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The action of yeast as an adsorbent in wastewater treatment: A Brief Review

J.A. Al-Najar[1], T.Lutfee, N.F.Alwan
Chemical Engineering Department, University of Technology, Alsinaa Street 52, Baghdad, Iraq

E-mail: 80179@uotechnology.edu.iq

Abstract. Yeast is a single-celled organism that is classified as a member of the fungi kingdom. Yeast has a significant role in the biological treatment of wastewater. The bio-sorption technology is applied to remove many pollutants such as heavy metal, dyes, and organic materials such as phenol. This technology is characterized by being inexpensive and environment-friendly. This research reviews yeast's effectiveness as an adsorbent in removing heavy metals, dyes, and phenol from wastewater. The effects of some factors such as the concentration of pollutants, pH of the solution, and yeast mass in the bio-sorption process are reviewed. The bio-sorption process at equilibrium can be described using the isotherm model such as Langmuir and Freundlich isotherm models reviewed in this paper.
Keywords: Yeast, Adsorbent, adsorption, wastewater

1. Introduction

Civilization development, growing industrialization, increased population, and human activities have led to the generation of huge wastewater quantities that cause environmental risks if discharged to surface water [1]. The main sources of wastewater can be classified into industrial, agricultural, and municipal [2]. The wastewater released from various Industries and agricultural sources containing many harmful pollutants such as heavy metals, dyes, and organic compounds [2]. Therefore, this wastewater must be treated to remove these harmful pollutants before discharged into the environment. According to the nature of pollutants, many physical and biological techniques are available to treat wastewater, such as adsorption, coagulation, chemical precipitation, membrane separation, ion exchange, flotation, solvent extraction filtration, and biological treatment [3]. Most of these methods are expensive and inefficient in treating low concentrations within the range of 1-100 mg/l [4]. Besides that, some of these methods result in toxic sludge, which requires an additional cost to the disposal of this toxic sludge, which makes some of these methods uneconomic [4]. Among these methods, the biosorption process using natural adsorbent material is the best for its low cost, easy operation, and efficiency in removing low concentrations [4][5]. Many materials can be used as natural adsorbents. Such materials include paper mill sludge [6], dried sewage waste [7], rice husk [8], date pits [9], and different biomass such as algae [5][10][11][12], fungi [10][12], and yeast, [1][3][13][14]. Yeast is a single-celled organism that is classified as a member of the fungi kingdom. Yeast plays an important role in the biological treatment of wastewater.

This paper provides a brief review of the research related to studying the use of yeast as an adsorbent in removing several pollutants such as dyes, heavy metals, and phenols, as well as a review of the factors that affect the removal efficiency such as the concentration of pollutants, the yeast mass, the pH of the solution, and the temperature.

2. Yeasts and its specification

Yeasts are a single-celled organism that is classified as a member of the fungi kingdom. They are a kind of eukaryotic microorganism. They are usually present in the environment and often separated from sugar-rich material. Yeast has attracted the attention of many researchers for their rapid growth and its high metabolic efficiency. The Japanese Research institutes recognized that applying yeasts in wastewater treatment technology for the first time in the world was in early 1990 [15]. Yeasts are classified into two categories [15][16]:

(1) Fermented yeast: this kind of yeast ferments six-carbon sugar into alcohol and carbon dioxide in the absence of oxygen.
(2) Oxidized yeast: this kind of yeast has strong oxidation ability and weak fermentation ability or no fermentation ability, such as yeast used in the wastewater treatment and petroleum processing industry.

3. The role of yeast in wastewater treatment

The biological treatment process of wastewater involves the activities of biomasses such as bacteria and yeast to clean water. This process depends on these biomasses' ability to bind different pollutants such as heavy metals, oil, dyes, and other organic material such as phenols onto its cellular structure [9]. Yoshizawa, at the end of 1970, designed a wastewater treatment process using yeast as an adsorbent. The ability of yeast in cleaning wastewater has attracted many researchers' attention and encouraged them to design such a process [15][16]. The following sections illustrate yeast's role in the removal of heavy metals, dyes, and phenol.

