Evaluation of the Correlation between Selected Quality Indices of Activated Carbon: A Review

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The choice of activated carbon for use depends on the quality, which is measured by selected indices. The correlation between BET surface area, iodine number, ash content and bulk density, major quality indices for characterisation were investigated in this study. The iodine number and surface area were strongly correlated ($R^2 = 0.9684$ and $0.9577$). The bulk density and ash content were highly correlated with surface area with coefficient of determination ($R^2$) values of 0.9040 and 0.9788 respectively for samples from same raw material under similar treatment. The ash content could also be used as an approximate estimate of iodine number and bulk density with $R^2$ values of 0.5966 and 0.6236 respectively.

Key Words: activated carbon, adsorption, activity, correlation, coefficient of determination

INTRODUCTION

Activated carbon, an amorphous, porous form of carbon with high surface area is the most widely used industrial adsorbent (Daintith, 2004), (Seader and Henley, 2007). It is used in the manufacture of protective gas mask for the entrapment of toxic gases in the plant and also in the manufacture respiratory devices for personal protection during chemical warfare. In medicine; activated charcoal (carbon) is frequently used treating and managing severe, acute poisoning (Cooney, 1995). In hydrometallurgy, it is used in precious metal (such as Au and Ag) recovery processes and also for the removal of organic pollutants in drinking water and industrial wastewater processing (Soleimani and Kaghazchi, 2008), (Adinata et al, 2007). Activated carbon is also used in the removal of compounds that adversely affect taste, colour and odour in food processing industries and also in the removal of dye in effluent streams in
the textile industry (Qureshi et al, 2008)(Bello et al, 2011). The versatility of activated carbon for use in the fore stated processes is due to its large surface area, a property that enables it to be used effectively for adsorption.

Depending on the intended use of activated carbon, various quality parameters including surface area, activity, bulk density and ash content are tested for in a sample. The surface area, the total area of the surface of a powder or a solid including both external and accessible internal surface (from voids, cracks, open porosity and fissures) is an important parameter used in the determination of the quality of activated carbon. Generally, the higher the measured surface area value of an activated carbon sample, the better the carbon for adsorption operations. It is usually determined by the BET (Brunauer, Emmett and Teller) method (ASTM Committee E02 on Terminology, 2005).

Activity, the measure of the adsorptive capacity of an adsorbent (activated carbon) usually determined by a standard test is a major quality test carried on activated carbon. Various forms of activity test are carried out depending on the end user application: Iodine number (standard for liquid phase application such as water treatment), Molasses number or Caramel decolourising performance (colour adsorption processes such as in sugar industry), carbon tetrachloride value (vapour phase application) fresh carbon activity (gold mine operations) (Desilva, 2000), (Faulkner et al, 1987), (http://www.igcl.com/php/activated_carbon.php).

Bulk density, the mass per unit volume of a material (activated carbon) including voids in the material is another parameter used sometimes to estimate the quality of carbon. A Low bulk density value may imply a relatively high surface area, a good indicator of high adsorption capacity. (ASTM Committee E02 on Terminology, 2005),(Saleh et al, 2008).

The ash content of activated carbon is the inorganic residue that remains when the carbonaceous portion is burned off. It is used as an estimate of the adsorptive property of carbon. The inorganic residues (mainly silica and oxides of metals) are non porous and hence high ash content invariably results in low adsorptive capacity of the carbon (ASTM Committee E02 on Terminology, 2005). Although considerable amount of research has been carried out on the production activated carbon from various raw materials for adsorption, little has been done on finding a concrete relationship (not speculative) between the quality indices used in characterising carbon. In this paper, a conscious effort is made in finding the correlation (if any) between selected quality indices (surface area, bulk density, iodine number and ash content) used in characterising activated carbon.

**TOOLS AND METHODS**

The correlation between the selected quality indices were determined by finding the Pearson correlation coefficient (R) values between the chosen parameters in the works of other authors on the subject matter using Microsoft excel spreadsheet. The meaningfulness or strength of the correlation coefficient is ascertained from the coefficient of determination ($R^2$). The formula for the correlation coefficient (R) is:

$$ R = \frac{1}{n-1} \sum \frac{(x - \bar{x})(y - \bar{y})}{s_x s_y} $$

Where $n$ is number of pairs of data, $\bar{x}$ and $\bar{y}$ are the means for $x$ and $y$ respectively, $s_x$ and $s_y$ represent the standard deviations for the $x$-values and $y$-values.
RESULTS AND DISCUSSION

Fig 1: Correlation between Iodine Number and Surface Area for Activated Carbon Prepared from Bituminous Coal, Carbonised at 800°C and Activated under same conditions with different chemicals. (Source: Adapted from Cuhadaroglu and Uygun, 2008.) (Cuhadaroglu and Uygun, 2008)

![Graph](image1)

\[ y = 0.625x + 223.8 \]
\[ R^2 = 0.957 \]

Fig 2: Correlation between Iodine Number and Surface Area for Activated Carbon from Jute Stick Char under same conditions but different Activation temperatures. (Source: Adapted from Asadullah et al., 2007) (Asadullah et al, 2007)

![Graph](image2)

\[ y = 0.94x - 120.3 \]
\[ R^2 = 0.968 \]
Fig. 3: Correlation between Bulk Density and Surface Area for different samples of Activated carbon used in industrial processes in Iran. (Source: Adapted from Soleimani and Kaghazchi, 2008) (Soleimani and Kaghazchi, 2008)

\[ y = -0.069x + 555.9 \]
\[ R^2 = 0.477 \]

