THE ANALYSIS OF THE ECONOMIC EFFICIENCY OF GEARWHEELS NITRIDING

The aim of this article is to analyze the influence of the more important factors determining the use of electrical energy and ammonia in the process of gearwheels nitriding used in truck engines. The following analysis is based on experimental research as well as the currently existing literature data. While performing the processes, the amount (the weight) of gearwheels, the setting of the furnace in a retort as well as the number of fan rotations were changed. The processes were carried out in a vertical furnace in the Institute of Machines and Motor Vehicles at Poznan University of Technology. The results show that the electrical energy usage increases with the rise in the number of gearwheels used in the heating of the batch (and the furnace). In the nitriding process (after the heating) the consumption takes the fixed value. The results also indicate that the increase in the number of gearwheels influences the ammonia usage in the process of heating as well as annealing (during nitriding). Little influence of the gearwheels orientation on the use of two analyzed factors as well as the influence of the number of fan rotations on the ammonia usage have been indicated. The increase in the number of fan rotations significantly lowers the usage of the gas.

Keywords: nitriding, gearwheels, consumption of ammonia, electricity consumption, fan rotations, nitriding potential

1. INTRODUCTION

Gas nitriding is one of the most commonly used methods in heat and thermochemical treatment. The first works on this method date back to the XIX century.

* Institute of Machines and Motor Vehicles; Poznan University of Technology.
Nitriding improves the surface layer properties of the element being processed, increases its endurance as well as its resistance to over-use and exhaustion [1]. Over the course of a hundred years a great number of methods of gas nitriding were discovered and researched. The methods differ, inter alia, in their compositions of nitriding atmosphere. The atmospheres can be divided into single-component and two-component. The one-component atmosphere includes nitriding with the use of ammonia only, which is a traditional process as well as the regulated process known as the ZeroFlow nitriding [3]. Nitriding in the two-component atmosphere, in turn, involves either ammonia and dissociated ammonia or ammonia and nitrogen. These processes are classified as regulated nitriding because, due to their adequate regulations of the process parameters (including temperature and the composition of the atmosphere in the furnace retort), they allow to produce layers with the required phase structure. The processes, however, differ from one another in their uses of ammonia and, as a result, in the emission of post-process gases into the environment. Previous research indicates that the ZeroFlow nitriding method studied at Poznan University of Technology is characterized by the lowest gas usage [7].

For years, the development of technology has increased people’s knowledge as well as awareness in the field of environmental protection, and, by extension, the rational use of natural resources. The norms and regulations concerning the use of natural resources as well as the emission of pollution have been established, and they are strictly abode [9, 11]. However, as yet no study precisely investigating the use of ammonia has been conducted. This issue has become highly relevant in the light of increasing requirements concerning the use of natural resources and environmental pollution. The following paper is based on the analysis of the use of ammonia as well as electrical energy depending on the orientation of the gearwheels in retort (with side surface parallel and perpendicularly to the direction of the atmospheric flow) and the changing fan rotations. The influence of the fan rotations on the speed of dissociation and, consequently, the use of ammonia and electrical energy have been investigated.

2. METHODOLOGY

2.1. The aim and range of the current research

The aim of the present study was to investigate the influence of economic factors on the very process of gas nitriding which depended on the modification of the chosen parameters, such as the size of the batch (the amount and weight of the gearwheels) and the power of the fan. The use of electrical energy and ammonia in a few processes of nitriding were analyzed. The very processes differed from each other on the basis of:
The analysis of the economic efficiency of gearwheels nitriding

- the size of the batch – 2, 7 or 13 gearwheels,
- the location of the batch – the batch was placed either parallelly or perpendicularly to the fan,
- the fan rotations – the range of the fan power was changed from 375 r/min to 1500 r/min,

The gas nitriding was conducted with the fixed nitriding potential $N_p$ equals 3.6. The time of the process was adjusted to the current process which was defined on the basis of the nitriding potential as well as the flow of ammonia.

2.2. Test stand and details used in nitriding process

Nitriding process was conducted in a horizontal furnace located in a laboratory in the Poznan University of Technology. Figure 1 shows furnace.

