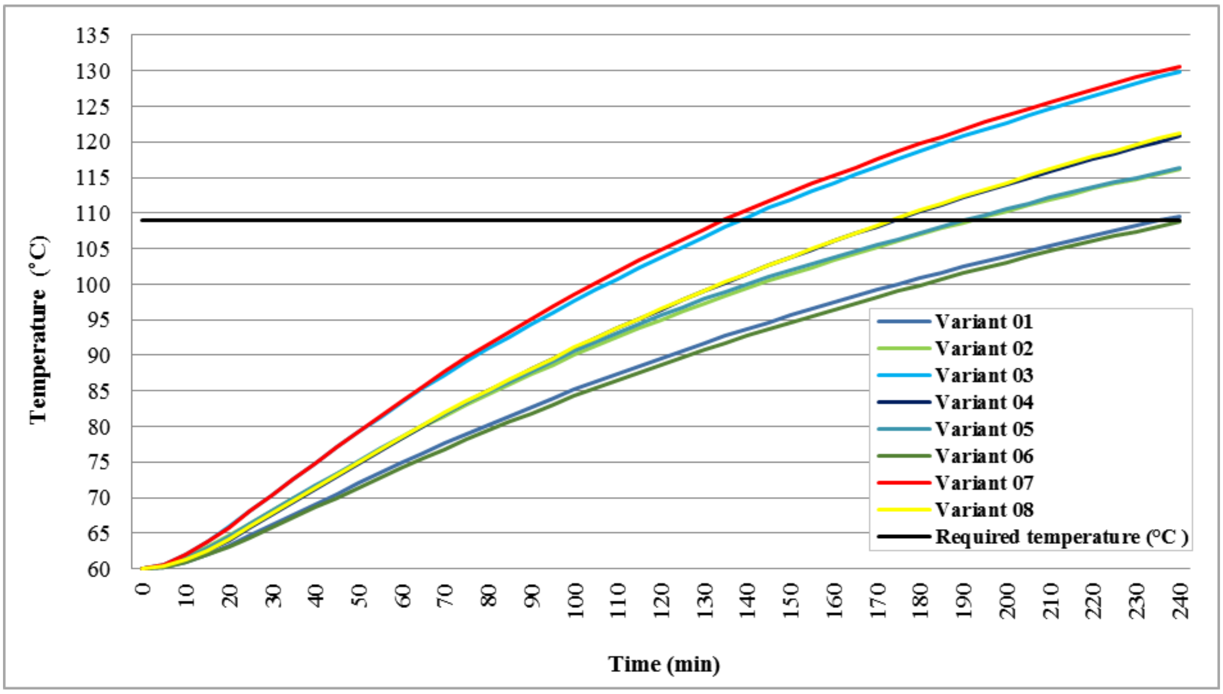

FIG. 10 COURSE OF TEMPERATURE IN THE STATOR FOR INDIVIDUAL VARIANTS (TIME VERSUS TEMPERATURE)

From the simulation results it was found that the compressor is heated quickest in the case where the input air has a temperature of 170 ° C and flow of 1000 l h-1. It was also indicated that the change in diameter of the tube has a minimal effect on the time of heating. In this respect, we consider the best alternative to be option no. 3, also due to the fact the heating process does not require interference with the production design of the compressor, which would be the case for variant no. 7 which requires changes in diameter of the tube.

V. COMPARING THE CURRENT STATE AND THE BEST VARIANTS

If the dehydration process is carried out with parameters as per variant number 3, the heating process will be reduced by 100 minutes (Tab. 2), which would mean that the overall process of dehydration, which in the current climate takes five hours, would shorten in to 3 hours and 20 minutes.

Figures 11 and 12 depict the thermal field on the structure. The temperature on the stator under current conditions reaches a value of 109 ° C. The temperature on the stator under variant no. 3, which has been selected as the best variant, reaches a value of 130 ° C. It is also seen that under variant 3, the temperature after 4 hours of heating all the components is approximately 20 ° C higher. From the temperature field in the structure of the compressor it can be seen that the hottest part of the compressor is the tube through which air flows. The coldest part is the stator, which forms the largest part of the compressor.