3.1 The removal of heavy metals

Heavy metals have occurred naturally in the earth, but they also release into the environment water from different sources, and their concentrations are increased because of human activities [17]. The main sources of heavy metals are mining, fertilizers, paint, batteries industry, etc. Heavy metals such as lead, copper, mercury, cadmium, nickel, arsenic, etc., harm human health due to their toxicity. For humans, the effects of exposure to any of the toxic heavy metals are shown in table 1 [18, 19, and 20]. The toxic effect is that the heavy metals do not degrade, so they accumulate inside the body faster than metabolism. Biosorption using natural adsorbent for removing heavy metals from wastewater has increasingly attracted many researchers. They have used biomass materials such as yeast, algae, and bacteria for heavy metals' biosorption. Saccharomyces Cerevisiae is the most common type of yeast used in water treatment. The present review focuses on the adsorption of heavy metals using yeasts and the factors that affect the biosorption process.

The experimental data from many researchers reported that yeast could be used effectively as a natural adsorbent material for the removal of many heavy metals such as Zn, Cd, Cr, Pb, Cu, Ar, Hg, Co, Ni [14, 16, 23, 24, 25, 27, 29, and 30]. Wang et al. [16] showed through a review study that yeast can adapt to different types of wastewater due to its resistance to osmotic pressure and acidity. This enables it to achieve a great effect in removing heavy elements. The potential of waste beer Yeast Saccharomyces Cerevisiae for removal of Lead from battery manufacturing industrial effluent has been studied [25]. The effect of pH, lead concentration, adsorbent concentration, agitation speed has been investigated too. The lead uptake was found to be 2.34 mg/g, and the experimental results were in agreement with Freundlich and Langmuir isotherm model. The results of this study indicate that the biosorption process using yeast as a natural adsorbent is a promising technique for removing lead from battery manufacturing effluents [25]. The effectiveness of yeast Saccharomyces Cerevisiae for biosorption of copper ion Cu (II) was investigated using different parameters such as the mass of yeast, Cu (II) concentration, pH of the solution, equilibrium time. This study shows that yeast Saccharomyces Cerevisiae gives a good removal

efficiency of 76% Cu (II) and a good maximum adsorption capacity of 4.73 mg/g. The biosorption process was to follow the Langmuir isotherm [27]. Massuad et.al. [29] reviewed the removal of heavy metals (Pb, Cd, As, and Hg) from foodstuffs using yeast Saccharomyces Cerevisiae as adsorbent at the different conditions, and the results of this study indicate the ability of Saccharomyces Cerevisiae in removing heavy metals [29]. So, the performance of yeast Saccharomyces Cerevisiae to remove heavy metals (Pb, Zn, Cr, Co, Cd, and Cu) from aqueous solution was evaluated through studying the effect of pH, temperature, sorbent mass, initial concentration, and contact time on the adsorption process [30]. The results indicate that the faster biosorption occurs at pH values (5-6) and the biosorption process described by Freundlich and Langmuir adsorption isotherms [30].

Table 1 The effect and source of some heavy metals [20]

Heavy metal	Major source	Toxic effect	References
Arsenic	Smelting, mining, rock sedimentation, pesticides,	Nausea, Vomiting, Diarrhea, Encephalopathy, Multi-organ, effects, Arrhythmia, Painful neuropathy, Bronchitis, dermatitis, bone marrow depression, hemolysis, hepatomegaly, Diabetes, ypopigmentation/Hyperkeratosis, Cancer	[18,21,22]
Cadmium	Plastic, welding, pesticide, fertilizer, mining, refining	Kidney damage, bronchitis, Gastrointestinal disorder, bone marrow, insufficiency, hypertension, Itai–Itai disease, weight loss, lung inflammation, Lung cancer, softening of bones, Proteinuria (excess protein in urine; possible kidney damage)	[18,23]
Chromium	Textile, dyeing, paints and pigments, steel fabrication	Hemolysis (red blood cell destruction), Acute renal failure, Lung cancer, vomiting, severe diarrhea	[18,24]
Lead	Mining, paint, pigments, electroplating, manufacturing of batteries, burning of coal	Anemia, brain damage, anorexia, malaise, loss of appetite, Liver, kidney, gastrointestinal damage, Nausea, Vomiting, Encephalopathy, Foot drop/wrist drop (palsy)mental retardation in children	[18,25]
Mercury	Batteries, paper industry, paint industries, mining	Damage to nervous system, protoplasm poisoning, corrosive to skin, eyes, muscles, dermatitis, kidney damage, Diarrhea, Fever, Vomiting, Stomatitis (inflammation of gums and mouth), Nausea.	[18,26]
Copper	Plating, copper polishing, paint, printing operations	neurotoxicity, and acute toxicity, dizziness, diarrhea	[5,11,13,27]
Nickel	Porcelain enameling, non-ferrous metal, paint formulation, electroplating	Chronic bronchitis, reduced lung function, lung cancer,	13,18,28]
Zinc	Mining, refineries, brass manufacturing, plumping	Causes short term „,,metal-fume fever", gastrointestinal distress	[13]

