ILLUSTRATING ENGINEERING CONCEPTS WITH A HOUSEHOLD WATER FILTER

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Abstract
Filtration and other methods of treatment of household drinking water supplies have become common in order to prevent the potential health hazards that can be caused by the untreated tap water. Filtration is been done at several stages based on the requirements from the government body, using different types of water filters. The most common small scale water filters used in homes use activated carbon filtration along with an ion exchange resin. In this paper, we discuss several mechanical and materials engineering concepts that can be demonstrated using an inexpensive household water filter pitcher. This experiment is developed for a sophomore level engineering audience. A commercially available filter used in water pitchers is analyzed in this experiment. The filter consists of activated carbon and ion exchange resin enclosed in a cylindrical body. The pitcher and its filter element are used to perform flow rate calculations, particle size measurement and pH calculations. Also, the experiment helps the student to learn about the purification processes and the importance of activated carbon and ion exchange resins in the field of separation and purification.

Introduction
The use of everyday life experiences serves as a great pedagogical tool for students being exposed to engineering concepts for the first time - much like a gourmet chef's description of the preparation of their favorite dishes with "a little bit of this and little bit of that."[1]. This kind of flexible approach helps the students to develop their critical thinking skills. Pithers and Soden[2] found that college graduates are expected to learn not only the content and methods of a discipline but also to develop 'generic' abilities. These generic abilities include a heavy emphasis on critical thinking skills. Potential employers also place a high priority on critical thinking skills. In a survey of industry experts and faculty, Maricle[3] found that critical thinking was the highest rated competency expected of new college graduates. We describe here a simple but effective experiment targeted at sophomore level engineering students to engage them in critical thinking by the use of active learning methods.

A commercially available pitcher-style water filter is used for this experiment. The replaceable filter element or candle consists of activated carbon particles and ion exchange resin particles in a cylindrical plastic container that fits into the clear body of the plastic pitcher. Carbon and resin particles are most widely used in separation and purification purposes. The activated carbon particles work on the adsorption principle, the trapping of impurities by strong physical bonds within the porous structure of carbon A formal definition of adsorption[4] is "The adhesion of the molecules of gases, dissolved substances, or liquids in more or less concentrated form, to the surface of solids or liquids with which they are in contact."

Commercial adsorbent materials such as carbon have enormous internal surfaces. Activated carbon has the highest volume of adsorptive porosity of any material known. Because of its large surface area (1 quart of granules = 6 football fields[5]), activated carbon has a great ability to adsorb organic molecules of liquids or vapors. Thus, when organic contaminated water is passed through activated carbon, the contaminants are attracted and held to the internal surface walls of the pores (Fig. 1). The contaminants get adsorbed because the attraction force of the carbon surface is stronger than the forces that keep them in solution. Also, large volumes of gases, including most poisonous ones, adhere to the activated carbon particles. Thus, due to its enormous adsorption capabilities, activated carbon is popularly used in many purification applications. Moreover, the activated carbon is very economical and easily available. Various grains and seed husks include rice[6,7], cotton-seed shell[8], wheat, sunflower, flaxseed, linseed, corn, soybean cake, jute stalk and grape marc can be pyrolyzed to a char at low temperature. Steam activation then results in activated carbon. The carbon applications is widely used in different industries apart from water purification like food-waste management, anti-nutrients or toxin removal, sugar substitute purification, frying oil treatment, plant cell tissue culture media, enzyme immobilization supports, pharmaceutical antidotes and fermentation process isolations.

