Effect of the strong magnetic field on copper adsorption processes on activated carbon

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In the presented studies an influence of the strong static magnetic field on the process of copper adsorption on activated carbon was analysed. The magnetic field was generated by the annular neodymium magnets, placed at the bottom of the glass reactors, with the magnetic induction value at the surface equal 0.517 T. Additionally, during the study an effect of temperature on the adsorption process efficiency and its susceptibility to the external magnetic field was also investigated. As a result of the study, it was found that using a magnetic modification can increase the efficiency of the adsorption process up to 80%. However, such a strong influence of the external magnetic field was observed only in the case of relatively low initial and equilibrium concentration of the adsorbate. With the increase of the equilibrium concentration, stimulating nature of the magnetic field weakened significantly until finally at an equilibrium concentration about 80 mg/dm3, it was almost negligible. In addition, it was also found that the magnetic field modifications were much more efficient if the adsorption processes were conducted at the higher temperature.

Keywords: Magnetic field modification, Copper adsorption, Heavy metals removal

Introduction

Heavy metal adsorption processes can be classified as one of the key processes used in modern environmental engineering technologies [1,2]. Copper, which was a metal analysed during the study, is classified as one of the microelements necessary for the proper functioning of the human body. However, it is also a representative of heavy metals group and despite its beneficial biostatic property, in the case of excess intake can lead to serious poisoning and even death [3,4]. That is why, it is a very important task for many waste water treatment plants, operating in the fields of different kind of heavy industrial plants, to ensure a sufficiently low copper concentration in wastewater discharged into municipal sewage treatment plants. [5].

However, the key element of the present study was to analyse an influence of the external static magnetic field on the mentioned adsorption processes of copper. The use of the external magnetic field to intensify various types of physicochemical processes is a well-known procedure for a long time. Nevertheless, only recently developed technology has allowed for the production of really strong and relatively inexpensive neodymium magnets, with the magnetic induction value reaching up to a few T. Therefore, many new opportunities have become, especially in systems in which the observed magnetic field effect was unsatisfactory due to the weak magnetic induction value because nowadays, a much stronger magnetic field can be used without a need of high investment costs.

The influence of strong magnetic fields on water and aqueous solutions was analysed not only for changes in macroscopic properties but also for analysing changes in molecular structure and intermolecular interactions [6-9]. As a result of the analyses, among the others, it has been shown, that due to the use of relatively strong, static magnetic fields in the range of 100-300 mT, it is possible to increase the specific heat of the water and change an internal energy of the molecules. [8]. In addition, it has been also noted that exposition to the external magnetic field, can cause an increase in a number of hydrogen bonds that occur between water molecules [10, 11]. Other studies related to this magnetic field effect on water properties have shown that water subjected to a strong static magnetic field tends to form slightly more ordered structures, especially in the interface areas and in the immediate vicinity of large hydrophobic particles[12]. Many other studies on the magnetic field influence on water and water solutions have been investigated, like a possibility of stimulating such processes as crystallization, dissolving of gases and even increasing the speed of some reactions occurring in the water phase [13-15].

Methods

The adsorbent used in the study was a granular activated carbon type *Chem WD-extra/w* by *Chempur* with a grains size in the range of 1-4 mm. The copper solutions used in the study were prepared by dissolving analytical pure copper nitrate (V) delivered by *Chem-Lab* company in the distilled water.

In addition, during the preliminary studies, an analysis of the effect of the reaction mixture pH values on the efficiency of the copper adsorption process on activated carbon was carried out. Based on preliminary studies, it was found that the efficiency of adsorption processes is highest at pH value between 5-7. However, during the adsorption process, the pH of the reaction mixture has increased and at the higher values, copper ions that were present in the solution at the beginning have started to precipitate. That is why it was decided to use an initial pH of 5 and after the 60 minutes, pH value of the reaction mixture at equilibrium state was about 6,7. The volume of the reaction mixture was 200 cm^3 and in every repetition, an activated carbon was added to the solution in the amount of 0,5 g.

The magnetic field that was used during the study was generated by annular neodymium magnets placed directly at the bottom of the glass reactor with the capacity equal 400 cm^3. Magnets type, used for this purpose was N38 and the magnetic induction values (measured in the magnetization axis, at a distance of 0.7 mm from the surface of the magnet) was equal 517 mT. In order to obtain the appropriate statistical significance of the results, all of the analysis conducted in the experiment was performed in 6 replicates both for modified and unmodified systems in every temperature and initial copper concentration values.

