Novel sorbents for flue gas purification☆

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Abstract
This paper presents a method for cleaning exhaust gas of nitrogen oxides using the process of physical adsorption on novel sorbents obtained from fly ash. Use of this method, combined with CO₂ capture, allows emission standards to be met.

Keywords: sorbents, nitrogen oxides, mesoporous material MCM-41, physical adsorption, fly ash

1. Introduction
Due to the obligations arising from the European Union climate-energy package emphasis is placed on reducing greenhouse gas emissions, especially CO₂, which is considered a major cause of global warming. In accordance with the requirements of the European Commission, by the year 2020, CO₂ emissions should be reduced by 20%, the share of renewable energy sources (RES) should increase by 20%. Since the share of coal in total CO₂ emissions is approximately 38%, and since it is the main fuel for energy production in Poland, the most appropriate technologies seem to be carbon capture and storage (CCS). The European Commission stresses that carbon sequestration will be a necessary condition for using coal as a fuel.

Great emphasis is put on CO₂ removal from flue gas using two methods: the absorption method, and adsorption on amine solid sorbents modified with amines. The main problem associated with these methods is the pollution of amines with compounds such as oxides of sulfur and nitrogen. As a result of chemical reactions between oxides and amines, irreversible reactions take place which causes degradation of amines. In the case of SO₂, safe concentrations should not exceed 10 ppm, while for oxides of nitrogen they should be less than 40 mg/Nm³ (20 ppm). In the case of nitrogen oxides, both methods of primary and secondary NOₓ reduction fail to achieve safe concentrations of nitrogen oxides in the exhaust gas. The most effective way to reduce emissions of nitrogen oxides is the SCR method, which achieves emission limits of 100 mg/Nm³. Unfortunately, this value is 5 times higher than that permissible for amines-based carbon capture.

The exhaust gas from a power plant boiler contains 95–97% NO, 3–5% NO₂, and about 0.5% N₂O. Because NO is an inert gas but easy to oxidize chemically, the author proposes to pick up the NO₂ in the process of adsorption on solid sorbents after first oxidizing NO to NO₂.

Sorbents such as mesoporous materials can be obtained, with benefits to the environment, from power

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(Wojciech Nowak)
Table 1: Chemical composition of fly ash

<table>
<thead>
<tr>
<th>Content of basic chemicals*, wt. %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LOI</td>
<td>2.97</td>
</tr>
<tr>
<td>S</td>
<td>0.16</td>
</tr>
<tr>
<td>C</td>
<td>3.41</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>51.39</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>24.9</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>3.72</td>
</tr>
<tr>
<td>CaO</td>
<td>4.35</td>
</tr>
</tbody>
</table>

*averaged values measured on a large sample

plant fly ash waste. Due to its chemical composition, fly ash is a valuable source of silicon and aluminum in the synthesis of mesoporous materials [1–8]. A number of applications of both microporous and mesoporous molecular sieve can be found in the literature. They are used among others in the purification of gases from pollutants such as carbon dioxide, sulfur dioxide, hydrogen sulfide, nitrogen oxides and mercury [2, 9–22]. In the case of materials synthesized from fly ash, information can also be found about their use in the purification of gases, mainly carbon dioxide, through adsorption.

This paper presents a method for cleaning exhaust gas of nitrogen oxides using the process of physical adsorption on novel sorbents obtained from fly ash. Use of this method, combined with CO$_2$ capture, allows emission standards to be met.

2. Experiment

2.1. Characteristics of the source material for the synthesis of the mesoporous material MCM-41

2.1.1. Chemical Composition

As a starting material fly ash derived from the combustion of coal in a pulverized boiler was used. The chemical composition of the fly ash was determined with use of an X-ray fluorescence spectrometer, and the results are presented in Table 1.

The ash had a SiO$_2$ content of 51.39 wt. %, 24.9 wt. % of Al$_2$O$_3$ and a CaO content of 4.35 wt. %. These data indicate that the ash in accordance can be classified as a silica ash (Polish standard BN-79/6722-09).

