

The effect of mineral matter on the physicochemical and sorption properties of brown coal-based activated carbons

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Abstract A series of new carbonaceous adsorbents has been obtained by means of direct and physical activation of Polish brown coal, characterised by high mineral matter content. The influence of activation procedure on the porous structure development, acidic and basic surface groups generation as well as the sorptive properties of the adsorbents prepared toward liquid and gas pollutants was tested. Additionally the effect of mineral matter presence on the physicochemical and sorption properties of materials prepared was studied. The final products were micro/mesoporous activated carbons of medium developed surface area ranging from 407 to 674 m²/g, showing strongly basic or intermediate acidic-basic character of the surface. The results obtained during this study showed that direct and physical activation of low quality brown coal led to activated carbons with very good sorption capacity both toward gas contamination of acidic character (especially nitrogen dioxide) as well as toward methylene blue and inorganic pollutants of molecules of size similar to that of iodine molecules. It was also proved that demineralization of prepared activated carbons by hydrochloric acid significantly reduced their ability to toxic gases sorption, but simultaneously increased the efficiency of removing impurities from the liquid phase.

Keywords Brown coal · Direct/physical activation · Activated carbons · Physicochemical properties · Toxic gases removal · Adsorption from liquid phase

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1 Introduction

Nowadays, adsorption processes are applied in many modern industrial and households technologies. Incessant progress in this field stimulates the search for new and effective but first of all low-cost adsorbents. From among the various materials used for this purpose (Goscianska et al. 2013; Wiśniewska et al. 2007, 2013, 2014; Kierys et al. 2013; Wiśniewska 2010, 2012; Krysztalkiewicz et al. 2002; Thomas and Syres 2012; De Smedt et al. 2015; Qian et al. 2015) the most popular and promising are the carbonaceous sorbents, especially activated carbons (Jiang et al. 2015; Deng et al. 2015; Sharma and Upadhyay 2009; Goscianska and Pietrzak 2015; Jiang and Chen 2011). Such materials could be prepared in a simple way by physical or chemical activation of variety of organic substances, including wood (Wang et al. 2009; Nowicki et al. 2015a), peat (Khadiran et al. 2015), fossil coals (Nowicki and Pietrzak 2011; Maroto-Valer et al. 2005; Teng et al. 1998) as well as many biodegradable (Karagöz et al. 2008; Soleimani and Kaghazchi 2008; Kazmierczak et al. 2013, 2015; Nowicki et al. 2015b) and industrial waste (Nakagawa et al. 2003; Hofman and Pietrzak 2011; Nowicki et al. 2013; Lin and Teng 2002). Taking into account economic and ecological aspects, particularly suited for this purpose are fossil coals of low quality, the use of which in a chemical industry (e.g. for degassing, gasification and liquefaction) or power generation is not very cost-effective, due to high nitrogen, sulfur or mineral matter content.

Many previous studies have shown that by thermochemical processing of brown coals, it is possible to obtain a wide range of activated carbons characterized by well-developed porous structure and good sorption properties to different kinds of pollution (Pokonova 1996; Toles et al. 1996; Burg et al. 2002a; Burg et al. 2002b; Bimer et al.

1998). However, the vast majority of the research made has been focused on the production of activated carbons from the precursors with a relatively low mineral substance content and even deliberately deprived of mineral admixtures (Starck et al. 2004; Pietrzak et al. 2006; Jurewicz et al. 2008; Pietrzak et al. 2008).

Therefore, the main objective of this study was to prepare a series of carbonaceous adsorbents by means of direct activation (simultaneous pyrolysis and activation of carbonaceous material) as well as physical activation of low quality brown coal and to investigate the effect of mineral matter presence on their physicochemical and sorption properties toward gaseous pollutants represented by nitrogen dioxide and hydrogen sulfide as well toward liquid impurities represented by methylene blue and iodine.

2 Experimental

2.1 Preparation of activated carbons

The starting raw sample was prepared from a Polish brown coal (Konin colliery), characterised by high ash content ~ 18 wt%. The precursor (B) was milled and sieved to the grain size of 2–4 mm, divided into two parts and subjected to two different treatments: (1) direct activation of starting coal with carbon dioxide (BA sample) and (2) pyrolysis of raw material followed by physical activation with carbon dioxide (BPA sample).

