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Phenol removal multi cell small water treatment device

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ABSTRACT

A conical one body multi cell, multistage water treatment filtration devices are designed to realize a couple of different processes. Their properties can be used for different technological processes (filtration, ion-exchange, active carbon sorption, etc.). As an example, the devices are studied experimentally for effective technological removal of organic contaminants (phenols) from water using polymeric adsorbents, strong-base anion exchange and active carbon sorption materials. These attempts to combine three processes in one filtration body did show successful results, while the small water treatment devices still being affordably priced. The main contribution of these devices is that they have very compact simple design, simple operative procedures, reduced quantity of valves for treated water and reagent flow regulation. The conical shape of the conical one body multi cell multistage water treatment filtration device ensures linear flow rate to slow down on its path. This hydraulic phenomenon plays a positive role during the sorption processes. The devices could be used as a small water treatment module for local drinking water treatment, etc.

Keywords: Phenol removal; Small water treatment device; Multistage filter; Multi cell filter

1. Introduction

Phenol is found in drinking water, air, automobile exhaust, tobacco smoke, marijuana smoke, and certain foods including smoked summer sausage, fried chicken, mountain cheese, and some species of fish. At this time, phenol is found in at least 184 of 1177 hazardous waste sites on the National Priorities List (NPL) in the United States drinking water from contaminated surface or groundwater supplies [1]. Repeated exposure to low levels of phenol in drinking water has been linked with diarrhea and mouth sores in humans; eating very large amounts of phenol can result in death. Laboratory animals that drank very large amounts of phenol in water had muscle tremors and loss of coordination. When exposures involve the skin surface, the size of the total exposed skin can influence the severity of the toxic effects. Small amounts of phenol put on the skin of animals for short times can cause blisters and burns on the exposed area, and spilling weak phenol solutions on large parts of the body (more than 25% of the body surface) can result in death. The effects of exposure to phenol on human reproduction and the developing fetus are unknown. Pregnant animals that drank water containing high amounts of phenol gave birth to offspring that had low birth weights and birth defects. We do not know whether phenol causes cancer in humans, but cancer occurs in mice when phenol is put on the skin. When phenol is combined with other chemicals that cause cancer and put on the skin, more cancer may occur than when the other chemicals are put on alone.

Industrial water is one of the critical subjects that are addressed under newly enforced environmental regula-

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tion in the world. Wastewater has to meet certain conditions of composition and flowrate prior to discharge to some natural water basin. In addition water resources are going to be scarcer, especially in some parts of the world. Water demand is on the rise due to increase in population, industrial firms, agriculture, etc. Water recycling is therefore becoming an important strategy in preventing water resources, actually the whole world. Due to chemical and biological processing, industrial and public wastewaters may contain varieties of organic contaminants (phenol, etc.). Some of these contaminants can be removed from water by biological treatment, adsorption onto sorbents, or by air stripping. However very often the transfer of phenolic contaminants from water to other substances only temporarily shifts the problem since the contaminants are still present. Such treated wastewater flows dumped to natural water basins that are used for drinking water purification stations could create a technological problem and produced drinking water could be no good.

Chemical oxidation processes are widely used to treat drinking water, wastewater, groundwater contaminated with organic and some other toxic compounds (phenol, etc.). Direct oxidation of aqueous solutions containing organic contaminants can be performed under a variety of conditions ranging from ambient conditions to supercritical contaminants oxidation at very high temperature and pressures. The oxidation may occur via one of three general pathways [2]:

- hydrogen abstraction;
- electron transfer and radical addition [3]
- photocatalic oxidation (PO) of organic solvents [4]

Chen et al. [5] utilized photochemical technology to eliminate phenols and reduce COD in industrial wastewater. The US EPA [6] investigated the use of laser induced photochemical oxidation destruction of toxic organics in leachates and groundwater. In [7] the authors investigated the use of vacuum ultraviolet radiation produced by an immersed Xe-excimer light for oxidative degradation of organic pollutants in aqueous systems. Solar detoxification of dichloracetic acids was studied by Goslich et.al. [8]. Using UV/H_2O_2, UV irradiation produces very reactive hydroxyl radicals that have very high oxidating capacity and attack the organic pollutants randomly [9,10]. When phenol is exposed to UV it is converted to high boilers such as catechol or polymers. However UV degradation process requires large time and once through degradation is not possible. Large time means higher power consumption and a large reactor volume.