The concentration of copper both in the initial solutions after the adsorption process was analyzed by using of the atomic absorption spectroscopy. The analyses were carried out using the *SpectrAA 880* Flame Spectrometer by *Varian*. Moreover, despite an analysis of the results obtained for selected initial concentrations, the parameters of Langmuir isotherm were also determined for the modified and unmodified systems at each of the tested temperatures. For this purpose, the classic Langmuir adsorption isotherm was used (eq.1.).

$$q_e = \frac{Q_{max} * K_L * C_e}{1 + K_L * C_e} \qquad (1)$$

Where,

q_e – Adsorbate removal at equilibrium state [mg/g]

Q_{max} – Theoretical maximum adsorption capacity [mg/g]

K_L – Langmuir constant [dm^3/mg]

C_e – Equilibrium concentration of adsorbate [mg/dm^3]

In scientific literature, there are many articles whose authors linearize Langmuir equation to one of the 4 most popular forms, in order to find the equation parameters more easily. However, such linearization leads to changes in dependent and independent variables, which in turn can cause errors in the results like overstating or under-estimating both data match R^2 coefficient and obtained model parameters. These problems have been extensively discussed by *Bolster and Hornberger* and by *Tran et al.*, in their works they indicating that the most reliable results of the calculations can be obtained when the model parameters are calculated directly from the original nonlinear form [16, 17]. Consequently, it was decided, that during the study, all model parameters would be calculated by using a nonlinear regression method from the original nonlinear Langmuir equation using a *MATLAB 2013R* software by *MathWorks®*.

Results and discussion

Based on the conducted research, it has been found that thanks to the simple modification of the adsorption process by using strong permanent magnets, the efficiency of the adsorption process can be significantly improved. This effect was stronger for the relatively low equilibrium concentrations and decreased markedly as the initial concentration was raised. The results presented below for the initial concentration of copper at 5 mg/dm^3 clearly indicate that, due to the use of mentioned modification, it is possible to significantly increase the efficiency of the adsorption processes (Fig. 1).

Analyzing the data from the figure above it can be seen that the influence of the external magnetic field on adsorption processes largely depends on the temperature at which the process is carried out. With the increase of the temperature, differences between the adsorption efficiency for unmodified and magnetically treated processes has also increased. For systems with an initial concentration of 10 mg / dm^3, the observed differences are similar to those in figure 1, and in the case of adsorption at 45°C, the magnetic field stimulation effect was even stronger (Fig. 2).

However, a stimulating effect of the magnetic field is weakening as the adsorbate equilibrium concentration increases and adsorbent efficiency approaches to the values near the theoretical maximum capacity of the adsorbent. The results of copper removal at each of the temperatures

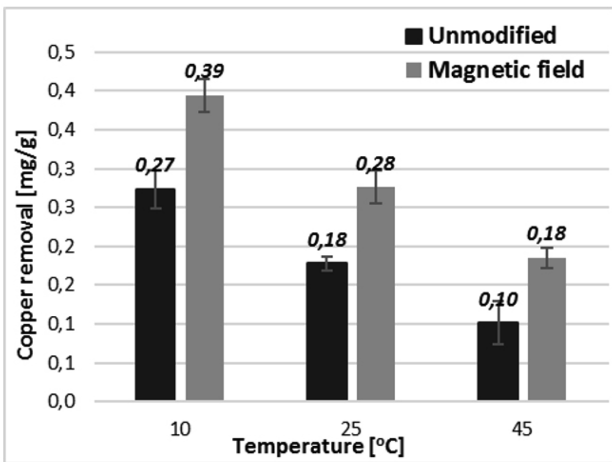

Fig. 1. Copper removal for the solutions with the initial concentration equal 5 mg/dm^3

for the highest tested initial concentrations, which was equal 90 mg/dm^3 were presented below (Fig. 3).

Analysis of all three figures indicates that as the temperature increased, the adsorption rate decreased, despite the fact, that overall adsorption capacity at higher temperatures was higher. In addition, except the presented analysis of changes for each of the initial concentrations during the study, an attempt was also made to characterize the investigated processes based on the Langmuir adsorption model. The table below presents the most important Langmuir isotherm parameters at each of the temperature both for modified and unmodified processes (Tab. 1).

