018525

REMOVALS

The Production of Activated Carbons from Sewage Sludge – WP12

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

PRIORITY 1.1.6.3 Global change and ecosystems

D12.1 Production of a range of activated carbons

Due date of deliverable: 30 June 2007
Actual submission date: 13 September 2007

Start date of project: 1 JULY 2006
Duration: 3 YEARS

Organisation name of lead contractor for this deliverable: Imperial College London

Revision 1

<table>
<thead>
<tr>
<th>Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissemination Level</td>
</tr>
<tr>
<td>PU</td>
</tr>
<tr>
<td>PP</td>
</tr>
<tr>
<td>RE</td>
</tr>
<tr>
<td>CO</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
1 Introduction

Deliverable 12.1 comprises the production of a range of activated carbons. Other than that it must have been completed by month 12 of the project, no further information has been given regarding the specifics of this task; what constitutes a ‘range of activated carbons’ is therefore open to debate. However, it is the belief of the leader of this Work Package that this deliverable has been successfully accomplished. In the text that follows, the methods employed to achieve this deliverable, the outcomes of this work and the justification for the claim that the deliverable has been achieved are given. The partners involved in the completion of this deliverable were Imperial College London – partner 14 (ICL) – and Université de Nantes – partner 2 (GPA).

2 Methodology

2.1 Sludges used

Three different sludges were utilised: at ICL, dewatered raw (DRAW) sludge and dewatered, mesophilic anaerobically digested (DMAD) sludge and at GPA, dewatered, aerobically digested (DAED), municipal WWTP sludge. The WWTP plant whence the GPA sludge came used organic polymers for sludge conditioning and thickening was achieved by gravity. Conventional band filters and centrifuging were used to dewater the GPA sludge.

All of the DMAD and DRAW sludge utilised in this project was, prior to being activated, sterilised, dried to constant mass at 105-110 °C and finally, ground below 10 mm in size. The sterilisation procedure comprised saturation in steam at 122 °C for 15 minutes using a Priorclave direct steam autoclave (London, UK) and was necessary to destroy any pathogens in the sludge, hence rendering...
it safe for handling by the sludge/laboratory operatives. The GPA sludge was dried for 48 hrs at 110 °C.

2.2 Equipment used

The carbons were prepared using a Carbolite rotary furnace with a 4.5 litre, 1 kg, capacity, quartz reactor.

2.3 Production of activated carbons by carbonisation

Prior to carbonisation, the sludges were dried to constant mass at 105 °C. Subsequently, ca. 200-250 g of sample was loaded into the quartz reactor, which was then installed within the furnace. A nitorgen flow of 500 ml/min of nitrogen (2 l/min was employed at GPA) was purged through the reactor for 20 minutes, subsequent to which the furnace heating controller was set to the target temperature and the heating element was turned on. The 500 ml/min flow of nitrogen was maintained throughout the whole duration of each carbonisation run and the heating rate was maintained at, variously, 3, 5, or 10 °C/min at ICL and at 10 °C/min at GPA. After the desired temperature was reached, the furnace was held under isothermal conditions for the designated dwell time (either 0, 1 or 2 hrs) and then automatically cooled down.

2.4 Production of activated carbons by physical activation

The methodology adopted was essentially the same as that employed for the carbonisation work, the key difference being that once the furnace had reached the target temperature, the appropriate activation reagent was admitted into the reactor, and the target temperature was maintained for the whole duration of the prescribed activation period. In the case of CO₂, a flow rate of 2 l/min was employed, whereas the flow rate of steam was 0.7 g/min; in the case of steam, the flow of nitrogen was maintained, its function being to act as a carrier gas. Once the end of the activation period had been reached, the flow of the activation reagent was arrested, the flow of N₂ reverted to its original flow rate and the furnace was left to cool.