![Fig. 1. Furnace type VTR used for nitriding](image)

There had been a set of 13 gearwheels used in nitriding process (from a well-known producer for trucks) consisting of 3 different types of gearwheels shown in the fig. 2. All the gearwheels are made of the same material, i.e. steel C45 and the difference is made between their weight and surface. The processes performed for the industrial.

![Fig. 2. Types of gearwheels used in nitriding process](image)
Basic parameters of nitrated gearwheels

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight [kg]</th>
<th>Surface [m^2]</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>3.98</td>
<td>0.13</td>
<td>4</td>
</tr>
<tr>
<td>2.</td>
<td>4.97</td>
<td>0.12</td>
<td>2</td>
</tr>
<tr>
<td>3.</td>
<td>5.91</td>
<td>0.18</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>65.97</td>
<td>2.02</td>
<td>13</td>
</tr>
</tbody>
</table>

2.3. Results

In order to measure consumption of electrical energy and ammonia, several nitriding processes had been conducted in the VTR5169 retort horizontal furnace. These processes allowed us to receive the results that show the relationship between the consumption and how big the batch and fan rotations is as well as how the gearwheels are located. There had been other processes used for the further analysis which had shown similar results. Results that are totally different than expected have not been mentioned, such as: process at the speed of the fan rotations 375 r/min (25% of maximal rotations). It was impossible to achieve the given nitriding potential at the level of 3.6 at such low speed. Consumption of ammonia at the level of 12 l/min was achieved. However, the nitriding potential was exactly equal to 2. Processes at the speed of 25% are analyzed only with regard to the energy being used.

![Graph showing consumption of ammonia during heating and annealing with different number of gearwheels](image)

**Fig. 3.** Consumption of ammonia during heating and annealing in the processes of nitriding with a different number of gearwheels

<table>
<thead>
<tr>
<th>Number of gearwheels</th>
<th>Heating [l]</th>
<th>Annealing [l/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1791.58</td>
<td>1.22</td>
</tr>
<tr>
<td>2</td>
<td>1797.40</td>
<td>2.09</td>
</tr>
<tr>
<td>7</td>
<td>1804.09</td>
<td>2.17</td>
</tr>
<tr>
<td>13</td>
<td>1828.21</td>
<td>2.58</td>
</tr>
</tbody>
</table>
Consumption of ammonia in heating process depends largely on rinsing of the ammonia, which always takes the same amount of time. For this reason, the results achieved are of similar value and a small difference was made due to variable number of gearwheels. During annealing, a medium consumption of ammonia was counted for a specific period of time in which there was a stability in the flow of the ammonia and nitriding potential. The difference in consumption depends on how big the batch is as in the heating process.

<table>
<thead>
<tr>
<th>Number of gearwheels</th>
<th>Heating [kWh]</th>
<th>Annealing [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>67.07</td>
<td>10.28</td>
</tr>
<tr>
<td>2</td>
<td>66.51</td>
<td>10.29</td>
</tr>
<tr>
<td>7</td>
<td>68.26</td>
<td>10.08</td>
</tr>
<tr>
<td>13</td>
<td>74.20</td>
<td>10.31</td>
</tr>
</tbody>
</table>

Fig. 4. Consumption of electrical energy during heating and annealing in the processes of nitriding with a different number of gearwheels

The results shown in the Figure 4 let us conclude that the size of the batch does not have a big effect on the energy used during the heating process due to the equal temperature in the whole batch and retort of the furnace. A little usage of carrying capacity of the furnace as well as a limited number of processes used tell us only a little about the conclusion. The heating power calculated during annealing can be seen in a similar way regardless of the size of the batch. This is confirmed by the fact that the size of the batch does not influence the energy consumption during annealing but only heating costs covered.

By comparing the electrical energy and ammonia being used during annealing, we can see the analogies in steps taken. However, while in annealing process, the consumption of the electrical energy stays the same, the consumption of ammonia increases together with the number of the gearwheels.