Direct activation of the precursor was carried out in a quartz tubular reactor heated by a resistance furnace at temperature of 850 °C, under a stream of carbon dioxide at the flow rate of 250 ml/min, for 45 min. Pyrolysis of starting materials was conducted under a stream of argon at the flow rate of 170 ml/min. A portion of precursor (about 15 g) was heated (10 °C/min) from room temperature to the final pyrolysis temperature of 700 °C and maintained for 30 min. After that, the gas flowing through the reactor was switched to carbon dioxide and the obtained char was subjected to physical activation at 900 °C, under a stream of carbon dioxide at the flow rate of 250 ml/min, for 45 min.

In order to check the influence of mineral matter present in the structure of the activated products on their physicochemical and sorption properties some part of the activated carbons was subjected to demineralization (D) with hot concentrated hydrochloric acid for 3 h. After demineralisation stage, the samples were washed with hot distilled water until free of chloride ions and dried at 110 °C for 24 h.

2.2 Sample characterization

Elemental analysis of the all samples under investigation was carried out using the Elementar Analysensysteme

instrument, model Vario EL III. The ash content was determined according to the ISO 1171:2002 standard: the dried sample was burned in a microwave oven at temperature 850 °C, for 60 min.

Nitrogen adsorption/desorption isotherms were measured at –196 °C using the Quantachrome Autosorb iQ surface area analyser. Prior to the isotherm measurements, the samples were outgassed at 150 °C for 8 h. BET specific surface area (S_{BET}) was evaluated in the range of relative pressures p/p_0 of 0.05–0.30. Total pore volume (V_t) was calculated by converting the amount adsorbed at $p/p_0 \sim 0.99$ to the volume of liquid adsorbate. Average pore diameter was calculated (d) was calculated from equation $d = 4V_t/S_{\text{BET}}$. Pore size distribution was calculated from the adsorption branches of isotherms using the BJH method. Additionally, micropore volume and area were determined by the t plot method.

The acid–base surface properties were evaluated according to the Boehm method (Boehm et al. 1964; Boehm 1994). Volumetric standard HCl (0.1 M) and NaOH (0.1 M) were used as the titrants. The pH of activated carbons was measured using the following procedure: a portion of 0.4 g the sample of dry powder was added to 20 ml of demineralised water and the suspension was stirred overnight to reach equilibrium. After that time, pH of the suspension was measured.

SEM images of the activated carbons were obtained using a scanning electron microscope (SEM) made by PHILIPS (Netherlands) in the following conditions: working distance of 14 mm, accelerating voltage of 15 kV and digital image recording by DISS.

2.3 Adsorption studies

2.3.1 Evaluation of H_2S and NO_2 sorption capacity

The adsorption tests were performed in dry (D) and wet (W, 70 % moisture content) conditions. Moreover, additional variant was applied: the sample was moistened by air with 70 % moisture content for about 30 min, and then the sorption capacity was determined in dry (MD) or wet (MW) conditions.

The samples sieved to a particle size between 0.75 and 1.5 mm were packed into a glass column (bed volume 3 ml). Dry or moist air with 0.1 % of H_2S or NO_2 was passed through the dry or moistened bed of the adsorbent at flow 450 ml/min, at room temperature. The breakthrough of H_2S or NO_2 were monitored using Q-RAE PLUS PGM-2000/2020 with electrochemical sensors. The tests were stopped at the breakthrough concentration of 100 ppm (in case of H_2S) or 20 ppm (for NO_2) because of the electrochemical sensor limits. The interaction capacities of each sorbent in terms of milligram of H_2S or NO_2 per gram of

adsorbent were calculated by integration of the area above the breakthrough curves, and from the toxic gas concentration in the inlet gas, flow rate, breakthrough time and mass of sorbent.