2.1.2. Thermogravimetric Analysis

The effect of temperature on the sample ash was investigated by the thermogravimetry method (TG) and differential thermal analysis (SDTA) using a Mettler Toledo TGA / SDTA 851e thermal analyzer. A sample of fly ash was heated in a platinum crucible at atmospheric pressure in an inert atmosphere (N$_2$) with a gas flow rate of 50 cm$^3$/min, in a temperature range of 293–1273 K with a heating speed 293 K/min. The weight of samples was 10 mg. The results of the studies, in the form of thermograms, are shown in Figure 1 as graphs illustrating the relationship between the weight change of a sample versus temperature (TG signal) and its first derivative (DTG).

The figure shows the three weight losses for the ash samples, with local minima at temperatures of 50°C, 500°C and 870°C respectively. The first loss is 0.02 mg, which is caused by water evaporation. The second loss, of 0.15 mg, is due to the dehydration of Ca(OH)$_2$. At 870°C there is a mass loss of 0.12 mg, resulting from the decomposition of CaCO$_3$. The total mass loss of the sample is 0.56 mg.

2.1.3. Analysis of the surface area

In order to examine the structure of fly ash, low-temperature nitrogen adsorption at 77 K was carried out on ASAP 2000 apparatus. After degassing the sample at 623 K the adsorption-desorption isotherms of nitrogen were measured. Based on these isotherms, the surface area, total pore volume, mean pore diameter, pore volume distribution as a function of their diameter and size distribution of surface area versus pore diameter were calculated.

Figure 2 shows adsorption/desorption isotherm curves as well as pore volume and size distribution of the surface as a function of their diameter.
presented adsorption/desorption isotherms of ash are consistent with the classification of IUPAC and these are the type II isotherms observed in macroporous adsorbents. From the presented curves can be seen that the adsorption is small at large values of $p/p_0$, and that the hysteresis loop, whose shape is related to the proper pore structure and which in this case can be classified as H3, starts at low relative pressures, indicating the small share of micropores in the structure.

Analyzing the distribution curves of specific surface as a function of pore diameter (Fig. 4), it should be noted that the largest share of the total surface area are pores with a diameter of 2.5–4.5 nm.

2.1.4. Images of the surface

In order to determine the shape and size of crystallite size in the range of 0.1–10 microns and its morphology and structure, fly ash samples were analyzed by scanning microscopy (SEM). The tests were performed using a Tesla BS-301 scanning electron microscope equipped with a Satellite digital imaging system.

The samples for SEM were prepared by spraying the surface of the tested materials with a thin layer of Au-Pd. Then digital images were taken with the SE detector microscope for various parts of the surface of these samples at different magnifications. Micrograms of the tested samples are shown in Fig. 5.

The presence of fly ash components such as SiO$_2$, calcium, and unburned carbon can be seen in these pictures.

2.2. Synthesis of mesoporous silica materials MCM-41

Extract from fly ash, a rich source of silicon and aluminum, is needed for the synthesis of MCM-41. To achieve this, the ashes were mixed with NaOH in a way allowing the mass ratio to remain at 1:1.2. Next the mixture was ground for 2 hours and then
Figure 5: SEM images of fly ash
Table 2: Element concentrations in the filtrate

<table>
<thead>
<tr>
<th>Elemental compositions</th>
<th>Concentration in the filtrate, mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1.2</td>
</tr>
<tr>
<td>Na</td>
<td>7.6·10^4</td>
</tr>
<tr>
<td>K</td>
<td>1.9·10^3</td>
</tr>
<tr>
<td>Ca</td>
<td>12</td>
</tr>
<tr>
<td>Mg</td>
<td>0.2</td>
</tr>
<tr>
<td>Al</td>
<td>8.4·10^2</td>
</tr>
<tr>
<td>Si</td>
<td>1.96·10^3</td>
</tr>
</tbody>
</table>

The sample was subjected to heat treatment at 823 K for 1 hour with a heating speed of 1 K/min. After cooling to room temperature the sample was ground again and mixed with water in a mass ratio of 1:4. The sample was shaken at room temperature for 12 hours. The sample was then filtered and the filtrate was subjected to ICP analysis. The results of the analysis are presented in Table 2.