The results achieved in nitriding process were also analyzed in regard with the different fan rotations. Figure 6 shows the consumption of ammonia and electrical energy for the fan rotations: 375 r/min (25% of the maximal power), 750 r/min
(50%), 1125 r/min (75%) and 1500 r/min (100%). The lowest consumption of electrical energy was found in the lowest power (the lowest fan rotations – 25%), the higher the rotations, the higher the consumption. How efficient the electrical engine in the fan is, has an influence on how much electrical energy is used. The retort of the furnace is driven by electric elements located in 3 places between the retort and the structure of the furnace. However, the movement of the atmosphere is possible due to the fan driven by the electrical engine. The efficiency of the electric elements equals almost 100% and the whole energy delivered to the electric elements is changed into the thermal energy. The efficiency of the electrical engine reaches 82%, and this may, therefore, suggest that the higher the fan rotations (the much more power it has), the higher the heating loss.

![Graph](image)

Fig. 5. Consumption of the electrical energy and ammonia in regard with the different fan rotations

It can be said from the Fig. 5 that ammonia consumption increases together with the fan rotations and that is the case, indeed, however, not for the whole scope of the fan rotations. The increased flow of ammonia for 375 r/min of the fan is necessary in order to achieve the given nitriding potential which is 3.6. The computer controls the flow of ammonia in a way to reach the given nitriding potential. Although it lets the maximal possible amount of ammonia into the furnace (12 l/min), it is still not possible to achieve the given nitriding potential.

3. SUMMARY

In this case study, consumption of electrical energy and of ammonia were analyzed during nitriding processes of gearwheels in a way of gas nitriding using the retort horizontal furnace. These processes were different in the size of the batch,
rotation power of the fan as well as the structure of the gearwheels in regard with the direction of gas flow. All the processes were conducted in 550°C and in nitriding potential $N_p$ which equals 3.6.

On the basis of these studies, it has been stated that weight of gearwheels affects consumption of electrical energy during heating. Magnitude differs from 66 kWh to 74 kWh and makes the difference at 10%. During annealing, the size of the batch does not affect consumption of electrical energy. The amount of energy delivered to the furnace covers heating loss caused by furnace structure.

There is a slight influence on consumption of electrical energy and of ammonia caused by changing the location of gearwheels. The size of the batch slightly increases consumption of ammonia, however, rinsing with ammonia has decisive impact on consumption of ammonia. Consumption of ammonia increases while annealing bigger number of gearwheels. The larger the nitrated surface, the higher the dissociation of ammonia and its consumption.

Increase in fan rotations also increases consumption of ammonia. It had been confirmed that at the low value of fan rotations (375 r/min), the value of a given nitriding potential is impossible to reached. The reason is that small amount of heat is delivered to the retort by fan in order to keep temperature that is required and bigger amount of heat by heating elements which result in higher temperature of retort’s walls that are responsible for ammonia dissociation. However, the higher the temperature of retort’s coat, the faster the ammonia dissociation and in the same time the bigger its consumption.

REFERENCES

ANALIZA EFEKTYWNOŚCI EKONOMICZNEJ AZOTOWANIA KÓŁ ZĘBATYCH

Streszczenie

W pracy analizowano wyniki badań eksperymentalnych oraz dostępnych danych literaturowych wpływ ważniejszych czynników determinujących zużycie energii elektrycznej i amoniaku podczas azotowania kół zębatych do silników samochodów ciężarowych, a w rezultacie koszty procesu. Podczas prowadzenia procesów zmieniano ilość (ciężar) kół, ustawienie w retorcie pieca i ilość obrotów wentylatora. Procesy prowadzono w piecu poziomym, znajdującym się Instytucie Maszyn Roboczych i Pojazdów Politechniki Poznańskiej. Wykazano m.in. że zużycie energii elektrycznej wzrasta ze wzrostem ilości kół w retorcie pieca. Podczas wygrzewania zużycie to przyjmuje wartość stałą. Wykazano również, że wzrost ilości kół wpływa na zużycie amoniaku zarówno podczas nagrzewania jak i wygrzewania (podczas azotowania). Stwierdzono niewielki wpływ ustawienia kół na zużycie obu analizowanych czynników, oraz wpływ ilości obrotów wentylatora na zużycie amoniaku. Wzrost obrotów wentylatora wyraźnie zmniejsza zużycie tego gazu.

Słowa kluczowe: azotowanie, koła zębate, zużycie amoniaku, zużycie energii elektrycznej, obroty wentylatora, potencjał azotowy