2.4.1 Development of the model of the relationship between the steam activation conditions employed and the textural characteristics of the generated SBAs

The response surface methodology (RSM) technique – a tool used to mathematically express the relationship between two or more variables (Karacan et al., 2007) – was employed to develop a model of the relationship between the activation temperature, activation time, and each of the key indicators of the SBA’s textural characteristics. The RSM technique has been previously used for modelling the response of carbonaceous precursors to activation by Bacoui, et al. (Bacoui et al., 2001), Rio, et al., (Rio et al., 2005a) and Karacan, et al., (Karacan et al., 2007) and the method utilised at ICL was based on the approach taken by the aforementioned. Firstly, the two independent variables – i.e., activation temperature and time, and the responses of the dependent variables – the BET surface area, micropore surface and T-plot surface area were coded into the form of a Doehlert matrix (Doehlert, 1970). The equation used for the coding of each of the two independent variables was:

\[ X_{ij} = \frac{U_{ij} - U_0}{\Delta U_j} \]

Where: \( U_{ij} \) = the value of the independent variable in experiment I; \( U_0 \) = the value of the independent variable at the pre-defined mid/central point of the data range, i.e., the value of the
independent variable when \( X_j = 0 \); \( \Delta U_j \) = the value of the independent variable in the experiment when \( X = 1 \), minus \( U_j^0 \)

Having coded the two independent variables, the next step was to assume that the relationship between each independent variable \( X_j \) and each dependent variable \( Y_j \) could be expressed by means of a 2\(^{nd} \) order, polynomial equation, \( i.e., \)

\[
Y_j = a_0 + a_1X_1 + a_2X_2 + a_{11}X_1^2 + a_{22}X_2^2 + a_{12}X_1X_2
\]

If \( X_1 \) is the activation time and \( X_2 \) is the activation temperature, then, as given by Bacouï, et al., (Bacouï et al., 2001): \( a_0 \) = the intercept term; \( a_1 \) = influence of the activation time; \( a_2 \) = influence of the activation temperature; \( a_{12} \) = the interaction effect between the activation time and activation temperature; \( a_{11} \) and \( a_{22} \) are ‘curve shape parameters’. The values for these constants were determined for each dependent variable by means of an algorithm run in MatLab, which, when given the response of each particular variable at the different activation temperatures and times tested, determined through an iterative process which values for the constants would produce an equation for a graph that best fitted the experimental data. The values for the activation temperature and time utilised for the midpoint, \( i.e., \) when \( X=0 \), were 825 °C and 1 hr respectively.

2.5 Production of activated carbons by chemical activation

The chemical activation study employed KOH flakes crushed by means of a food processor; DMAD char carbonised at 1000 °C with a 0 hrs dwell time under a heating rate of 5 °C/min served as the SBA precursor. Two forms of the DMAD char were used: as received and milled, the latter having been crushed below 150 μm by means of a pestle and mortar.

A 1:1 ratio of char to KOH (by mass) was employed for all of the activation tests – the mass of char employed was 3-5 g. Two impregnation methods were tested, which were based on the KOH impregnation methods employed by Ros et al., (Ros et al., 2006), Guo, et al., (Guo et al., 2007) and Olivares-Martin et al., (Olivares-Marin et al., 2006): firstly, dry, where the KOH and char were placed into a glass beaker and then physically stirred until the mixture appeared to have been homogenised; secondly, incipient wetness, where the KOH and char were placed into a beaker, into which was then added sufficient distilled water to fully cover the mixture. The beaker holding the resulting slurry was then subsequently covered with a glass dish and heated on a heating mantle at ca. 80 °C for 2 hrs.

Each KOH-char mixture was activated by being placed inside a quartz tube with an internal diameter of 36 mm. This was, in turn, inserted within a metre long quartz tube with an internal diameter of 43 mm, which was subsequently inserted in a Carbolite tube furnace; the quartz tubes were configured such that the sample-containing quartz tube was sited within the furnace’s heating zone. At the inlet-end, the outer tube was sealed using a metal disc, through which ran a K-type thermocouple and a gas inlet pipe. The metal disc was affixed to the tube by means of a nut and bolt assembly attached to the tube; mineral fibre was placed at the cylinder and metal lid interface to prevent cracking of the tube during the sealing procedure.

The gas inlet tube was connected to a N\(_2\) supply; the flow of N\(_2\) was controlled by a combination of a gas regulator and a rotameter fitted with a needle valve. At the gas outlet end, the quartz tube was sealed with a polypropylene bung, which was perforated with an open-ended quarter-inch stainless steel tube for the discharge of the waste gases; the entire rig was housed within a fume cupboard.

Upon the completion of the sealing procedure, a N\(_2\) flow of 300-400 ml/min was fed through the reactor and once a period of approximately 20 minutes had passed, the furnace’s temperature controller was set to the required activation temperature and the furnace’s heating element was switched on. The furnace did not have any means of controlling the heating rate, which averaged at
around 35 °C/min. On reaching the target activation temperature, the furnace was held under isothermal conditions for the whole duration of the activation period, subsequent to which the heating element was switched off and the furnace cooled down through the application of compressed air onto the external surface of the outer quartz tube. The temperature recorded by the thermocouple within the reactor was monitored for the entire duration of the activation period; the furnace’s temperature-control dial was adjusted when the temperature measured by the thermocouple deviated from the target temperature by more than 10 °C.