2. Experimental

The technology considered in this work is adsorption. Adsorption has proven to be an effective technology in removing organic contaminants from water. Treated water and regenerant elution solution flows of adsorbent recycling is becoming very positive cost-effective strategy. These technologies could reduce the time and could be more cost-effective. Polymeric resins and activated carbon are used to remove phenols from water and aqueous solutions [11–13]. Adsorption of phenol and chlorinated phenols as a method used to treat drinking water, wastewater, groundwater became very useful and important. These contaminants formed in many industrial processes are highly toxic and are very often resistant to technologically applied biological, chemical and other methods of water treatment mentioned above. Chlorinated phenols in particular are quite resistant to all these methods. The economic effectiveness of using adsorption technologies relies on process of regenerating the spent adsorption material. The used adsorption material can be regenerated many times using diluents or thermal regeneration by means of hot air at elevated temperature (if the adsorption material is active carbon).

The objective of this work is to investigate the treatment of phenolic wastewater or model phenol containing drinking water using different adsorption materials (polymeric resins and active carbon) by means of multi cell multi process water treatment devices created by us.

Polymeric resins used are Amberlite XAD macroreticular adsorbents [14,15]. These adsorbents are hard insoluble beads of porous polymer [16]. They are characterized by a spectrum of surface polarities which range from non-polar at one extreme to very highly polar at the other. Within the series of these adsorbents a variety of surface areas, porosities and pore size distribution is also represented. The pore structure of three non-polar and moderately polar adsorbents Amberlite XAD were determined by means of BET and mercury intrusion technique "Carlo Erba 1500". The results obtained are shown in Table 1. Owing to these differences in surface properties the Amberlite XAD adsorbents display a wide range of sorption behavior, a number of applications employing them (wastewater treatment as a major area, pharmaceutical field-to adsorb complex: organic protein species, enzymes, hormones etc.). Amberlite XAD-4 was found to be an outstanding adsorbent for phenol and chlorinated phenols (chlorophenol, dichlorophenol, trichlorophenol) removal from aqueous solutions [14,16]. At a flow rate of 5 dm^3/dm^3.h it adsorbs average 10.0–13.0 g.phenol/dm^3 adsorbent. It should be also mentioned that a salt background enhances the adsorption of phenols. This is true for all hydrophobic adsorption processes. For example, Amberlite XAD-2 and Amberlite XAD-4 are quite effective in adsorbing many organic contaminants from brines.

Discussing the sorption properties of polymeric adsorbents, it should be mentioned that flow rate is an important parameter in designing an adsorption process and device. At high flow rate early leakage is experienced.

The cost effectiveness of using adsorption technologies relies on the process of regenerating the adsorption material used. After a working sorption cycle, elution

Table 1
Pore-structure properties of the Amberlite XAD adsorbents

Amberlite XAD adsorbents	Total porosity by mercury porosimetry (cm^3/g)	Surface area(BET) (m^2/g)	Average pore radius (nm)	Dipole moment
Amberlite XAD-2	0.634	294.8	2.5	0.3
Amberlite XAD-4	0.973	782.1	3.0–3.5	0.3
Amberlite XAD-7	1.137	449.1	4.5–5.0	1.8

of phenol was accomplished well with aqueous sodium hydroxide. This illustrates the principle that an ionized species is much less strongly adsorbed than neutral one. To regenerate the adsorbents, a low concentration of caustic was desirable because high concentrations tend to "salt on" the phenol adsorbed and are actually less effective elution agents. However, the concentration was not to low as then to many bed volumes eluant should be used to provide sufficient caustic to neutralize the phenol. For complete elution 4 bed volumes of elution agent was desired (≈ 0/2–0.4% appears to be the optimum concentration of eluant).

An important consideration in choosing an adsorbent is the effect of multiple cycling on the adsorbent capacity. Extensive loss of capacity due to irreversible sorption is obviously understandable. The change in phenol capacity of Amberlite XAD-4 was opposite. With multiple cycling the original phenol capacity was not lost and actually increased slightly in later cycles (Fig. 1).

The objective of this work is to investigate the treatment of phenolic wastewater or model phenol containing drinking water using different adsorption materials (polymeric resins and active carbon) by means of multi cell multi process water treatment devices (conical and cylindrical) created by us. The idea was to investigate the effect of linear flow rate on the technological behavior of filters. The construction of the device allows regeneration of the exhausted sorption beds to be made on the basis

