Effect of ceramic waste as an adsorbent

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Abstract. The scope of this work is in using non-recyclable material to remove dye from industrial water as an adsorbent media which is an ideal method as compared with expensive options of treatment. In recent years, economical and safe methods are required for the treatment of dyehouse effluents. Ceramic powder waste was used to remove methylene blue from wastewater. Different initial dye concentration (10, 20 & 30) ppm, adsorbent doses (0.5, 1, 1.5, 2, 2.5 & 3) gm, pH (4-9) and contact time 0, 30, 60, 90 and 120) min. was studied. The best removal efficiency was at pH=5m contact time 90min, dose 2gm. FTIR was tested for the adsorbent media.

Keywords
Adsorption, ceramic materials, Methylen blue, Langmuire

1. Introduction
Large quantity of wastewater is produce during dye production and textile manufacturing processes by using dyes to colour textiles and products [1]. In industry, water soluble dyes are used for the colouring of different substrates, like leather, hair, textiles, paper, food and cosmetics. Colour removal from domestic and industry has gained importance in the last few years, for its visibility and toxicity [2]. Activated carbon is usually used as an adsorbent for its strong capacity of adsorption, good removal efficiency, but it is expensive [3,4,5]. With the development of industry of ceramic as industry waste is generated, it restricts the development of the industry of ceramic and causes impact on the environment. The waste ceramic components cannot be utilized, also appears in resources of waste. Ceramic is made in origin of clay, where it is used as an adsorbent in the treatment of water [6]. Cost is reduced information of the product and it is safe environmentally. The comprehensive treatment of waste ceramic in industry became important in industry of ceramic [7,8]. Recycled waste is a useful material in industry of ceramic for sustainable industry development [9, 10]. The major purpose of this work is to exploit the possibility of using a ceramic waste as adsorbent in water treatment.

2. Materials and methods
2.1 Methylene Blue dye (MB)
Figure 1 shows the chemical compound of heterocyclic aromatic which is called as – methylthionine-chloride or Methylene Blue with molecular formula as: C₁₆H₁₈ClN₃S, 3H₂O. Its physical and chemical properties are shown in table 1.
Figure 1. Methylene Blue dye chemical structure

Table 1. Physical and chemical properties and pharmacokinetics of MB used in this research [11]

| chemical and Physical Properties | Values |
|----------------------------------|--------|
| Temperature of Melting           | 180º   |
| Temperature of Boiling           | No data|
| Water Solubility                 | 35.5 g/l-1 |
| value of pH                      | 3 (10g/l H₂O) |
| Molecular weight                 | 319 g/mol-1 |
| Colour                           | Dark blue-green in oxidized form, colorless in reduced form (leukomethylene blue) |
| Formula                          | C₁₆H₁₈N₃ClS |

2.2. Preparation of ceramic waste
Ceramic waste materials (brick waste) were grounded in to powder form. At first, it was crushed manually and then mechanically by ball mill and then it was dried in air. Sieve’s analysis was performed to achieve 300 µm particle size. Chemical characteristics of powder ceramic are shown in table 2

Table 2. Chemical analysis of ceramic waste [12]

| Elements | Ratio by Wt. % |
|----------|----------------|
| SiO₂     | 50.22          |
| Al₂O₃    | 16.72          |
| Fe₂O₃    | 6.14           |
| CaO      | 14.9           |
| MgO      | 4.22           |
| Na₂O     | 0.90           |
| K₂O      | 2.14           |
| P₂O₅     | 0.15           |
| LiO      | 3.12           |

2.3. Adsorption method
The dye removal efficiency of the prepared Ceramic powder was calculated using equation 1 as follows [13-14]:

\[
\% \text{Removal} = \left( \frac{c_i - c_f}{c_i} \right) \times 100 \quad \ldots (1)
\]

Where,
C_i = initial solute concentration
C_f = final solute concentration
At time = t, the adsorption capacity of the Ceramic powder, q_t (mg/g) was determined as follows:

\[
q_t = \frac{(C_i - C_t) \times V}{m} \quad \cdots (2)
\]

Where,
C_i = initial dye concentration
C_t = concentration of Methylene Blue dye (MB) at time t
q = Adsorbed dye amount at given adsorbent amount (mg/g).
V = solution’s volume
m = weight of the Ceramic powder (gm).
The adsorption rate at equilibrium (q_e) was determined using equation 3 as follows:

\[
q_e = \frac{(C_i - C_e) \times V}{m} \quad \cdots (3)
\]

Where,
C_e = concentration of Methylene Blue dye (MB) at equilibrium.