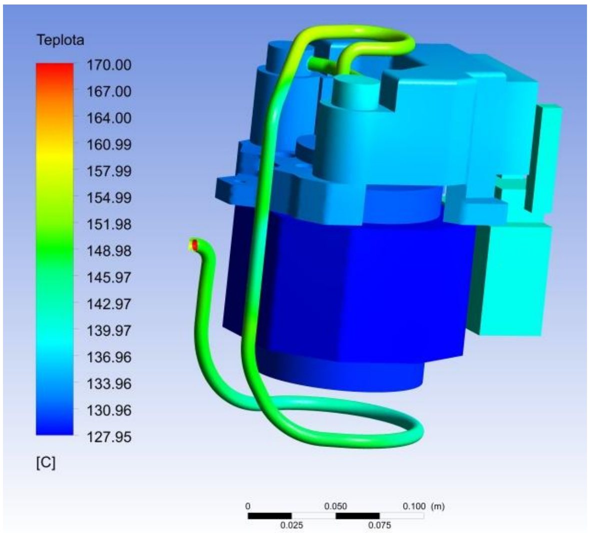

FIG. 11 TEMPERATURE ON THE STRUCTURE UNDER CONDITIONS AS PER VARIANT NO. 3 AFTER 240 MINUTES

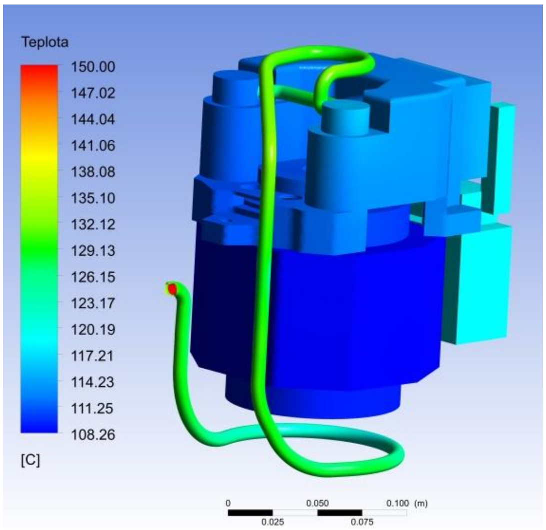

FIG. 12 TEMPERATURE ON THE STRUCTURE UNDER CURRENT CONDITIONS AFTER 240 MINUTES

Figure 13 depicts the temperature on the surface of the structure under variant 3 at a time of 140 minutes, when the compressor reaches the desired temperature of 109 ° C. The heating process will, after 140 minutes, be terminated because the entire structure of the compressor reaches the desired temperature.

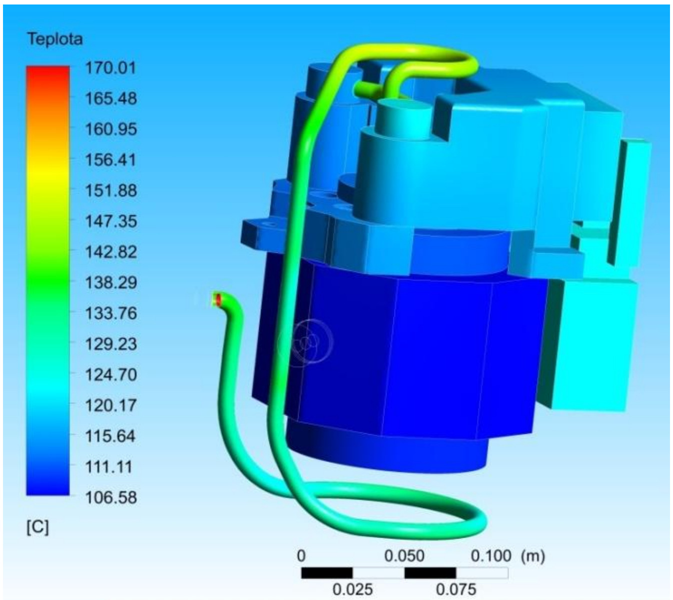

FIG. 13 TEMPERATURE ON THE STRUCTURE FOR VARIANT 3 AFTER 140 MINUTES

Figures 14 and 15 depict the thermal field in the cross-section of the compressor, where the displayed temperature of the air in the area of the cover is shown.