The results shown in Table 2 show that the silicon content in solution was 1.96·10^3 mg/l and aluminum content was 8.4·10^2 mg/l. A surfactant-matrix solution was added to a previously prepared extracted solution of silicon. For this purpose, CTAB (cetyltrimethylammonium bromide—C_{16}H_{33}(CH_{3})_{3}NBr) was dissolved in distilled water and NH_4OH was added. Next it was added to the supernatant (silicon extract) so that the molar ratio in the gel was SiO_2:CTAB:H_2O = 1:0.15:170. The pH of the solution was adjusted to 11 by adding CH_3COOH and it was adjusted several times while heating the mixture at 373 K for 4 days. The crystallized sample was then filtered and washed with distilled water to remove excess NaOH and dried at 373 K for 24 h. In order to remove the sample matrix it was calcined at 823 K for 2 hours with a heating speed of 1 K/min.

Figure 6 shows a picture of the mesoporous sieve MCM-41 that was finally obtained.

The adsorption properties of the obtained material were examined by nitrogen adsorption at 77 K, which enabled determination of the total surface area, total pore volume and pore volume distribution according to their diameter.

Table 3 shows the data obtained for the ash and the material obtained from it.

Table 3: Pore characteristics of fly ash and MCM-41

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pore vol-</th>
<th>Specific surface area</th>
<th>Pore diameter,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>volume, cm^3/g</td>
<td>SB.E.T., m^2/g</td>
<td>nm</td>
</tr>
<tr>
<td>Ash</td>
<td>0.001</td>
<td>0.6</td>
<td>9.11</td>
</tr>
<tr>
<td>Material</td>
<td>0.673</td>
<td>980</td>
<td>2.74</td>
</tr>
<tr>
<td>MCM-41</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The SBET specific surface of fly ash was 0.6 m^2/g, total pore volume of 0.001 cm^3/g with an average pore radius of 9.11 nm. For the obtained material the specific surface SBET of fly ash was 980 m^2/g, total pore volume of 0.673 cm^3/g with an average pore radius of 2.74 nm.

The resulting material was also analyzed using a high-resolution D8 Advance Powder Diffractometer with a Ge monochromator (length radiated CuKα_1 = 1.5406 Å). Reflections were recorded with a LynxEye silicon strip detector. Measurements were performed using a cuvette made of polymethylmethacrylate. Diffraction patterns were recorded at room temperature for 10-70° 2Θ with steps of 0.0499, at 1 step/sec. During the measurements the sample was rotated at 30 rotations/minute. Measurements were performed at X-ray generator tube voltage of 35 kV and current of 50 mA.
Figures 7 and 8 show low and high angle diffraction patterns of the received material.

As can be seen from Figure 7, the low angle diffraction pattern contains the characteristic peak of mesoporous material MCM-41. In the sample material, the presence of pores with uniform mesopores and amorphous silica was observed.

The resulting material was also analyzed using scanning electron microscopy (SEM) to determine the morphology and porous structure. Preparations for SEM were prepared by spraying the surface of the tested materials with a thin layer of Au-Pd. Then the digital images of different parts of the surface of these preparations at different magnifications were taken with the microscope. Pictures of the tested samples are shown in Figure 9. SEM photos of mesoporous material from fly ash MCM-41 show that the material structure is mostly particle agglomeration. Photomicrographs show a regular arrangement of the channels.

In the pictures, the hexagonal structure of the resulting mesoporous material MCM-41 can be seen.

Both diffractometric and scanning analysis, as well as adsorption isotherms confirm that mesoporous material MCM-41 with a hexagonal structure was obtained.

2.3. Adsorption

In order to determine the suitability of obtained sorbents in the process of adsorption of NO$_2$, the sorption capacity characteristics of the NO$_2$ was determined. Figure 10 is a schematic diagram of the laboratory test rig on which the tests were performed. The position includes:

- Vertical tube furnace,
- Exhaust gas analyzer,
- Computer system of data acquisition,
- Rotameters,
- Mixer,
- Cylinders of gases.