2.3.2 Adsorption from liquid phase

Determination of the iodine adsorption was performed according to the ASTM D4607-94(2006) standard. In a brief: samples of the prepared activated carbons (of particle size below 0.09 mm) of equal portion of 0.2 g were added to 20 ml of 0.1 M iodine solution and 5 ml of 5 % HCl. Next, the mixture was shaken for 4 min, filtered through filter paper and washed 50 ml of water. The resulting solution was titrated with 0.1 M sodium thiosulphate until the solution become colourless (1 % starch solution was used as an indicator). Determination of the methylene blue adsorption was performed using the following procedure: samples of the prepared activated carbons (of particle size below 0.09 mm) of equal portion of 0.0025 g were added to 50 ml of the methylene blue solution with initial concentrations from 30 to 120 mg/l and the suspension was stirred for 24 h to reach equilibrium. After the adsorption equilibrium had been achieved, the solution was separated from the adsorbent by filtration on syringe filters ABLUO™–CAMEO™ (pore size: 1.2 μm).

The concentrations of the methylene blue in the solution before and after adsorption were determined using a double beam UV–Vis spectrophotometer (Cary Bio 100, Varian) at a wavelength of 665 nm. The equilibrium adsorption amounts (q_e , mg/g) were calculated according to the following formula:

$$q_e = \frac{(c_i - c_e) \cdot V}{m}, \quad (1)$$

where c_i and c_e (mg/l) are the initial and equilibrium concentrations of the methylene blue, V (l) is the volume of the solution, and m (g) is the mass of adsorbent used, respectively.

3 Results and discussion

3.1 Elemental composition of the activated carbons prepared

According to the data presented in Table 1, the precursor used for the study is characterised by relatively high content of mineral substance as well as organic non-carbon impurities, especially oxygen. Both pyrolysis and activation of the starting brown coal cause significant changes in its structure. Thermo-chemical treatment brings a substantial increase in the content of C^{daf} , accompanied by a

Table 1 Elemental composition of the precursor, char and activated carbons and yield of activation process (wt%)

Sample	Ash	C^{daf*}	H^{daf}	N^{daf}	S^{daf}	O^{daf**}	Yield
B	18.8	65.1	6.2	0.6	1.7	26.4	–
BA	33.6	85.1	1.2	0.9	3.5	9.3	21.6
BAD	19.7	88.9	1.0	1.1	2.9	6.1	–
BP	24.1	87.1	1.6	0.9	1.2	9.2	38.3
BPA	38.6	82.2	1.3	1.5	2.5	12.5	81.1
BPAD	12.9	92.4	1.4	1.3	1.4	3.5	–

* Dry-ash-free basis

** Determined by difference

considerable decrease in the content of the other elements, with the exception of sulphur. These changes are certainly related to the high temperature of the process, which is responsible for breaking of the least stable chemical bonds present in the carbonaceous matrix and consequently, for the removal of heteroatoms in the form of simple gas or liquid compounds. High temperature treatment of the precursor (independent on the variant) causes also a significant increase in the ash content, as evidenced by the fact that the activation products are characterized by almost twice higher content of mineral substances than the starting material.

As follows from further analysis of the data presented in Table 1 and in Fig. 1, activated carbons treatment with hydrochloric acid results in a significant decrease in ash content, especially in case of BPAD sample, which contains threefold less mineral ballast than the respective BPA sample, untreated by HCl. Partial demineralisation of the samples brings also some changes in their elemental composition. Samples BAD and BPAD show a slightly higher content of carbon than BA and BPA and at the same time a lower content of hydrogen, sulphur and in particular oxygen.

3.2 Textural parameters of activated carbons

Analysis of the data presented in Table 2 has shown that both the direct and two-stage activation of brown coal, do not allow efficient development of surface area and porous structure. The surface area of the activated carbon prepared varies between 407 and 436 m²/g, whereas the total pore volume varies between 0.34 and 0.39 cm³/g. The main reason behind so poor textural parameters of the materials prepared probably is a very high content of inorganic substance, which can be deposited in the pores and consequently block the access of the adsorbate molecules to smaller pores. The porous structure of both activated carbons includes micropores with high contribution of