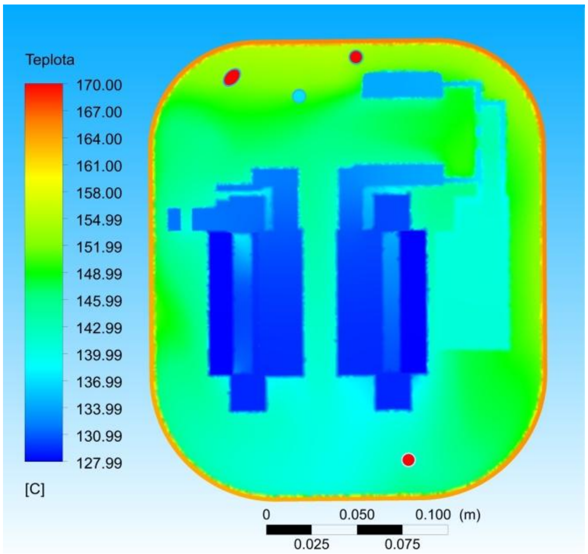

FIG. 14 TEMPERATURE OF THE AIR IN A CROSS-SECTION OF THE COMPRESSOR UNDER THE CONDITIONS OF VARIANT 3 AFTER 240 MINUTES.

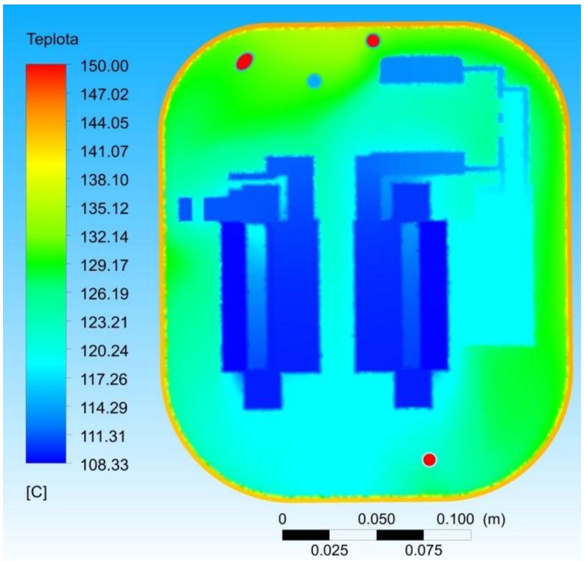

FIG. 15 TEMPERATURE OF THE AIR IN A CROSS-SECTION OF THE COMPRESSOR UNDER CURRENT CONDITIONS AFTER 240 MINUTES

Figures 16 and 17 depict the velocity field of air flow in the space of the cover. The air achieves the highest speed in the inlet pipe. The airflow reaches a higher speed under option 3 for this reason that under variant 3 there is a higher air flow at the inlet to the compressor.