Due to the limits for NO$_x$ emission being set at the level of 200 mg/Nm$^3$, a mixture of air (21\% O$_2$, 79\% N$_2$) and nitrogen dioxide at concentrations of 50 ppm NO$_2$ (100 mg/Nm$^3$) and 100 ppm (200 mg/Nm$^3$) and gas consisting of 15\% CO$_2$, 6\% O$_2$ and 79\% N$_2$ were used in the research. Tests were conducted at temperatures of: 25°C, 60°C and 80°C. The gas stream with a fixed volume flux regulated by the rotameter passed through the furnace tube, inside which sorbent was placed on the grate. After the gas passed through the sorbent, changes in concentrations were recorded by an IMR 6000P analyzer at intervals of 10 s. The range of the analyzer measuring NO$_2$ was 0–250 ppm, subrange 0.5\% with an accuracy of +/−1\%. Sorption capacity was calculated on the basis of the weight of gas adsorbed on the sorbent (as well as by weighing the mass increase of the sample before and after the process) and expressed in mg of
Figure 9: SEM images of MCM-41
gas per 1 g of sorbent. During the adsorption process the variable parameters were: temperature of the process, the NO$_2$ concentration and the presence of CO$_2$ in the gas mixture. The desorption process was conducted at 100°C in a helium flow. The tests were performed using MCM-41 sieve obtained from fly ash. Prior to use, the sieves were heated at 100°C temperature in a helium flow.

The adsorption process was conducted until the bed adsorption capacity was exhausted. From the results obtained, curves of NO$_2$ concentration as a function of time, called breakthrough curves, were created. They were used to calculate the mass of NO$_2$ adsorbed on the sorbent and the sorption capacity, expressed in mg NO$_2$/g of sorbent.

Figure 10 presents a diagram of the NO$_2$ removal process, involving the capture of nitrogen dioxide on solid sorbent obtained from fly ash.

The system consists of two columns filled with a suitable sorbent. Gas containing NO$_2$ enters the system and passes through the first column where, at a temperature of 25°C, the adsorption process takes place. When the adsorbent bed is exhausted, the desorption process is carried out at a temperature of 100°C in the presence of a helium gas flow. Desorbed gas is derived from the system. The continuity of the process is assured as the presented system consists of two columns, in which the adsorption-desorption processes take place alternately. The adsorption process occurs in the first column at the same time as the desorption process takes place in the second column.

2.3.1. Nitrogen dioxide adsorption on mesoporous sieve MCM-41

The sieve MCM-41 obtained from fly ash was used for testing purposes. NO$_2$ gas at a concentration of 100 ppm/air was passed through the bed (MCM-41).

The study was carried out at 25°C. The data obtained is used to plot changes in the concentration of NO$_2$ gas over time. The horizontal axis indicates the time of the adsorption process, and the ordinate axis the ratio of NO$_2$ gas concentration at the outlet of the column to the concentration of NO$_2$ supplied to the column. These curves are called breakthrough curves and the breakthrough time of the bed can be determined from them. The breakthrough time is required to calculate the mass of adsorbed gas on the sorbent and the sorption capacity of sorbent. Figure 11 shows the breakthrough curves of MCM-41 sieves at a concentration of 100 ppm NO$_2$.

The curve was used to calculate the sorption capacity of MCM-41 sieve at the level of 0.1 mg NO$_2$/g of sorbent.
2.3.2. Effect of impregnation with a solution of PEG on the sorption capacity of MCM-41 sieve

To increase the sorption capacity and selectivity of the obtained material in terms of nitrogen dioxide, the sorbent was modified. This modification consisted of wet impregnation with polyethylene glycol solution.

The modification procedure was conducted as follows:

After dissolving 4 grams of PEG in 32 g of ethanol, 4 g calcined sieve MCM-41 was added. Subsequently, the sample was stirred for 8 hours and then the solution was evaporated. The resulting material was impregnated with 50% polyethylene glycol PEG and labeled MCM-41-PEG(50).

The prepared sorbent was subjected to the adsorption process at a temperature of 25°C while passing through a bed of sorbent NO₂ gas at a concentration of 100 ppm/air. Figure 12 shows the breakthrough curve of MCM-41-PEG(50) sieve. The curve was used to calculate the sorption capacity: for sieve MCM-41-PEG(50) it was 1.35 mg NO₂/g of sorbent.

Table 4 shows data collected from studies conducted for sieve MCM-41 and for its modification:

<table>
<thead>
<tr>
<th>No.</th>
<th>sample</th>
<th>Sorption capacity of NO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>MCM-41</td>
<td>mg/g sorbent</td>
</tr>
<tr>
<td>2.</td>
<td>MCM-41-PEG(50)</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Table 4: Sorption capacity

As can be seen, the sorption capacity of sieve whose surface has been modified was about 3 times greater than that of the unmodified sieve.