Once the activated carbon had been recovered from the reactor, it was necessary to remove the unreacted KOH and the extraneous products of reaction. Thus, it was ground below 500 μm in size with a mortar and pestle – in some instances this stage was omitted - and then placed in a glass beaker, to which was subsequently added a 4 molar (M) solution of HCl – 20 ml of HCL was utilised for each gram of char that had been activated. The resulting mixture was heated for 1 hr on a heating mantle at 80-90 °C – during heating, a glass cover was placed on top of the beaker - and then the solid matter remaining was recovered and thoroughly rinsed in distilled water by filtration with Whatman 541 filter paper.

2.6 Characterisation of textural characteristics

The SBAs produced at ICL have had their textural characteristics analysed by a Beckman-Coulter Omnisorp 100 continuous volumetric gas adsorption analyser. All samples were ground to a maximum size of 0.5 mm, and ~0.25 g of sample was degassed at 150 °C to reach a vacuum of 10⁻⁵ to 10⁻⁶ torr. After degassing, the evacuated samples were analysed using default instrument parameters, for their adsorption/desorption characteristic using nitrogen gas at 77 K. The data was then used to calculate the surface area according to the BET method (Brunauer et al., 1938). The mesopore and micropore surface area was determined by the t-plot method (Lippens and Boer, 1965) and the micropore surface area was determined by subtracting the t-plot surface area from the BET surface area.

At GPA, the mesopore volume of the SBAs was measured by mercury porosimetry (Micrometrics Auto pore IV 9500). The porosimeter enabled the penetration of the mercury up to a pressure of 2050 × 10⁵ Pa, which, according to the Washburn equation, corresponded to an approximate pore width of 8 nm. Each analysis was repeated twice and the experimental error was found to be less than 10 %.

The microporous structure of the SBAs at GPA was determined from nitrogen adsorption/desorption isotherms at 77 K using a Micrometrics, ASAP 2010 adsorption instrument. Prior to the analysis, carbon samples were degassed at 150 °C for about 48 hours. The specific surface area was measured using the BET model from the adsorption of N₂ gases on the surface of the material. The mesopore (2 – 50 nm) and micropore (< 2 nm) volumes were calculated using the BJH and Horwath and Kawazoe model respectively.

2.6.1 Calculation of BET surface area on a dry, ash-free (daf) basis

To determine the BET surface area of the samples on a dry, ash-free (daf) basis, the parent sludge was heated at 650 °C until constant mass, whereupon the BET surface area of the mass remaining of the sample – the ash – was then determined. The daf BET surface area of any sample produced from the sludge was then calculated using the equation below (Kulaots et al., 2004).

BET Surface area on a dry, ash free basis (m²/g) =
3 Results

3.1 Production by carbonisation

The BET and micropore surface areas of the DMAD and DRAW chars are displayed below in Figure 3.1-1. It is noticeable that despite their lower ash content, at carbonisation temperatures below 900 °C, the DRAW chars exhibit lower surface areas than the DMAD chars. This can be attributed to the higher presence of volatiles and in particular, tarry residues, which obstruct the pores within the char, hence lowering its apparent porosity. At 900 °C, where it can be assumed that all of the volatile matter has been expelled, the DRAW sludge exhibits a higher porosity than the DRAW sludge, although this relationship is inverted at 1000 °C. This fluctuation may be due to differences in the carbonaceous structure of the two sludges; this can affect the manner in which the carbonaceous phase realigns itself at high carbonisation temperatures and hence develops porosity.

The highest BET surface area attained by the chars is ca. 155 m²/g, which is, in fact, higher than the highest BET surface area reported in the literature for a carbonised sewage sludge (141 m²/g (Bandosz and Block, 2006)). It is thus apparent that carbonisation does have some use as a means of developing activated carbons.