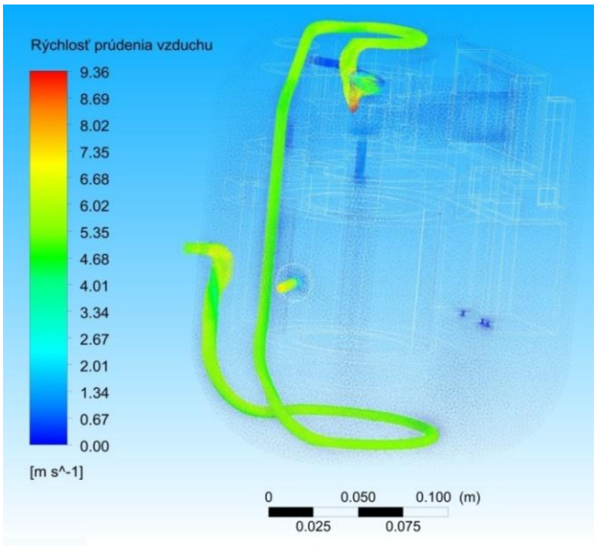

FIG. 16 SPEED OF AIR FLOW UNDER THE CONDITIONS OF VARIANT NUMBER 3

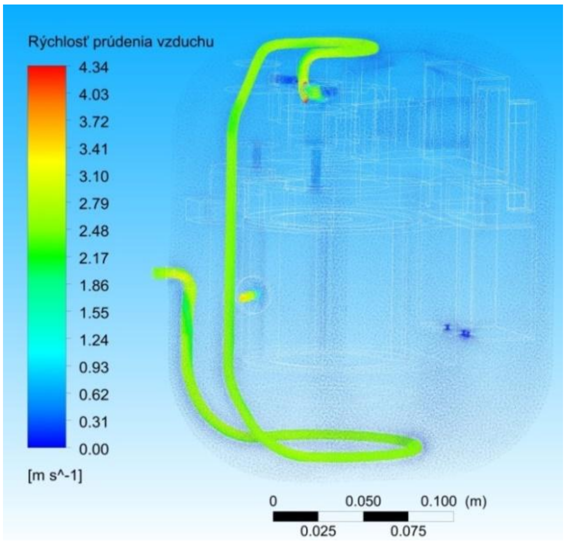

FIG. 17 SPEED OF AIR FLOW UNDER THE CURRENT CONDITIONS

VI. EFFECT OF PERIOD OF SHORTENING THE PROCESS OF DEHYDRATION ON PRODUCTION OF THE COMPRESSOR

Under current conditions the process of dehydration in one oven takes 300 minutes. Each oven has a capacity of 720 units of compressors. Under the conditions of variant 3, the process of dehydration in one oven takes 200 minutes. The next step is to see how this shortening affects the manufacture of compressors.

6.1 Shortening the production of one compressor under the conditions of variant no. 3

In tab. 3 it is shown how shortening the process of dehydration is reflected in the heating of one compressor unit.

TABLE 3
TIME OF HEATING OF 1 UNIT COMPRESSOR – COMPARISON OF CURRENT STATE AND VARIANT NO. 3

Number of compressors (units)	Current state – time criterion (s)	Variant 3– time criterion (s)
720	18000	12000
1	25	16.6

If the length of the dehydration is converted to one compressor, it is obvious that under present conditions a single compressor is heated for 25 seconds. If the dehydration time is reduced by 100 minutes, the time take to produce a single compressor on the production line is shortened by an average of 8.4 seconds.

6.2 Number of heated compressors per day under the conditions of variant no. 3

If the under current conditions 720 units of compressors are heated over 5 hours, under the conditions of variant 3 this number will be heated in only 3 hours and 20 minutes. In tab. 4 the number of compressors that can be heated in 24 hours is shown.

TABLE 4
NUMBER OF HEATER COMPRESSORS IN 24 HOURS –COMPARISON OF CURRENT STATE AND VARIANT NUMBER 3

Current state		Variant no. 3	
Time (s)	Number of units	Time (s)	Number of units
18000	720	12000	720
3600	144	3600	216
86400	3456	86400	5184

For tab. 4 it can be seen that under the current conditions for the process of dehydration over 5 hours 720 compressor units are heated; on a per hour basis this is 144 units and a daily average of 3456 units.

If the parameters from variant 3 are used then over 24 hours in one over as many as 5184 compressor units are heated, which in comparison with current conditions is an increase of 1728 units.

6.3 Reducing the heating time of the current number of compressors heater over 24 hours

Under current conditions during one day 3456 compressor units are heated. Tab. 5 shows over what period of time this number of compressors would be heated under the conditions of variant number 3.

TABLE 5
HEATING TIME, TOTAL NUMBER OF COMPRESSORS – COMPARISON OF CURRENT STATE AND VARIANT NO. 3

Number of compressors (ks)	Current state – time criterion (hours)	Variant no. 3 – time criterion (hours)
3456	24	16

If the current number of compressors is heated daily, i.e. 3456 units, then under the conditions of variant no. 3 this number of compressors is heated in 16 hours which is 8 hours earlier than under current conditions.