3.2 The removal of synthetic dyes

One of the matters of concern is the contamination of water with dyes generated in water from the effluent of different industries such as dyeing, paper and pulp, textile, paint, tannery industries, pharmaceutical, and food industries. These industries usually use synthetic dyes due to their ease of use, low synthetic cost, as well as the variety of its colors, compared to the natural colors [31]. Throwing industrial wastewater containing dyes without pretreatment into the environmental water streams causes a hazardous effect on the aquatic life and human health as well. So the process of getting rid of dyes became a major environmental issue. Adsorption using microorganisms as biomass adsorbent is an effective and economical method. Many microorganisms such as bacteria, actinomycetes, fungi, and algae have been used for their ability to remove dyes from wastewater. Therefore, yeasts belong to the taxonomic group called fungi. The most common yeast known is Yeast Saccharomyces cerevisiae, which is used in the baking and brewing industry. Yeasts are inexpensive, available, and also grow fast and resist unsuitable conditions. [31]. recently, extensive research has been conducted on yeast as a promising alternative to existing treatment methods [31][32][33][34]. A magnetic baker's yeast (MB) prepared by cross-linking baker's yeast and nano-Fe2O4 has been used as a natural adsorbent to remove methyl violet (MV) in wastewater. SEM, XRD, and FTIR examined the prepared MB. The results showed that the Fe2O4 was distributed over the surface of yeast biomass. This surface contains functional groups such as amino, carboxyl, and hydroxyl, responsible for the bio-sorption of MV. MB can efficiently remove MV and can readily regenerate by utilizing a magnetic field. The optimum conditions obtained were pH 6, MV concentration 300mg/l, and contact time 30 min. the biosorption capacity at optimum condition was 60.84 mg/g [33]. Another research prepared MB by glutaraldehyde method and then chemically modified with ethylenediaminetetraacetic dianhydride (EDTAD). The resulting is EDTAD-modified magnetic baker's yeast (EMB) used to remove MB dye from water [34]. The ability of both EMB and MB for removal of methylene blue dye was investigated, and the results show that EMB gives higher biosorption capacity at pH range 4-8 in comparison with MB.

In addition, various factors affect the adsorption of dyes by yeast, such as pH, initial dye concentration, yeast mass, and temperature. The important factor affecting the biosorption capacity of adsorbent, the solubility of dyes, and the color of dyes is the solution's pH. A review study reported that the net charge on the yeast adsorbent surface affects the solution's pH because the yeast surface contains various functional groups such as a polymer, carboxyl hydroxide, amino, and phosphate [31]. This study explains that at the acidic media (when pH is lower) the adsorbent surface becomes positive due to the proton's presence and thus will increase the electrostatic attractiveness of anionic dyes to the surface of the adsorbent. However, when the medium is basic (at high pH), the adsorbent surface becomes negative, thus will attract the cationic dyes. The effect of pH on the biosorption process of three anionic textile dyes by yeast has been investigated at a dye concentration of 100 mg/l for 60 min contact time and temperature 30oC. The results indicated that the optimum removal of dyes was found at pH 2 for the three anionic dyes [32]. Also, the results show that the three dyes' removal efficiency increased as the pH values of the aqueous solution decreased. These results are in agreement with other researches [31, 32]. Tian et al. [33] investigated that MB's biosorption capacity for removing methylene violet increases as the aqueous solution's pH increases and reaches the maximum at pH 6. Another research reported that the optimum conditions for removing Remazol blue dye from textile wastewater using Baker's yeast cell were obtained at pH 2 ± 0.02, adsorbent weight 0.25g, and dye concentration 100 mg/l [35].

3.3 The removal of phenols

Phenols are organic substances of environmental importance due to their high toxicity, even at low concentrations. Phenols compounds are present in the effluents of different industries such as pharmaceutical, oil refineries, petrochemicals, plastic, paper, etc. [36, 37, and 38]. These effluents must be

treated before discharging into the environment; otherwise, it will be polluted the drinking water, damage human health, and other environmental hazards [39]. But, due to the high toxicity of phenols, they are subjected to specific restrictions and regulations. The allowable concentration of phenols in drinking water is 1 µg/l according to WHO recommendation, and its concentration in wastewater must be lower than 1 mg/l thus according to the regulations by the US Environmental Protection Agency and the European Union directive number 80/778/EC [39,40].