2.3.3. The influence of temperature on the sorption capacity of MCM-41 sieve

As the impregnated sorbent had a higher sorption capacity relative to NO₂ than the base sorbent (without impregnation), further tests were performed on the impregnated material MCM-41-PEG(50) to determine the effect of temperature and concentrations of NO₂ as well as the presence of synthetic gas.

The temperature influence on the sorption capacity was determined by measurements at the temperatures of: 25°C, 60°C, 80°C at a concentration of 100 ppm NO₂.

Figure 13 presents the breakthrough curves for sieve MCM-41-PEG(50) at temperatures: 25°C, 60°C, 80°C at a concentration of 100 ppm NO₂. Sorption capacity was calculated on the basis of breakthrough curves. At 25°C sorption capacity was 1.35 mg NO₂/g of sorbent, at the temperature of 60°C it was 0.11 mg NO₂/g of sorbent; the lowest sorption capacity was at the temperature of 80°C: 0.10 mg NO₂/g of sorbent.

Table 5 shows the sorption capacity of the sieve MCM-41-PEG(50) at different temperatures.

As can be seen from Table 5 and the results obtained, as the temperature rises the sorption capacity for sieve MCM-41-PEG(50) decreases. The largest sorption capacity of the material was at 25°C, while
Table 5: Sorption capacity for sieve MCM-41-PEG(50)

<table>
<thead>
<tr>
<th>No.</th>
<th>Sorbent</th>
<th>Temperature, °C</th>
<th>Sorption capacity of NO₂, mg/g sorbent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>M</td>
<td>25</td>
<td>1.35</td>
</tr>
<tr>
<td>2.</td>
<td>CM-</td>
<td>60</td>
<td>0.11</td>
</tr>
<tr>
<td>3.</td>
<td>41-</td>
<td>80</td>
<td>0.1</td>
</tr>
</tbody>
</table>

2.3.4. NO₂ concentration influence on the sorption capacity of MCM-41 sieve

In order to determine the NO₂ concentration influence on the sorption capacity, studies were carried out using NO₂ gas at concentrations of 100 ppm/air and 50 ppm/air at 25°C. Figure 14 shows the breakthrough curves for sieve MCM-41-PEG(50) for concentrations of 50 and 100 ppm.

The sorption capacity of sorbent at a concentration of 50 ppm was 0.27 mg NO₂/g of sorbent, while for the concentration of 100 ppm it was 0.31 mg NO₂/g of sorbent. Table 6 presents the data of sorption capacity for different concentrations of NO₂ gas.

As can be seen from Table 6, the sorption capacity for sieves through which the gas at concentration of 50 ppm was passed is about 5 times larger than the capacity of the sieve through which gas at a concentration of 100 ppm flowed.

Table 6: Sorption capacity for sieve MCM-41-PEG(50)

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of sorbent</th>
<th>The concentration of NO₂, ppm</th>
<th>Sorption capacity of NO₂, mg/g sorbent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>MCM-41-PEG(50)</td>
<td>50</td>
<td>6.65</td>
</tr>
<tr>
<td>2.</td>
<td>MCM-41-PEG(50)</td>
<td>100</td>
<td>1.35</td>
</tr>
</tbody>
</table>

Figure 14: Breakthrough curves of NO₂/air for a sieve MCM-41-PEG(50) at concentrations of 50 ppm and 100 ppm

Figure 15: Breakthrough curves of NO₂/air and NO₂ + 15%, 6% O₂, 79% N₂ for a sieve MCM-41PEG(50)

2.3.5. Influence of flue gas presence on the sorption capacity of sieve MCM-41

The aim of this research was the application of sieves from fly ash in the process of flue gas cleaning before carbon-capture process. Due to this fact, the sorption capacity in the presence of exhaust gas components, i.e. 15% CO₂, 6% O₂, 79% N₂ was determined. Gases with the same flow stream of 0.5 l/min after mixing in the mixer were placed into the oven. The study was conducted at 25°C at a concentration of 100 ppm NO₂.

Figure 15 shows the breakthrough curves for the sieve MCM-41-PEG(50) in the flow of NO₂ and in the presence of a mixture containing carbon dioxide. The sorption capacity for sieve MCM-41 for gas NO₂ (100ppm)/air was 0.5 mg NO₂/g of sorbent, while for NO₂ in the presence of carbon dioxide it was 1.11 mg/g sorbent.