From this finding it follows that the number of compressors which is heated in one day under current conditions would now be heated in 16 hours.

6.4 Effect of shortening the dehydration process from various perspectives

From the previous findings, it can be seen that shortening the dehydration process affects the actual production of the compressor. It can be noted that a change of parameters in the process of dehydration can quicken the average time for the manufacture of compressors by 8.4 seconds. When assessing the total number of heated compressors during the day we can say that 10728 more units per day of compressors can be heated than under current conditions. When assessing the overall heating time of compressors every day it can be said that 3456 compressors can heated 8 hours quicker than under current conditions.

6.5 Change in consumption of electrical energy with changed parameters

The current consumption of the electrical oven is on average 26 MWh per month. If the temperature of the air increases from current 150 °C to the required 170 °C, it is possible to expect that the consumption of the oven will increase to an average of 29.4 MWh per month. In tab. 6 it is possible to see the average consumption per year, month and day for individual parameters of heating.

TABLE 6
CONSUMPTION OF ELECTRICAL ENERGY OF ONE OVEN

Consumption of electrical energy	Heating to 150 °C	Heating to 170 °C
MWh per year	313	352
MWh per month	26	29.4
MWh per day	0.854	0.964

The average consumption of electrical energy per day under current heating conditions for heating 3456 compressor units is estimated at 0.854 MWh. After conversion to the average consumption per compressor, this value is 0.248 kWh. From previous observations is follows that under changed conditions for variant no. 3 it is possible to heat daily up to 5184 compressor units; even if the total consumption for the day is higher, the power consumption per compressor is only 0.186 kWh.

TABLE 7
POWER CONSUMPTION OF ONE OVEN PER COMPRESSOR

Period	Number of heated compressors under current conditions (ks)	Number of heated compressors under conditions of variant no. 3 (ks)	Consumption of oven under current conditions (MWh)	Consumption of the oven under conditions of variant no. 3 (MWh)	Consumption of oven per one compressor under current conditions (kWh)	Consumption of oven per one compressor under conditions of variant no. 3 (kWh)
Year	1 261440	1 892160	313	352		
Month	105120	157680	26	294	0.248	0.186
Day	3456	5184	0.857	0.964		

From tab. 7 it follows that for a quantity of 3456 compressors heated per day, under current conditions the consumption of the oven is an average of 26 MWh per month. Under changed parameters as per variant No. 3, the average monthly consumption for the same number of compressors 18.92 MWh, which means reducing the consumption of one electric oven by 7.08 MWh.

Under changed conditions of variant 3 it is possible to heat 5184 compressors per day. If this number of compressors is heated per oven in one day the consumption will be 28.3 MWh per month, which would mean an increase in electricity consumption of 2.3 MWh per month. The number of heated compressors per day would be increased by 1728 units.

It is therefore up to the decision of the company whether to heat more compressors per day and thereby increase electricity consumption by 2.3 MWh per month, or to heat the current number of daily compressors with lower electricity consumption.

From previous findings it follows that if the parameters from variant 3 are used to heat the same number of compressors and electricity consumption of one oven will drop by 7.08 MWh per month.

Considering that the process uses two electric ovens and total consumption in the process of dehydration would decrease by about 14:16 MWh per month. Power consumption should therefore be lower by 27.23%. This would mean that the total cost of operating electric ovens would be reduced by 27.23%.

VII. CONCLUSION

By evaluating all the variants of simulations it was found that the dehydration process can be accelerated by up to 100 minutes. This shortening of the dehydration process can have an impact on the overall production of the compressor. It can be stated that in the process of dehydration more compressors can be heated per day. It has also been shown that the same number of compressors can be produced as today with lower operating costs for the electric oven. It is therefore a matter for the company to decide whether to produce more compressors per day or to produce the current number of compressors with lower production costs. In production with the current number of compressors the company can save more than 27% of the cost of operating the electric ovens used in the dehydration process.

ACKNOWLEDGEMENTS

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