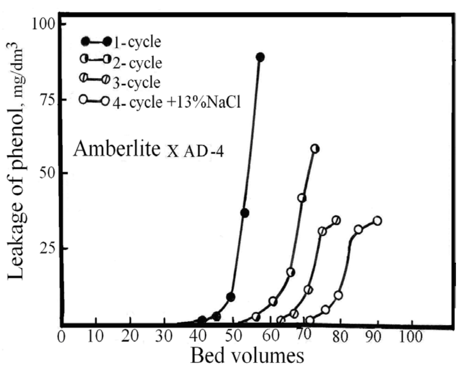
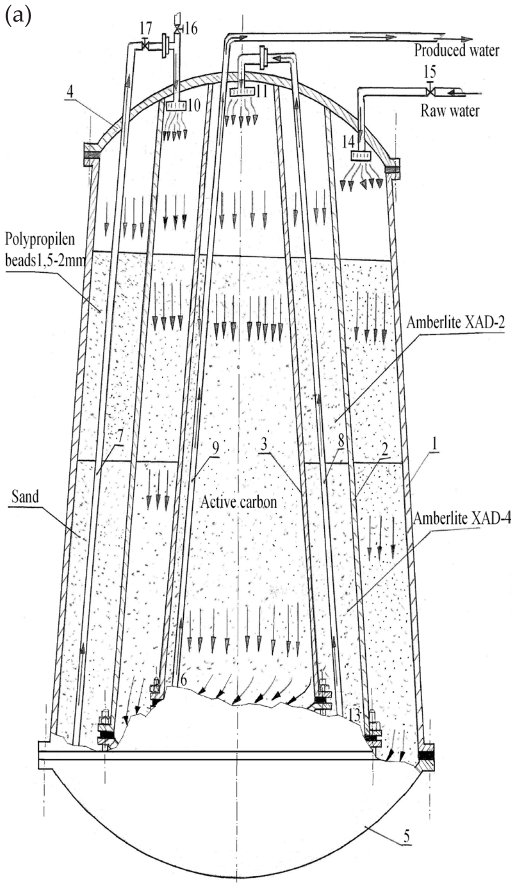


Fig. 1. Effect of multiple cycling upon phenol capacity of Amberlite XAD-4 during phenol adsorption from aqueous phenol solution with concentration C = 250 mg/dm^3.

of gravitation phenomenon, locally by the user. We tried to create these multi cell conical and cylindrical small water treatment devices with a simple, cost-effective and user friendly application. Its technological behavior and effectiveness depend on the linear flow rate of treated water during a working period and during the regeneration period. It was our motive to create a conical one body multi cell, multistage water treatment filtration device and a cylindrical one body multi cell multistage water treatment filtration device. Then we carried out experiments with the same parameters, the same loaded filtration materials, the same flow rate, etc. It is known that the linear flow rate is an important parameter in designing adsorption technologies. The conical shape of our device actually provides reducing of a linear flow rate on flow path caused by enlargement diameter of the conical shape of this three cell device. Treated water flow or regenerant regeneration flow passes the entrance with a small diameter and goes out through an outlet with a larger diameter. Passing is realized at the same flow rate but at a different (smaller) linear flow rate.

The design of the devices is shown in Fig. 2. They consist of three separated conical (or cylindrical) cells which can be loaded with different filtration and sorption materials. It has only three valves for treated water and regeneration flow control and regulation (Fig. 2). As an example of filtration–sorption variant, the cells of both devices were loaded with materials written on the sketch (polypropilen beads, sand, Amberlite XAD-2, Amberlite XAD-4, active carbon).

The sorption process technology is known and used for phenol removing from aqueous solutions Amberlite XAD-4 [15,16]. From a scientific point of view it was very important to clarify the influence of the physical (pore) structure of adsorbents [17–20] and to evaluate the effect of used linear flow rate on the ability to be effectively regenerated and washed from the phenol, chlorinated phenols and organic humus substances retained into their pore structure during the working functional period of drinking water treatment. The effect of linear flow rates depending on a construction of phenol removing device should also be discussed. As an example for functionality, the multi process small water treatment filtration devices loaded with materials mentioned above have been designed to provide uncompromising phenol con-



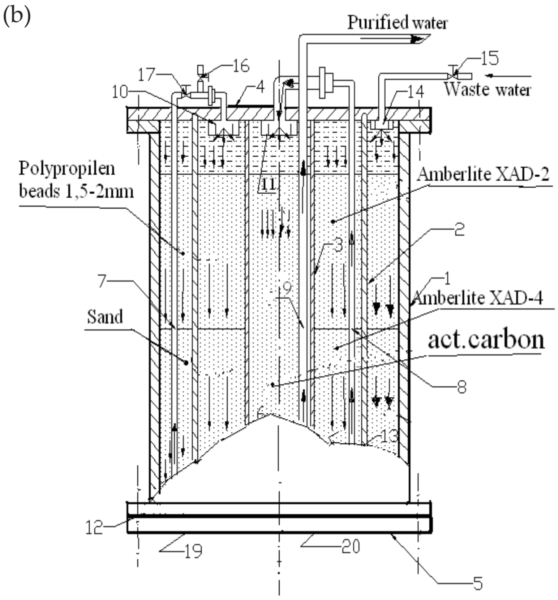


Fig. 2. Principal schemes of conical (a) and cylindrical (b) multi cell small wastewater (or natural phenol contaminated water) treatment devices: 1 – outside conical body; 2 – first inside conical body; 3 – second inside(central) conical body; 4 – upper cover; 5 – lower cover; 6–9 – communicative tubes; 10–14 – nozzles; 15–17 – valves.

taminated water purification and quality while still being affordably priced.