For comparison, the results of sorption capacity
Table 7: Sorption capacity sieve MCM-41 and MCM-41-PEG (50)

<table>
<thead>
<tr>
<th>No.</th>
<th>Type of sorbent</th>
<th>Gas</th>
<th>Sorption capacity of NO$_2$, mg/g sorbent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>MCM-41</td>
<td>100 ppm NO$_2$</td>
<td>0.5</td>
</tr>
<tr>
<td>2.</td>
<td>MCM-41</td>
<td>100 ppm NO$_2$ + 15%CO$_2$, 6%O$_2$, 79%N$_2$</td>
<td>1.11</td>
</tr>
<tr>
<td>3.</td>
<td>MCM-41</td>
<td>15%CO$_2$, 6%O$_2$, 79%N$_2$</td>
<td>33.83*</td>
</tr>
<tr>
<td>4.</td>
<td>MCM-41-PEG(50)</td>
<td>50 ppm NO$_2$</td>
<td>6.65</td>
</tr>
<tr>
<td>5.</td>
<td>MCM-41-PEG(50)</td>
<td>100 ppm NO$_2$</td>
<td>1.35</td>
</tr>
<tr>
<td>6.</td>
<td>MCM-41-PEG(50)</td>
<td>100 ppm NO$_2$ + 15%CO$_2$, 6%O$_2$, 79%N$_2$</td>
<td>0.68</td>
</tr>
<tr>
<td>7.</td>
<td>MCM-41-PEG(50)</td>
<td>15%CO$_2$, 6%O$_2$, 79%N$_2$</td>
<td>19.51*</td>
</tr>
</tbody>
</table>

*CO$_2$ sorption capacity

for the sieve MCM-41 and MCM-41-PEG(50) were collected and presented in Table 7.

The sorption capacity of MCM-41-PEG(50) in the presence of CO$_2$ was 0.68 mg NO$_2$/g of sorbent, however for a sieve placed in a flow of NO$_2$ (without CO$_2$) at a concentration of 50 ppm NO$_2$ it was 6.65 mg NO$_2$/g of sorbent, and for a concentration of 100 ppm, 35 mg NO$_2$/g sorbent.

2.4. Discussion of results

The study shows that several parameters affect the sorption capacity of mesoporous materials. One is temperature. As the temperature increases, the sorption capacity of sieves for NO$_2$ decreases. The highest sorption capacity was observed for sieve MCM-41-PEG(50) at 25°C while at 80°C this value fell to 0.1 mg NO$_2$/g of sorbent.

Another parameter is the NO$_2$ concentration. When comparing the sorption capacity for different NO$_2$ concentrations, it was observed to be higher for the sieve through which gas flowed at a concentration of 50 ppm. The presented data shows that impregnating mesoporous sieves with a polyethylene glycol solution increased the sorption capacity of the sieves. The highest sorption capacity was obtained for impregnated sieves that were obtained from pure reagents and commercial sieves. However, satisfactory results were also obtained for the sieves made from fly ash.

3. Conclusion

Based on studies of both the synthesis of mesoporous materials from fly ash and the study of the adsorption process of nitrogen dioxide on the received materials, it can be seen that fly ashes from burning coal, lignite, and biomass co-firing in pulverized and fluidized bed as well, due to their significant silicon and aluminum content, are suitable materials for the synthesis of mesoporous sieves. Synthesis of mesoporous sieves from fly ash enables management of both ashes stored in landfill as well as those from current production. Modification of the ashes into the sieve allows one to obtain valuable mesoporous sorbents from the combustion of waste by-products, such as ashes, for re-use in the energy sector. Modification of materials obtained by impregnation with a polyethylene glycol solution allows one to obtain materials with enhanced properties, such as sorption capacity, relative to NO$_2$. The sorption capacity of impregnated sieves for NO$_2$ sorption was higher than for base sieves (without impregnation). The study performed at different temperatures showed that the sorption capacity of the sieve MCM-41-PEG(50) falls as temperature rises. The presence of gas with a composition of 15% CO$_2$, 6% O$_2$, 79% N$_2$ has only a very marginal effect on capacity.

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References