Fig. 4: Correlation between Bulk Density and Surface Area of Activated carbon from different raw materials by both physical and chemical activation (Source: Adapted from Yusufu et al., 2012) (Yusufu et al, 2012)

\[ y = -0.001x + 1.621 \]
\[ R^2 = 0.904 \]
Fig. 5: Correlation between Surface Area and Ash Content of Activated carbon from Olive Mill Waste Chemically activated with KOH (Source: Adapted from Moreno-Castilla et al., 2001) (Moreno-Castilla et al, 2001)

\[ y = -178.8x + 1718 \]
\[ R^2 = 0.978 \]

Fig. 6: Correlation between Surface Area and Ash Content of Different samples of Activated carbon used in industrial processes in Iran (Source: Adapted from Soleimani and Kaghazchi, 2008) (Soleimani and Kaghazchi, 2008)

\[ y = -48.06x + 1305 \]
\[ R^2 = 0.747 \]
Fig. 7: Correlation between Bulk Density and Ash Content of Activated carbon from Palm Oil Shell Physically activated at 750°C (optimum conditions for different sizes)  
(Source: Adapted from Vitidsant et al., 1999)  
(Vitidsant et al, 1999)

![Graph showing the correlation between Bulk Density and Ash Content](image)

\[ y = 0.002x + 0.474 \]
\[ R^2 = 0.517 \]

Fig. 8: Correlation between Bulk Density and Ash Content of Activated carbon from different raw materials by both physical and chemical activation (Source: Adapted from Yusufu et al., 2012)  
(Yusufu et al, 2012)

![Graph showing the correlation between Bulk Density and Ash Content](image)

\[ y = 0.002x + 0.566 \]
\[ R^2 = 0.623 \]
Fig. 9: Correlation between Iodine Number and Ash Content of Activated Carbon from Fluted Pumpkin Seed Shell by Chemical activation (Source: Adapted from Verla et al., 2012) (Verla et al, 2012)

![Graph showing correlation between Iodine Number and Ash Content of Activated Carbon.](image)

\[ y = -3.142x + 286.5 \]
\[ R^2 = 0.572 \]

Ash Content (%)

Iodine Number (mg/g)

Fig. 10: Correlation between Iodine Number and Ash Content of Activated Carbon from Palm Oil Shell Physically activated at 750°C( optimum conditions for different sizes) (Source: Adapted from Vitidsant et al., 1999) (Vitidsant et al, 1999)

![Graph showing correlation between Iodine Number and Ash Content of Activated Carbon.](image)

\[ y = -6.496x + 574.0 \]
\[ R^2 = 0.596 \]

Ash Content (%)

Iodine Number (mg/g)

The Iodine number values and the BET surface area were highly correlated (Fig.1 and Fig.2). About 96% - 97% of the variation in iodine number can be explained by variations in the surface area. This is probably the reason why in liquid phase applications, the iodine number remains the basic quality test for adsorptive capacity of carbon, a measure of the
available surface area for adsorption processes. A similar trend of high correlation between iodine number and surface area was observed elsewhere (Vitidsant et al, 1999).

Generally, an expected inverse relation exists between density and surface area (Saleh et al, 2008). This assertion is confirmed by the nature of the high coefficient of determination ($R^2 = 0.9040$) in Fig. 4. Although a relatively weak correlation ($R = 0.6908$) exist between density and surface area as shown in Fig. 3, about 48% of the variation in density may be accounted for by variations in the surface area. Bulk density may there only be used for approximate estimation surface area (adsorption capacity for that matter).

The ash content is known to interfere with pore structure development and hence adversely affect adsorption. High ash content may therefore correspond to low surface area (Devī et al, 2012). As shown in Fig. 5 and Fig. 6, there is a strong correlation between surface area and ash content. For activated carbon from the same raw material and prepared in similar manner (olive mill waste activated with KOH), about 97% of the variations in the surface area are explained by the variations in ash content (Fig. 5). A similar trend is observed in the same work when $H_3PO_4$ was used as activating agent (Moreno-Castilla et al, 2001). However, for activated carbon samples from different precursors, variations in surface area may only be explained by about 75% variations ash. The Disparity could be a reflection of degree of variation in the chemical composition of each raw material which reflects in the inorganic residues after combustion, the ash content. A positive correlation exists between the density of activated carbon and the ash content (Fig. 7 and Fig. 8). Variations in density may be explained by variations in ash content by 50-60%. The observed trend in ash and density is expected as both parameters impact negatively on surface area as seen in the foregoing analysis.

Generally, the inorganic residues that make up the ash (such as $SiO_2$, $Na_2O$) are non adsorptive and therefore high ash content in an activated carbon sample may correspond to low iodine number. Although there is a general negative correlation between the iodine number and ash content (Fig. 9 and 10), the ash content is not as strongly correlated to the iodine number ($R^2 = 0.60$). The ash content could perhaps only be used as a rough estimate of the iodine number and any other measure of activity.

**CONCLUSION**

The studies conducted on some selected quality indices of activated carbon (BET Surface area, Iodine number, ash content and bulk density) from randomly selected scholarly articles on the subject matter gave an indication of a very strong correlation between Iodine number and Surface area ($R^2 = 0.9684$ and $0.9577$). Disparities in the correlation between density and surface area as well as ash content and surface area, show that ash and density may only be useful for approximate estimation of surface area or when the carbon samples are from the same raw material and produced in like manner. Though moderate, a correlation exist between bulk density and ash content ($R^2 = 0.517$ and $0.6236$). The ash content may also be used as an approximate forecast of Iodine number ($R^2 \approx 0.60$).

**REFERENCES**