In the investigated cases, the three cell filtration body was not loaded solely with granular polypropilen filtration material, sand, polymeric adsorbent resins and active carbon sorption material. Actually, the devices were experimented for sand filtration and sorption of local water treatment devices that might be loaded and used with different filtration materials depending on the technological purpose. They were used to treat model drinking water polluted with phenol. In order to compare technological behavior, the filtration devices were loaded with ion exchange resins and polymeric adsorbents as shown in Tables 2 and 3.

It was found that adsorption capacity of anion exchangers OH-ion groups is much higher than that of Cl-ion form. After a couple of sorption cycles the anion exchangers lost their capacity [21]. The best technological behavior was shown by polymeric adsorbent Amberlite XAD-4, followed by Amberlite XAD-2 and Amberlite XAD-7 (Table 1).

The devices were loaded with materials written on the sketch and device features and price were optimized, and the performance of the conical device did show more positive results.

The regenerants eluting agents used were as follows:

- Water miscible organic solvents: methanol, ethanol, acetone (for hydrophobic impurities elution
- Pure solvents for regenerating resin fouled by oil and antifoams
- Dilute bases (NaOH 0.2–0.4%) for phenol and other weakly acid impurities elution
- Strong bases (NaOH 2–4%) for regenerating resins fouled with proteins, peptides

3. Conclusions

1. Multi cell conical small water treatment devices with a simple, cost-effective and user friendly application are created. Their technological behavior and effectiveness depend on a linear flow rate of treated water during the working period and during the regeneration period. The conical shape enlargement diameter of the conical device actually provides linear flow rate reducing a flow path caused by this shape.

2. The functions of the devices are experimented by means of difference sorption materials (polymeric adsorbents without ion exchange functional groups and different types of anion exchange resins). Polymeric adsorbent Amberlite XAD-4 shows the best technological behavior.

Table 2
Results obtained by model phenol containing drinking water treatment using different adsorption materials loaded in cylindrical (b) multi cell small waste water treatment device: concentration 250 mg/dm^3, linear flow rate CH = 5 dm^3/dm^{3}h, temperature = 20°C

Loaded material	Ads. capacity "0" leakage (g.phenol/dm^3 sorbent)			Bed volumes up to "0" leakage		
	Cycles			Cycles		
	I	II	III	I	II	III
1. Polymer sorbents						
Amberlite XAD-2	4.2	4.1	4.1	17	16.2	16.2
Amberlite XAD-4	9.8	11.1	12.7	39	44.4	51.8
Amberlite XAD-7	3.6	3.2	3.2	14.5	13	13
Wofatit Y-29	2.7	2.0	1.4	11	8	8
2. Strong base anion exchangers (OH–form)						
Duolite A101D	75.7	68.3	42.1	303	273	168
Varion ATM	74.2	66.9	35.7	297	267	143
Wofatif SZ-30	59. 2	57.1	29.3	237	143	117

Table 3
Results obtained by model phenol containing drinking water treatment using different adsorption materials loaded in conical multi cell small wastewater treatment device: concentration 250 mg/dm^3, linear flow rate CH = 5 dm^3/dm^{3}h, temperature = 20°C

Loaded material	Ads. capacity "0" leakage (g.phenol/dm^{3}sorbent)			Bed volumes up to "0"leakage		
	Cycles			Cycles		
	I	II	III	I	II	III
1. Polymer sorbents						
Amberlite XAD-2	5.4	4.9	5.0	21.7	19.5	20.1
Amberlite XAD-4	11.2	12.9	13.6	44.8	51.4	54.5
Amberlite XAD-7	3.9	3.6	3.6	15.5	14.4	14.4
Wofatit Y-29	2.9	2.4	1.7	11.6	9.6	149
2. Strong base anion exchangers (OH –form)						
Duolite A101D	78.2	69.7	44.5	312.6	278.9	7.0
Varion ATM	77.4	68.6	37.2	309.5	274.2	178
Wofatif SZ-30	61.2	59.3	30.9	245	237	123

3. Preferably used small water treatment device should be with a conical shape loaded with polymeric adsorbent Amberlite XAD-4.

4. The multi cell small water treatment devices have three separated vertical cells. This property allows us to load there different sorption and anion exchange materials without contacting each other during the water treatment and regeneration periods, avoiding an abrasive destruction of sorption beads. This property allows also regenerating different ion-exchange or sorption materials without removing them outside. It is a better property as compared to the so called "mixed bed filters".

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