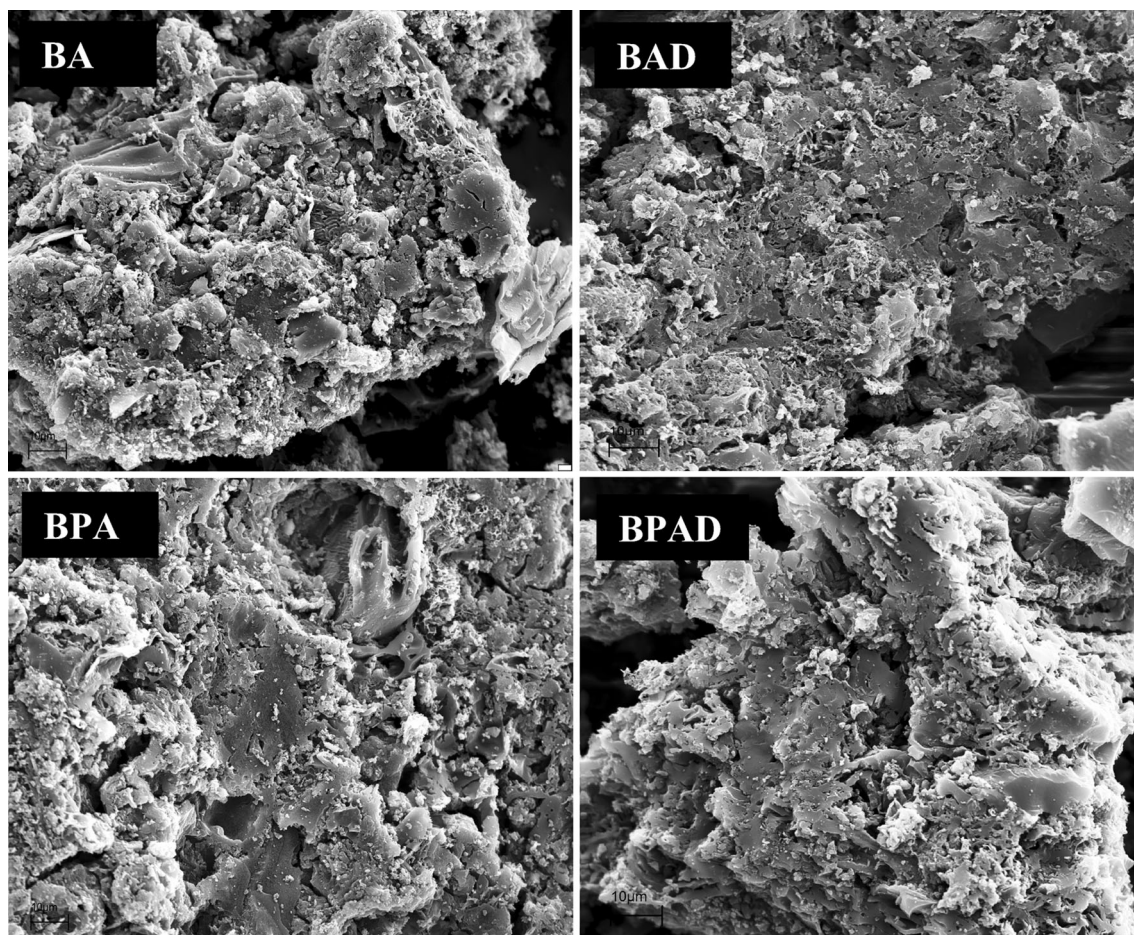


Fig. 1 SEM images of the activated carbons

Table 2 Textural parameters of the activated carbons

Sample	Surface area (m ² /g)	Pore volume (cm ³ /g)	Micropore volume (cm ³ /g)	Micropore contribution	Average pore diameter (nm)
BA	407	0.34	0.18	0.53	3.38
BAD	674	0.90	0.20	0.22	5.38
BPA	436	0.39	0.17	0.44	3.86
BPAD	590	0.49	0.23	0.46	3.38

mesopores as follows from low micropores contribution in the total pore volume, relatively high average pore diameter (Table 2), as well as from nitrogen adsorption isotherms and pore size distribution presented in Figs. 2 and 3, respectively. According to the IUPAC classification, the isotherms obtained for BA and BPA samples are close to type I, characteristic of microporous and mesoporous materials with pore size close to the micropores range. However, broad hysteresis loops (H4 type) prove the presence of pores of greater diameters. As follows from the course of pore size distribution curves, these are mainly mesopores with diameters ranging from 2 to 15 nm.