3. Results and Discussion
3.1 FTIR analysis of Ceramic Material
The FTIR spectrum of ceramic waste is shown in Figure 2, before and after adsorption, this showed that the spectrum of both calcite and clay peaks, didn’t show any degradation. Figure shows the wave length which is less than 1000 cm\(^{-1}\) represents the alkane group, and demonstrates broad absorption peaks at 1978.97-2438.02 cm\(^{-1}\) and 1978.97-2160.27 cm\(^{-1}\) respectively before and after adsorption process, this indicates that the dye was adsorbed and that water has not been eliminated from the structure which means the movement of minerals from plant roots.
Fig 2-a.: FTIR test for ceramic waste - Before adsorption
3.2 pH effect. pH is important during the process of adsorption. Figure 3 showed pH effect on capacity of Methylene Blue dye (MB) adsorption on the prepared Ceramic powder. Figure shows the capacity of Methylene Blue dye (MB), adsorption was found to be affected by pH changes in the solution. pH range was (4 – 9). The highest dye removal was when pH = 4.

Fig. 2-b. FTIR of ceramic waste- after adsorption

| No. | Wavenumber (cm⁻¹) | Intensity | Chenal Intensity | Chenal Wavenumber (cm⁻¹) | Chenal Intensity |
|-----|------------------|-----------|------------------|--------------------------|------------------|
| 1   | 3428.27          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 2   | 3426.84          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 3   | 3424.23          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 4   | 3421.62          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 5   | 3419.01          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 6   | 3416.41          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 7   | 3413.81          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 8   | 3411.21          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 9   | 3408.61          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 10  | 3406.01          | 1.809     | 1.545            | 3433.15                  | 1.809            |
| 11  | 3403.41          | 1.809     | 1.545            | 3433.15                  | 1.809            |

Comment:
- No. of Scans: 10
- Resolution: 0.1
- Apodization: None
- User: RAHMAN
3.3 Effect of Ceramic powder concentration. Ceramic powder doses were varied between (0.5 to 3.0 g) and the effects of doses were studied on the adsorption efficiency at initial dye concentration of 30 ppm, pH 5 and temperature of 25°C. As shown in Figure 4, the removal efficiency was increased as the Ceramic powder concentration increased. A higher adsorbent concentration gives larger surface area with high porosity. However, at a higher adsorbent concentration, there was no significant increase in the dye removal efficiency (slight increase) because there was no appreciable surface area increase due to solvent saturation and the consequent conglomeration of the exchanger particles with filling the porosity between the ceramic particles. Meanwhile, an adsorbent concentration of 3 g/100 mL was found to be the ideal concentration for maximum dye adsorption.

4. Adsorption isotherms
Models of Langmuir and Freundlich isotherms, adsorption isotherms were studied. The Langmuir model (Equation 4) has monolayer homogeneous area of coverage, identical and energetic site of adsorption equivalent on the surface of a molecule [12].

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{K_L q_m C_e}$$ … (4)

Where
- $q_e$ = amounts of dispersed Methylene Blue dye (MB) (mg/g) adsorbed at equilibrium
- $C_e$ = concentration of the dye (mg/L) when the solution is at equilibrium.
- $q_m$ = capacity of monolayer adsorption (mg/g)
- $K_L$ = constant of Langmuir adsorption (L/mg) which relates to the free adsorption energy
The model of Freundlich (Equation 5) assumes a physicochemical adsorption on heterogeneous surfaces.

\[
\log q_e = \log K_F + \frac{1}{n} \log C_e \quad \ldots \ (5)
\]

Where, 
\(K_F\) and \((1/n)\) = Freundlich adsorption isotherm constants, indicating the extent of adsorption and the adsorption intensity, respectively.

The best adsorption capacity of the prepared Ceramic powder was determined at a temperature of 25°C, pH 6, the initial dye concentration of 30 ppm, and different adsorbent concentrations (0.5 to 3 g) using the Langmuir isotherm equation. Table 3 provides the values of \(R^2\) and the isotherm constants while the linear plot of \(1/q_e\) vs. \(1/C_e\) is shown in Figure 5. The best correlation coefficient value indicates the suitability of the Freundlich isotherm, which gave best fit with the equilibrium data \(R^2 = 0.996\). However, the data was found to fit with both models of isotherm because the value of \(R^2\) was 0.99 (Figure 6). Table 3 also presented the isotherm parameters with slope of the plots derived from the intercept.

| Isotherm constant | Langmuir | Freundlich |
|------------------|----------|------------|
| correlation coefficient | \(R^2\) | q_m | \(K_L\) | \(R^2\) | \(K_F\) | \(N\) |
| Value            | 0.9906   | 8.06      | 0.154 | 0.9932 | 6.915    | 0.348 |

![Figure 5. Freundlich adsorption isotherm for blue methylene dye](image_url)
Figure 6. Langmuir adsorption isotherm for blue methylene dye

5. Conclusions
Cost is an important factor for adsorbents feasibility of dyehouse effluents. Cost analysis is not stated and the expense of adsorbents is different that depends on the processing and availability of source. Brick ceramic waste shows a good adsorption capacity which makes it an effective adsorbent for the low cost removal of dyes. The evidence that brick waste is a good adsorbent is; $R^2$ reached 99% when pH = 5, temperature is 25°C and contact time = 30 min, indifferent initial dye concentration 30 ppm and waste doses (2-3) mg. This indicated a high removal efficiency.

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