Therefore, many treatment methods have been used to eliminate phenols from water, such as membrane process, adsorption, oxidation, solvent extraction, and biological treatment [38][39][40]. The present review study focuses on using yeast as a promising adsorbent for phenol removal using a biosorption technique. Several studies have used yeast to remove phenols [3, 41, and 43]. The biosorption capacity of yeast saccharomyces Cerevisiae for removal of phenols and the effect of pH, adsorbent weight, contact time, and initial concentration of phenols have been investigated. This research's experimental data showed that the bio-sorption of phenol decreased with increasing the value of pH. At low pH, yeast's surface was covered by protons and created strong electrostatic attraction forces with the negative charge of phenol. While at high values of pH, a high amount of OH-1 ions would be in the solution. Therefore, repulsion and competition occur between OH-1 ions and phenol molecules, leading to lower phenol bio-sorption [3][44]. The same conclusion has been reported to remove phenols by yeast and other adsorbents [42][43][44][45][46]. The effect of the weight of yeast on the removal phenol has been studied [3]. This study reported that the amount of phenol uptake per unit mass of adsorbent decreases with increasing adsorbent weight. In other words, the percentage of removal of phenol increases with increasing the mass of adsorbent. These results can explain that as the adsorbent's weight increases, the number of adsorption sites available in the adsorbent increases. Other researchers have reported similar trends [42][44][45][46][47]. The contact time is one of the important parameters to indicate the equilibrium time in the biosorption process. Studies reported that the adsorption capacity increase with increasing contact time and then reaches equilibrium; then, the capacity remains constant as the time continues to increase [3][42][44].

4. Calculation of adsorption capacity

At equilibrium, the adsorption capacity can be calculated by applying mass balance in a batch adsorption system containing a certain volume of solution and a certain amount of adsorbent [4, 9, 37, and 46]:

$$q_e = \frac{V}{m}(C_o - C_e) \tag{1}$$

Where q_e is the amount of solute adsorbed at equilibrium, V is the volume of pollutant solution of wastewater (m^3 or litter), and m is the mass of adsorbents, which is yeast in our study, C_o and C_e are the initial and final or equilibrium concentration of solute (mg/l).

5. Adsorption isotherms

In general, adsorption isotherm is a method for determining a specific adsorbent material's suitability for an adsorption process. Adsorption isotherm gave the relationship between the amount of adsorbate adsorbed by weight of adsorbent (q_e) and the adsorbent's concentration in the concentration (C_e) at equilibrium. It fixed the temperature [20][30] as shown in Figure1. From the behavior of the curves in Figure 1, it is possible to determine the nature of the adsorption process and also the feasibility of an adsorbent for the adsorption process [48].

The amount of adsorbate adsorbed by an adsorbent at equilibrium indicates the maximum adsorption capacity of the yeast at equilibrium. The equilibrium adsorption data can be analyzed using equilibrium

adsorption isotherm models. The most important isotherm models used for modeling the adsorption data are Langmuir and Freundlich [3][10][20][30][34][42][49].
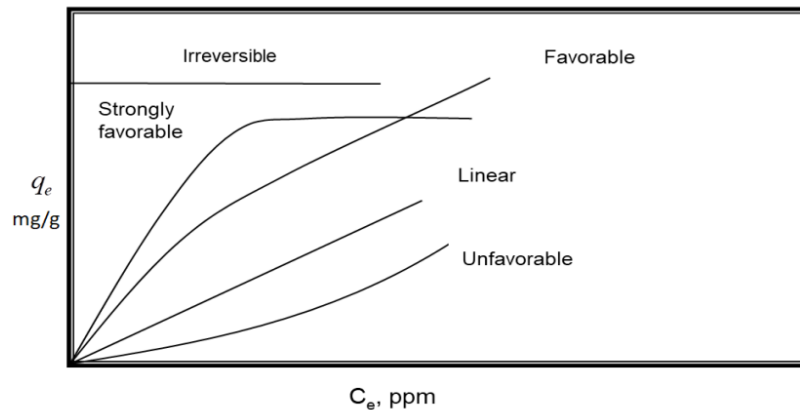

Figure 1 Adsorption isotherm types [48]

Langmuir isotherm model: This model suggested by Langmuir based on a homogeneous surface, which indicates the monolayers coverage of solute on the adsorbent (yeast) surface with an infinite number of uniform adsorption sites and it is described by the following equation [50]:

$$q_e = \frac{Q_m b C_e}{1 + b C_e} \tag{2}$$

The linear form of Langmuir isotherm equations is given below:

$$\frac{C_e}{q_e} = \frac{1}{Q_m b} + \frac{1}{Q_m} C_e \tag{3}$$

Where q_e is the adsorption capacity at equilibrium (mg/g), C_e the concentration of solute in aqueous solution at equilibrium (mg/l), Q_m is the Langmuir parameter related to maximum adsorption capacity (mg/g), and b is the Langmuir parameter related to adsorption free energy (l/mg). The Langmuir model cannot describe the adsorption process precisely, especially when the surface is heterogeneous [10].