As follows from further analysis of the data presented in Table 2 and in Figs. 2 and 3, activated carbons treated by hydrochloric acid show much more beneficial textural parameters than un-modified samples, which is most probably a result of removal of a significant part of the ash. This assumption is confirmed by the fact that the BAD and BPAD samples are characterized by a much higher total pore volume than the corresponding samples not treated with hydrochloric acid. What is more, much wider hysteresis loops observed in the course of nitrogen adsorption isotherms for samples BAD and BPAD, confirm the earlier assumption that the mineral substance can block a

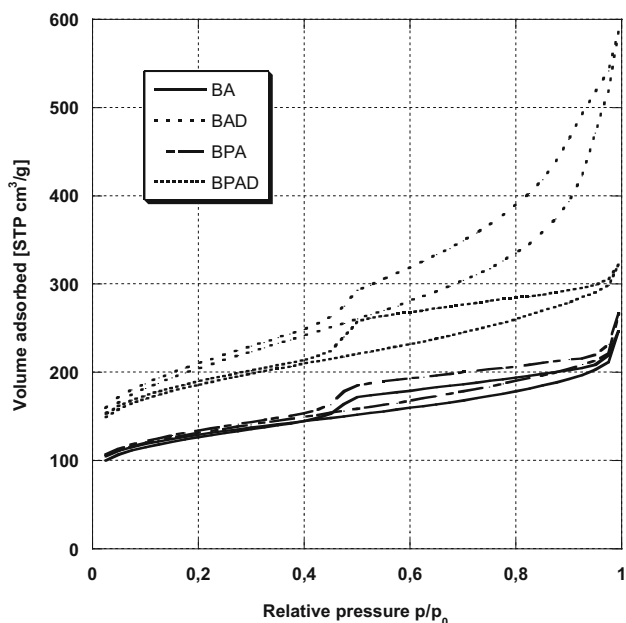


Fig. 2 Nitrogen adsorption/desorption isotherms of the activated carbons

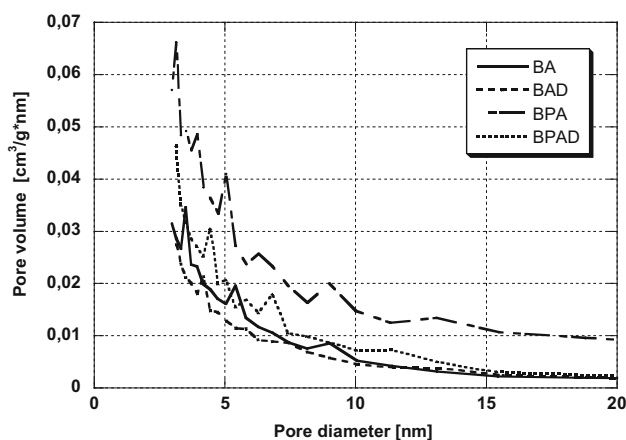


Fig. 3 Pore size distribution of the activated carbons

significant part of pores present in the structure of the materials obtained. It is particularly well seen for sample BA subjected to direct activation. After removal of a considerable portion of ash, there was a nearly threefold increase in the total pore volume, and more importantly, an increase in the contribution of mesopores from 46 to 78 %. On the basis of this observation, it can be also assumed that the conditions of direct activation process were too drastic for the precursor applied, leading to partial combustion of organic substance and formation of wider pores, as confirmed by a greater average pore diameter for samples BA and BAD. However, this issue requires further study.

3.3 Acid–base properties of activated carbons

According to the data presented in Table 3, the materials obtained show a diversity of acid–base properties as can be concluded from the content of oxygen functional groups varying in the range 1.21–5.77 mmol/g and pH values varying from 3.94 to 12.36. As seen, the content and type of the oxygen functional groups depend on the variant of activation as well as treatment of the resulting carbons by hydrochloric acid. As far as the unmodified samples are concerned (BA and BPA), a strongly basic character of the surface is observed ($\text{pH} > 11.5$). It is of course a consequence of the high content of mineral substance in the structure of the precursor, which undergoes transformations during pyrolysis or activation processes and remains in the structure of the products. As regards the samples treated with hydrochloric acid (BAD and BPAD), they show completely different acid–base properties of the surface. The total amount of the surface oxygen groups (1.21–2.19 mmol/g) as well as pH value (~ 4) are much lower in samples BAD and BPAD and, in contrast to the samples BA and BPA, a domination of functional groups of acidic character is observed in them. It is most probably the effect of removal of a significant part of mineral substance present in the activated carbons structure, during the acid washing step.