Figure 3.1-1: BET and microporous surface area exhibited by carbonised DRAW and DMAD prepared between 250 °C and 1000 °C using a heating rate of 5°C/min and a 0 min dwell time
3.2 Production by physical activation

3.2.1 Steam activation

The steam activation of both the dried DMAD and DRAW sludges was investigated. Initially, the work centred on the activation of the DRAW sludge; the BET surface areas attained using a dwell time of 1 hr are displayed below in Figure 3.2-1. It is apparent that the optimum activation temperature was 825 °C, yielding a SBA with a peak BET surface area of 215 m²/g.

In order to ascertain how the DMAD sludge would respond to activation, it was elected to employ the RSM approach – see section 2.4.1 for further information - rather than the conventional, ‘matrix’ methodology. The key factor in this decision was the relative rapidity with which the RSM technique could be used to determine the optimum activation conditions. The data produced from the laboratory investigations undertaken for this work is shown below in Table 3.2-1.

![Figure 3.2-1: BET and micropore surface areas attained by steam activation of the DRAW sludge using a dwell time of 1 hr and a heating rate of 5 °C/min](image)

**Table 3.2-1: Textural characteristics of SBAs created by steam activation of the dried, DMAD sludge**

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Time (min)</th>
<th>BET S. A. (m²/g)</th>
<th>Micropore S. A. (m²/g)</th>
<th>T-plot S. A. (m²/g)</th>
<th>Ash content (wt.%)</th>
<th>BET daf S. A. (ash S. A. =22 m²/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>719</td>
<td>60</td>
<td>124</td>
<td>62</td>
<td>62</td>
<td>78.3</td>
<td>491</td>
</tr>
<tr>
<td>750</td>
<td>20</td>
<td>128</td>
<td>61</td>
<td>66</td>
<td>76.5</td>
<td>471</td>
</tr>
<tr>
<td>750</td>
<td>100</td>
<td>145</td>
<td>69</td>
<td>77</td>
<td>80.5</td>
<td>655</td>
</tr>
<tr>
<td>825</td>
<td>5</td>
<td>126</td>
<td>58</td>
<td>68</td>
<td>79.2</td>
<td>520</td>
</tr>
<tr>
<td>825</td>
<td>60</td>
<td>165</td>
<td>74</td>
<td>91</td>
<td>81.0</td>
<td>773</td>
</tr>
<tr>
<td>825</td>
<td>117</td>
<td>161</td>
<td>62</td>
<td>99</td>
<td>84.0</td>
<td>891</td>
</tr>
<tr>
<td>900</td>
<td>20</td>
<td>157</td>
<td>67</td>
<td>90</td>
<td>80.5</td>
<td>712</td>
</tr>
<tr>
<td>900</td>
<td>100</td>
<td>144</td>
<td>50</td>
<td>94</td>
<td>88.7</td>
<td>1100</td>
</tr>
<tr>
<td>931</td>
<td>60</td>
<td>143</td>
<td>53</td>
<td>91</td>
<td>87.8</td>
<td>1016</td>
</tr>
<tr>
<td>825</td>
<td>60</td>
<td>164.0</td>
<td>76</td>
<td>88</td>
<td>81.5</td>
<td>788</td>
</tr>
<tr>
<td>825</td>
<td>60</td>
<td>164.4</td>
<td>76</td>
<td>88</td>
<td>81.1</td>
<td>775</td>
</tr>
<tr>
<td>825</td>
<td>60</td>
<td>165.3</td>
<td>76</td>
<td>89</td>
<td>81.1</td>
<td>781</td>
</tr>
</tbody>
</table>
The equations describing the relationship between the activation temperature and time and the dependent variables, along with the optimum values of these two independent variables for the maximisation of each of the dependent variables, are given below, where $X_1$ is the activation time and $X_2$ is the activation temperature:

**BET surface area – $Y_1$**

$$Y_1 = 164.6375 + 6.9446X_1 + 6.9176X_2 - 14.3631 - 9.3156 - 7.6 X_1X_2$$

Maximum BET surface area = 166 m$^2$/g; attained when temperature = 837.5 °C and dwell time = 73.33 min

**Micropore surface area – $Y_2$**

$$Y_2 = 75.5227 - 3.2883X_1 - 0.4394X_2 - 8.4201 X_1^2 - 6.9034 X_2^2 - 6.1513X_1X_2$$

Maximum micropore surface area = 76 m$^2$/g; attained when temperature = 812.5 °C and dwell time = 60 min

**T-plot surface area – $Y_3$**

$$Y_3 = 89.1147 + 10.2329X_1 + 7.357X_2 - 5.943 X_1^2 - 2.4122 X_2^2 - 1.4487X_1X_2$$

Maximum meso- and macro-pore surface area = 98 m$^2$/g; attained when temperature = 875 °C and dwell time = 113.33 min

The graphs produced from these three equations are shown below in Figure 3.2-2, Figure 3.2-3 and Figure 3.2-4 respectively.