The type of the adsorption isotherm type can be determined from the calculation of the so-called separation factor (R_s), using the Langmuir parameters and from Table.2 [51]:

$$R_s = \frac{1}{1 + b C_o} \tag{4}$$

Table 2 values of separation factor (R_s) and type of isotherm [51]

Rs	Isotherm type
Rs > 1	Unfavorable
Rs = 0	Linear
0 < Rs < 1	Favorable
Rs < 0	Irreversible

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Freundlich isotherm model is the first known relationship [52]. An empirical correlation assumed that the adsorption is non-ideal and reversible and can be occurred by forming multilayers on the heterogeneous surface of the adsorbent. The following equation can give this model:

$$q_e = K_F C_e^{1/n} \qquad (5)$$

The linear form of the Freundlich equation is:

$$log q_e = log K_F + \frac{1}{n} log C_e \qquad (6)$$

Where the Freundlich parameter: K_F and n represent the adsorption capacity and intensity, respectively. The Freundlich isotherm gives more precise results than that of the Langmuir for the heterogeneous adsorption process [10]. The experimental data of adsorption process in several kinds of literature that used yeast as adsorbent material for removal of heavy metals [14][20][24][27][29][30], dyes [6][8][32][33][34][35] and phenols [3][46][47] from water were correlated with Langmuir isotherm model and Freundlich isotherm equations. Most of the experimental adsorption data fitted well to the Langmuir model.

6.   Review of biomass adsorbent uses

The initial conditions of removal of different pollutants using natural biomass as natural adsorbent are illustrated in Table 3:

Table 3: the initial conditions of biosorption process using biomass adsorbent

Biomass adsorbent	Adsorbate	T °C	pH	C_o mg/l	W_t g/l	N r.p.m	Time	Isotherm model	q mg/g	References
Spirogyra	Cu	25	1-7	50-300	5-20		80 min	Langmuir	49.50	[11]
Cystosiera compressa	Cu, Pb	25	1-9	50-500	0.4-20	200	30-300 Min	Freundlich	----	[12]
argassum vulgare	Cu, Pb	25	1-9	50-500	0.4-20	200	30-300 Min	Freundlich	----	[12]
argassum vulgare	Cu, Pb	25	1-9	50-500	0.4-20	200	30-300 Min	Freundlich	----	[12]
Agaricus campestri	Cu, Pb	25	1-9	50-500	0.4-20	200	30-300 min	Freundlich	----	[12]
Saccharomyces Cerevisiae	Pb	30	1-6	25-100	5-35	50-200	----	Freundlich	2.34	[25]
Saccharomyces Cerevisiae	Cu	28	5	5-50	5	200	24 hr	Langmuir	4.73	[27]
Saccharomyces Cerevisiae	Pb, Zn, Cr, Co, Cu, Cd,	27	2-8	10-100	0.5- 1	200	5-180 min	Langmuir Freundlich	----	[30]
Saccharomyces Cerevisiae	Methyl orange dye	37	3-11	100-600	1-5	180	48 hr	-----	----	[1]
Saccharomyces Cerevisiae	Ramazole blue dye	25	1-6	100-600	1.2-5	180	1 hr	Freundlich	----	[35]
Saccharomyces Cerevisiae	Phenol	27	1-12	10-160	6-200	75 Strokes /min	4 hr	Langmuir	----	[3]
Saccharomyces Cerevisiae	Phenol	25	3-11	25-100	2	150	6 hr	Langmuir	17.96	[47]

7. Conclusion

From the above study, the following can be concluded:

1) Yeast is suitable for treating different types of wastewater due to its resistance to different conditions such as acidic environments or osmotic pressure.

2) Yeast is inexpensive, available adsorbents, and suitable for removing many kinds of pollutants like heavy metals, dyes, and organic materials such as phenols.

3) Through current research, research has confirmed the ability of yeast to remove many types of pollutants. Therefore, our future orientation will conduct a number of practical researches to prove the effectiveness of yeast in removing a number of pollutants, which are heavy elements, dyes and phenols from wastewater.

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