3.4 Sorption abilities of the activated carbons toward nitrogen dioxide and hydrogen sulphide

The main premises in favor of undertaking the adsorption study toward gas pollutants of acidic nature were the high content of mineral substance in the activated carbons structure as well as the presence of a high number of basic surface functional groups, which, according to previous literature reports, have a positive impact on the effectiveness of removal of this type of pollution (Yuan and Bandoz 2007; Feng et al. 2005; Nowicki et al. 2013, 2014; Kante et al. 2012). To verify this supposition, all the materials prepared were subjected to adsorption tests in four variants. The results of relevant measurements are given in Tables 4 and 5.

The results clearly illustrate a significant effect of the variant of activation, post-activation treatment with hydrochloric acid as well as conditions of the adsorption tests on the sorption capacity towards H_2S and NO_2 . Moreover, each of the prepared materials shows a definitely higher sorption capacity towards nitrogen dioxide, therefore, the results regarding this pollutant will be discussed first. As the results obtained for individual samples vary significantly depending on the adsorption conditions, it is difficult to point out a single material of the best adsorptive performance. The most effective adsorbent in

Table 3 Acid–base properties of the activated carbons

Sample	pH	Acidic groups (mmol/g)	Basic groups (mmol/g)	Total content (mmol/g)
BA	11.61	0.05	5.46	5.51
BAD	4.01	0.72	0.49	1.21
BPA	12.36	0.32	5.45	5.77
BPAD	3.94	1.40	0.79	2.19

Table 4 NO₂ breakthrough capacities of the activated carbons (mg/g_{ads})

Sample	Dry conditions		Wet conditions	
	D ^a	MD ^b	W ^a	MW ^b
BA	46.0	75.1	54.6	192.5
BAD	14.4	20.4	27.6	16.6
BPA	34.7	101.2	87.3	174.8
BPAD	32.1	31.7	33.6	15.8

^a Without pre-humidification^b After pre-humidification**Table 5** H₂S breakthrough capacities of the activated carbons (mg/g_{ads})

Sample	Dry conditions		Wet conditions	
	D ^a	MD ^b	W ^a	MW ^b
BA	2.2	11.8	56.3	75.5
BAD	1.4	1.9	2.6	2.2
BPA	4.2	8.1	27.5	44.9
BPAD	1.1	1.5	2.0	1.8

^a Without pre-humidification^b After pre-humidification

dry conditions (46.0 mg/g) was sample BA, obtained by direct activation with CO₂ at 850 °C, whereas from among the samples subjected to pre-humidification (MD conditions), the most efficient proved sample BPA obtained by physical activation, which adsorbed 101.2 mg NO₂. The least effective sorbent of nitrogen dioxide during adsorption both in dry and mix-dry conditions was sample BAD whose sorption capacity was 14.4 and 20.4 mg/g, respectively. The sorption capacity of the second sample subjected to hydrochloric acid treatment (BPAD) also decreased, but to a lesser extent. These results clearly indicate a significant impact of mineral matter on the adsorption capacity of nitrogen dioxide.

Also the presence of water in the system has a significant effect on the efficiency of NO₂ removal. Pre-humidification of the adsorbent bed by using a stream of moist air, appreciably enhance the sorption capacity of the materials,

especially for samples not subjected to demineralization. It is particularly well seen for sample BPA, for which almost a threefold increase in the amount of adsorbed gas is observed. Much more beneficial impact on the efficiency of NO₂ removal brings a change in the conditions of sorption, from dry to wet.