**Figure 3.2-2: Relationship between activation time, temperature and BET surface area of SBAs produced by steam activation of the DMAD sludge**
Figure 3.2-3: Relationship between activation time, temperature and micropore (internal) surface area of SBAs produced by steam activation of the DMAD sludge

Figure 3.2-4: Relationship between activation time, temperature and mesopore (external) surface area of SBAs produced by steam activation of the DMAD sludge

It is clear, when the data presented in Table 3.2-1 and Figure 3.2-2 is compared with the data obtained from the steam activation of the DRAW sludge – presented in Figure 3.2-1 – that the DRAW sludge is a better activated carbon feedstock (in terms of the textural characteristics of its descendent activated carbons) than the DMAD sludge. This can be attributed to its lower ash content (as discussed in section). However, the data shown in Figure 3.2-1 suggests that BET surface areas much in excess of 220 m²/g will not be attainable by the steam activation of the sludges. Ultimately, this is the consequence of the sludges’ high ash content.

3.2.2 CO₂
The results of the physical activation work conducted using CO₂ are displayed in Table 3.2-2. Focusing first on the top 7 rows of results, it is noticeable that this method did not exhibit any greater efficacy than steam activation, yielding at best, an SBA with a BET ash surface area of 171 m²/g. It is important also to note that in relation to steam activation, more severe, i.e., higher
activation temperatures and longer dwell times, were required to maximise the BET surface areas, which correlates with CO₂’s lower reactivity (Byrne and Marsh, 1995). Calculation of the BET surface area of the SBAs on a dry, ash-free (daf) basis (see section 2.6.1 for details of the calculation) revealed that BET surface areas as high as 1007 m²/g were attainable. The gross disparity between the daf and actual BET surface area of the SBAs reflects their high ash content - 45-87 wt.% - and the low BET surface area of the ash fraction – 22 m²/g.

The finding that the SBAs produced had a high daf BET surface area prompted an investigation into the BET surface areas that would be attainable if the SBAs were de-ashed by HCl washing. The results from this investigation are shown in the bottom three rows of Table 3.2-2, where it is apparent that this technique proved highly effective in boosting the BET surface area and correspondingly, the micropore and mesopore volume. An interesting facet of the data presented is that the de-ashing process engenders a ca. two thirds increase in the BET surface area of the ash-free fraction. Whilst this dramatic increase might, at least in part, arise from errors in the daf calculation procedure, it is indisputable that the de-ashing process has a strongly positive effect on the porosity of the carbonaceous fraction. A similarly dramatic increase in the BET surface area of a carbonised, sewage sludge sample was observed by Ros et al., (2006); prior to HCl digestion in a 5 M HCl solution, the char had a BET surface area of the sample from 13 m²/g, subsequent to HCl digestion, the sample’s BET surface area was 188 m²/g. Ros et al., (2006) proposed that this sharp increase in the BET surface area stemmed not only from the removal of much of the inorganic matter, but also from an improvement in the accessibility the carbon fraction’s pores.

Table 3.2-2: Textural characteristics of SBAs produced by CO₂ activation (daf = dry, ash free basis)