Based on the data presented in the table it can be concluded, that with the increase of temperature, both for modified and unmodified processes, theoretical total adsorption capacity of the adsorbent (Q_{max}) increase significantly. However, at each of the tested temperatures, these values are slightly higher for unmodified systems. This may be due to the fact that, in the case of magnetic field modified processes, the adsorption saturation seems to be easier

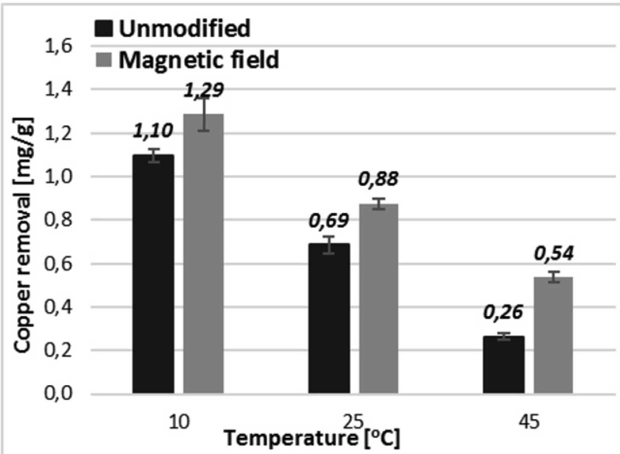

Fig. 2. Copper removal for the solutions with the initial concentration equal 10 mg/dm^3

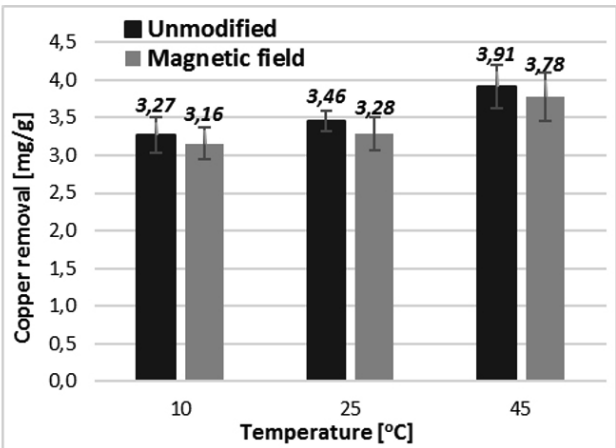

Fig. 3. Copper removal for the solutions with the initial concentration equal 90 mg/dm^3

Table 1. Parameters of Langmuir isotherm equations for modified and unmodified copper adsorption (Qmax [mg/g $_{adsorbent}$])

	10 °C		25 °C		45 °C	
	Q_{max}	R^2	Q_{max}	R^2	Q_{max}	R^2
Unmodified	3,972	0,814	4,647	0,655	5,783	0,566
Magnetic modification	3,876	0,867	4,238	0,676	5,710	0,564

at lower equilibrium concentrations, which in turn could have an impact on the presented values of the theoretical model parameters.

Conclusion

As a result of the studies, it was found that the use of strong external magnetic fields can be an effective method of increasing the efficiency of copper adsorption processes. This fact is a very important conclusion, mostly because of the small investment costs associated with the purchase and the proper installation of neodymium magnets. Moreover, despite the installation expenses, there are no other upkeep and exploitation costs related to that modifications. Most of the adsorption modification methods, that are nowadays in the common use are based on the using of aggressive chemical reagents to modify some of the adsorbents properties. However, those methods not only generate additional wastes but also raise the operating costs of the plant. In the case of magnetic field modifications, there is no increase in the further cost of the process which is a very important factor for the potential investors and users of the wastewater treatment plants.

However, the fact remains that it is still not fully clear of how magnetic fields affect the adsorption processes. By analogy with the electric field, it seems possible, that it may in some way influence in the difference between the energy levels of HOMO and LUMO orbitals of the reacting molecules, which in turn could also affect the performance and kinetics of the reaction in such a field [18]. Of course, this is only one of the possible hypothesis trying to explain the observed changes in the adsorption processes caused by the external magnetic field. However, this problem certainly requires further research, because a better understanding of this modification can lead to the important contribution to the development of techniques of water and wastewater treatment processes.

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