The most effective adsorbent in wet conditions (87.3 mg/g) was the sample obtained by physical activation, whereas in mix-wet conditions the best sorption ability showed sample BA, which adsorbed up to 192.5 mg/g. Similarly as in dry conditions, the results obtained for carbons subjected to demineralization (BAD and BPAD) are much less satisfactory, especially in mix-wet conditions, in which differences between samples treated and untreated by hydrochloric acid reach from 159 to 175 mg/g. Moreover, the effect of the pre-humidification of the adsorbent bed prior to the measurement under wet conditions is much greater than in dry conditions. However, it should be noted that for the samples subjected to demineralization this procedure brings a negative result.

As was mentioned above, all the activated carbons under investigation exhibit significantly less favourable adsorption capacity towards hydrogen sulphide (Table 5). Similarly as for NO₂, the ability of H₂S sorption from gas flux is to a high degree determined by the method of activation, post-activation treatment as well as the conditions of adsorption test. The highest sorption capacities were found for the BA sample obtained by direct activation of the precursor. Slightly less satisfactory results were also obtained for the BPA sample obtained by physical activation. Unfortunately, both samples treated by hydrochloric acid showed very poor sorption abilities towards hydrogen sulphide (< 3 mg/g), irrespective of the adsorption conditions.

All samples showed the lowest H₂S sorption capacities on adsorption in dry conditions (D). This result means that strongly basic surface character, high content of mineral substance (in the samples untreated by HCl) or medium-developed surface area (the samples treated by HCl) are not sufficient for effective removal of H₂S from the flux of gases. According to the data collected in Table 6, the most important in the process is the presence of steam in the system. As seen, the wetting of adsorbent bed with moist air (MD conditions) improves sorption capacities of the activated carbons, but mainly for samples not subjected to

Table 6 Adsorption isotherms constants for the adsorption of methylene blue onto the activated carbons at 22 ± 2 °C

Sample	Langmuir			Freundlich		
	R ²	Q ₀ (mg/g)	K _L (l/mg)	R ²	K _F (l/mg)	1/n
BA	0.998	138.88	9.00	0.882	131.94	0.059
BAD	0.989	185.18	4.15	0.969	111.43	0.201
BPA	0.999	153.84	16.25	0.902	133.35	0.049
BPAD	0.995	156.25	3.76	0.980	100.92	0.154
Norit [®] SX2 ^a	0.999	161.29	15.50	0.7384	143.35	0.037

^a Commercial activated carbon

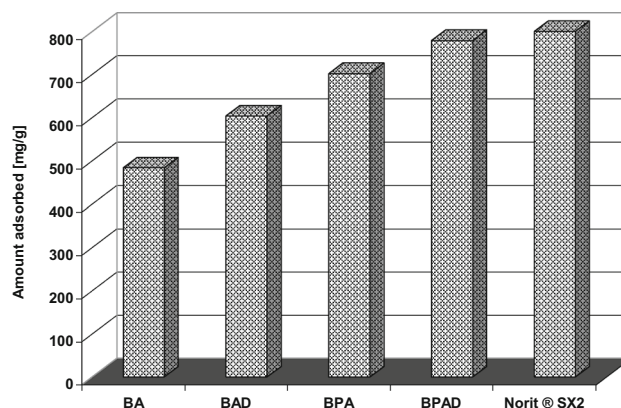
demineralisation, for which four or fivefold increase was observed. Most probably it is a result of generation of a thin film of water on the surface of carbon matrix as it is conducive to H₂S bonding. More impressive effect was obtained when the process of adsorption was performed in wet conditions (W). A continuous presence of steam in the flux of gases flowing through the adsorbent bed is evidently favourable for H₂S removal as the sorption capacities towards H₂S are much higher than those in dry as well as mix-dry conditions.

The greatest increase in the sorption capacity (about 25 and 35 times, respectively) with respect to that measured in dry and mix-dry conditions was observed for sample BA, obtained by direct activation of starting coal. The sorption capacities obtained for sample BPA were approximately by 50 % lower. Unfortunately, for the samples treated with hydrochloric acid this improvement was minimal, as indicated by the sorption capacities not exceeding 3 mg/g. On the basis of these results it can be definitely concluded that the presence of mineral substance is conducive to effective removal of H₂S from the flux of gases, especially in the presence of water.