<table>
<thead>
<tr>
<th>Carbonisation conditions</th>
<th>Activation conditions</th>
<th>De-ashed</th>
<th>BET surface area (m²/g)</th>
<th>daf BET surface Area (m²/g)</th>
<th>Micropore volume (cm³/g)</th>
<th>Mesopore volume (cm³/g)</th>
<th>Macropore volume (cm³/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>Dwell time (hrs)</td>
<td>Temperature (°C)</td>
<td>Dwell time (hrs)</td>
<td>No</td>
<td>&lt;5</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>550</td>
<td>2</td>
<td>700</td>
<td>2</td>
<td>No</td>
<td>153</td>
<td>319</td>
<td>0.07</td>
</tr>
<tr>
<td>550</td>
<td>2</td>
<td>800</td>
<td>2</td>
<td>No</td>
<td>151</td>
<td>1007</td>
<td>0.06</td>
</tr>
<tr>
<td>600</td>
<td>2</td>
<td>700</td>
<td>2</td>
<td>No</td>
<td>&lt;5</td>
<td>-</td>
<td>n.s.</td>
</tr>
<tr>
<td>600</td>
<td>2</td>
<td>800</td>
<td>2</td>
<td>No</td>
<td>147</td>
<td>294</td>
<td>0.06</td>
</tr>
<tr>
<td>600</td>
<td>2</td>
<td>900</td>
<td>0.5</td>
<td>No</td>
<td>125</td>
<td>962</td>
<td>0.05</td>
</tr>
<tr>
<td>600</td>
<td>1</td>
<td>900</td>
<td>0.5</td>
<td>Yes</td>
<td>368</td>
<td>518</td>
<td>0.16</td>
</tr>
<tr>
<td>600</td>
<td>1</td>
<td>900</td>
<td>1</td>
<td>Yes</td>
<td>477</td>
<td>701</td>
<td>0.2</td>
</tr>
<tr>
<td>600</td>
<td>1</td>
<td>900</td>
<td>2</td>
<td>Yes</td>
<td>622</td>
<td>1037</td>
<td>0.26</td>
</tr>
</tbody>
</table>

### 3.3 Production by chemical activation

The BET surface area, T-plot surface area (i.e. meso- and macro-pore surface area) and micropore surface area of the SBAs created by chemical activation are shown below in Table 3.3-1. The results suggest that grinding the char, prior to its impregnation and activation is highly beneficial, which, given that the char and KOH must be in physical contact to react, is not unexpected.

The most significant element of the results shown in Table 3.3-1 is the high surface areas attained by this method. Although in the literature, a BET surface area of up to 1686 m²/g (Ros et al., 2006) was achieved by the chemical activation with KOH of a sewage sludge char, the KOH to char ratio...
of 3:1 utilised in that investigation was 3:1; low (1:1) ratios were preferred for this investigation due to their higher commercial viability.

Table 3.3-1: Textural characteristics of samples prepared by chemical activation of DMAD char at an activation temperature and dwell time of 700 °C and 1 hr respectively.

<table>
<thead>
<tr>
<th>Size prepared precursor ground below</th>
<th>Impregnation conditions</th>
<th>BET surface area (m²/g)</th>
<th>T-plot surface area (m²/g)</th>
<th>Micropore surface area (m²/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not ground &lt;150 μm</td>
<td>Mixed with crushed KOH (dry)</td>
<td>584.5</td>
<td>279.2</td>
<td>305.3</td>
</tr>
<tr>
<td>Not ground Heated at 80 °C with crushed KOH in incipient wetness solution for two hrs</td>
<td>673.8</td>
<td>325.7</td>
<td>348.1</td>
<td></td>
</tr>
<tr>
<td>&lt; 150 μm</td>
<td>Heated at 80 °C with crushed KOH in incipient wetness solution for two hrs</td>
<td>636.4</td>
<td>316.8</td>
<td>319.6</td>
</tr>
<tr>
<td></td>
<td>Heated at 80 °C with crushed KOH in incipient wetness solution for two hrs</td>
<td>649.4</td>
<td>350.1</td>
<td>299.3</td>
</tr>
</tbody>
</table>

4 Conclusions

A large range of activated carbons have been produced from sewage sludge; the activated carbons have been shown to vary in terms of their textural characteristics (their BET surface area for example ranges from 649.4 m² g⁻¹ to less than 5 m² g⁻¹) and inorganic (ash) content. In order to produce this range of activated carbons, as opposed to just producing a large number of activated carbons with uniform characteristics, different preparation methods (carbonisation, physical and chemical activation, acid washing) and sewage sludge types (DMAD, DRAW and DAED) were employed.

Although their surface chemistry has not been assessed, it can be assumed that the activated carbons also exhibit a large diversity in their surface chemistry characteristics and accordingly, their uptake of specific pollutants; carbons produced by the carbonisation of sludges are generally highly basic in nature (Rio et al., 2004, 2005b, Seredych and Bandoz, 2006, 2007), as are carbons produced by activation with CO₂ (Jindarom et al., 2007). Sewage sludge derived carbons that have been washed in HCl on the other hand are, irrespective of the activation/carbonisation method, acidic (Bagreev et al., 2001, Martin et al., 2002, 2003, Rio et al., 2005a). In order to meet the requirements set by the next (and final) deliverable – 12.2 – the performance of these activated carbons will be studied in a range of different applications.

5 References