So attractive sorption capacities of the activated carbons not subjected to demineralisation are most probably a consequence of chemisorption of NO₂ and H₂S on the adsorbents surface, that occurs according to the mechanism proposed earlier by Bandosz research group (Pietrzak and Bandosz 2007; Bagreev et al. 2001), assuming formation of the corresponding nitrates and sulphides, in the reaction between the molecules of the adsorbed gas and metal oxides present in the mineral substance. However, a detail explanation of this issue needs further studies.

3.5 Sorption abilities toward iodine and methylene blue

The data presented in Fig. 4 and in Table 6 clearly illustrate a significant effect of the method of activation as well as post-activation on the sorption abilities towards the liquid pollutants studied. However, in contrast to the gas pollutants removal, more effective adsorbents toward

**Fig. 4** Adsorption of iodine onto activated carbons

liquid impurities are samples subjected to demineralisation. Most probably it is a consequence of better developed surface area and porous structure of these samples.

From among the samples untreated by hydrochloric acid, more effective adsorbent toward both adsorbates proved to be sample BPA (obtained by two-stage activation), whose sorption capacity was 702 mg/g for iodine and 156.25 mg/g for methylene blue, respectively. As mentioned above, partial demineralisation of the activated carbon samples significantly improves their sorption properties. Iodine number of samples BAD and BPAD is by 120 and 77 mg/g higher than that of the corresponding samples untreated by HCl. Towards methylene blue, an increase in the sorption capacity of the samples is much lower, from 2.41 mg/g for sample BPAD to 46.3 mg/g for sample BAD. A much better result obtained for sample BAD sample is most probably related to a considerable higher mesopores contribution in its porous structure (Table 2). It should be also noted that sorption capacities of most of the samples prepared are similar to those achieved for commercial micro/mesoporous activated carbon—Norit[®] SX2, which is very often used in practice, for water purification.

According to the equilibrium adsorption isotherms presented in Fig. 5, the amount of adsorbed methylene blue increases significantly with increasing initial dye

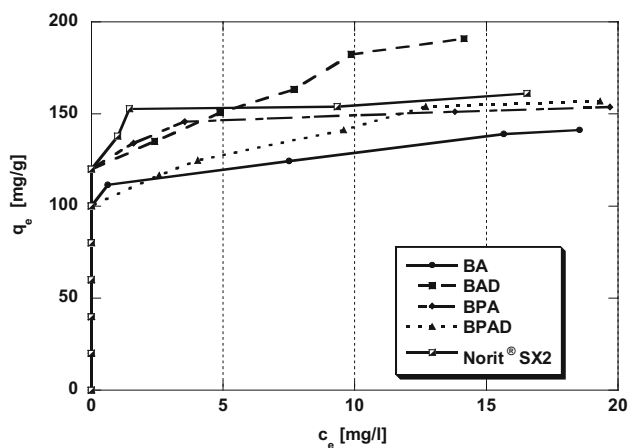


Fig. 5 Adsorption isotherms of methylene blue onto activated carbons

concentration, up to saturation. As the shape of isotherms is single and smooth, it suggests a monolayer coverage of the adsorbents surface with methylene blue molecules. R^2 values ranging from 0.989 to 0.999 (Table 6) show that the adsorption of methylene blue onto the activated carbons prepared is described by the Langmuir model. In addition, the $1/n$ value in the range between 0 and 1 indicated that the adsorption conditions were favourable and methylene blue molecules had free access to the pores present in the activated carbons structure.

4 Conclusions

The above discussed results have confirmed that brown coals with a high mineral matter content can be successfully applied as precursors of cheap activated carbons, showing very good sorption capacity towards gas contaminants of acidic character (especially nitrogen dioxide) as well as toward methylene blue and inorganic pollutants of molecules whose size is similar to that of iodine molecules. As shown by the results, the effectiveness of NO_2 and H_2S removal from the flux of gases, depends first of all on the conditions of adsorption. It has been proved that preliminary wetting of the adsorbent bed as well as the presence of steam in the mixture of gases passed through the adsorbent, significantly increase the amount of the pollutants removed. Moreover, demineralization of prepared activated carbons by hydrochloric acid significantly reduced their ability to toxic gases sorption, but simultaneously increased the efficiency of removing impurities from the liquid phase.

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