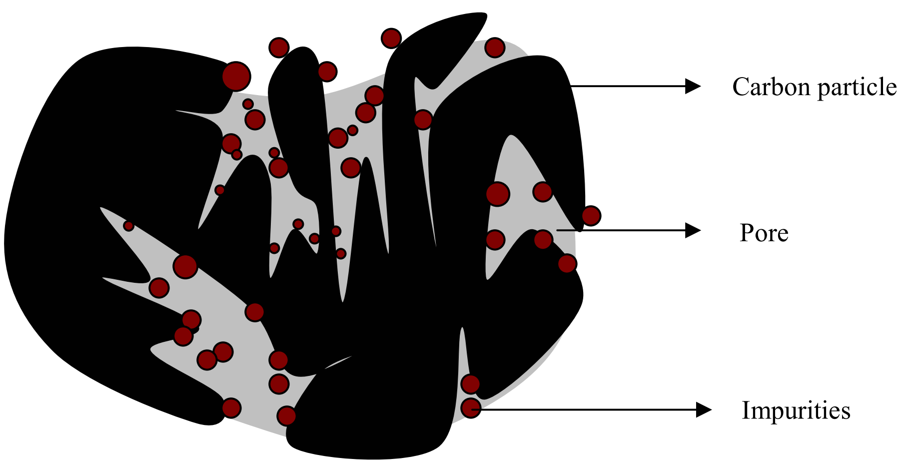


Fig. 1. Activated carbon granule shown with the adsorbed impurities

The ion exchange process percolates water through bead-like spherical resin materials (ion-exchange resins). Ions in the water are exchanged for other ions fixed to the beads. The two most common ion-exchange methods are softening and deionization. Softening is used primarily as a pretreatment method to reduce water hardness prior to reverse osmosis (RO) processing. The softeners contain beads that exchange two sodium ions for every calcium or magnesium ion removed from the "softened" water. Deionization (DI) beads exchange either hydrogen ions for cations or hydroxyl ions for anions. The cation exchange resins, made of styrene and divinylbenzene containing sulfonic acid groups, will exchange a hydrogen ion for any cations they encounter (e.g., Na^+, Ca^{++}, Al^{+++}). Similarly, the anion exchange resins, made of styrene and containing quaternary ammonium groups, will exchange a hydroxyl ion for any anions (e.g., Cl^-). The hydrogen ion from the cation exchanger unites with the hydroxyl ion of the anion exchanger to form pure water. These resins may be packaged in separate bed exchangers with separate units for the cation and anion exchange beds. Or, they may be packed in mixed bed exchangers containing a mixture of both types of resins. In either case, the resin must be "regenerated" once it has exchanged all its hydrogen and/or hydroxyl ions for charged contaminants in the water. Ion exchange resins are also widely used in different applications like, corn syrup treatment, water treatment, citrus fruit juice debittering, dye removal from waste water, removal of organic from gases, sugar refining industry and metal recovery process.

Principle

This experiment is designed to be offered to sophomore level mechanical engineering students in their first departmental lab course MEEN 300 – Mechanical Engineering Lab I. The experiment is designed for the basic understanding about the

- Filtration process carried out using a pitcher water filter
- Working principle and the application of activated carbon particles and ion exchange resin
- Flow rate calculations
- pH value measurement and its importance
- particle size measurement using a sieve scale

Experimental Procedure

Fig. 2. A household water pitcher and its filter element

(i) Flow rate measurement:

Flow rate measurement is a direct measurement of water flow through the filter. Water is poured into the filter container for purification. Different filters have different flow rates. Also, the flow rate changes over the lifetime of the filter. In our case, we compared the flow rates for two different brands of residential water filter pitchers. The flow rate is calculated based on the time taken for a fixed amount of water to flow through the filter. The experiment can be repeated for different amounts of water (in our case, 0.5 liter and 1 liter). Sample readings are shown. The students from their own calculations learn that flow rate depends on the starting quantity of liquid (the head) and not just on the size of the filter.

	Fluid Quantity (l)	Time (s)	Flow rate (l/min)
Filter A (Using Brita Filter)	0.5	88	0.341
	0.5	92	0.326
	0.5	91	0.330
	1.0	167	0.359
	1.0	159	0.377
	1.0	182	0.330
Filter B (Using Pur Filter)	0.5	101	0.297
	0.5	101	0.297
	0.5	110	0.273
	1.0	161	0.373
	1.0	181	0.332
	1.0	194	0.310

(ii) pH value measurement

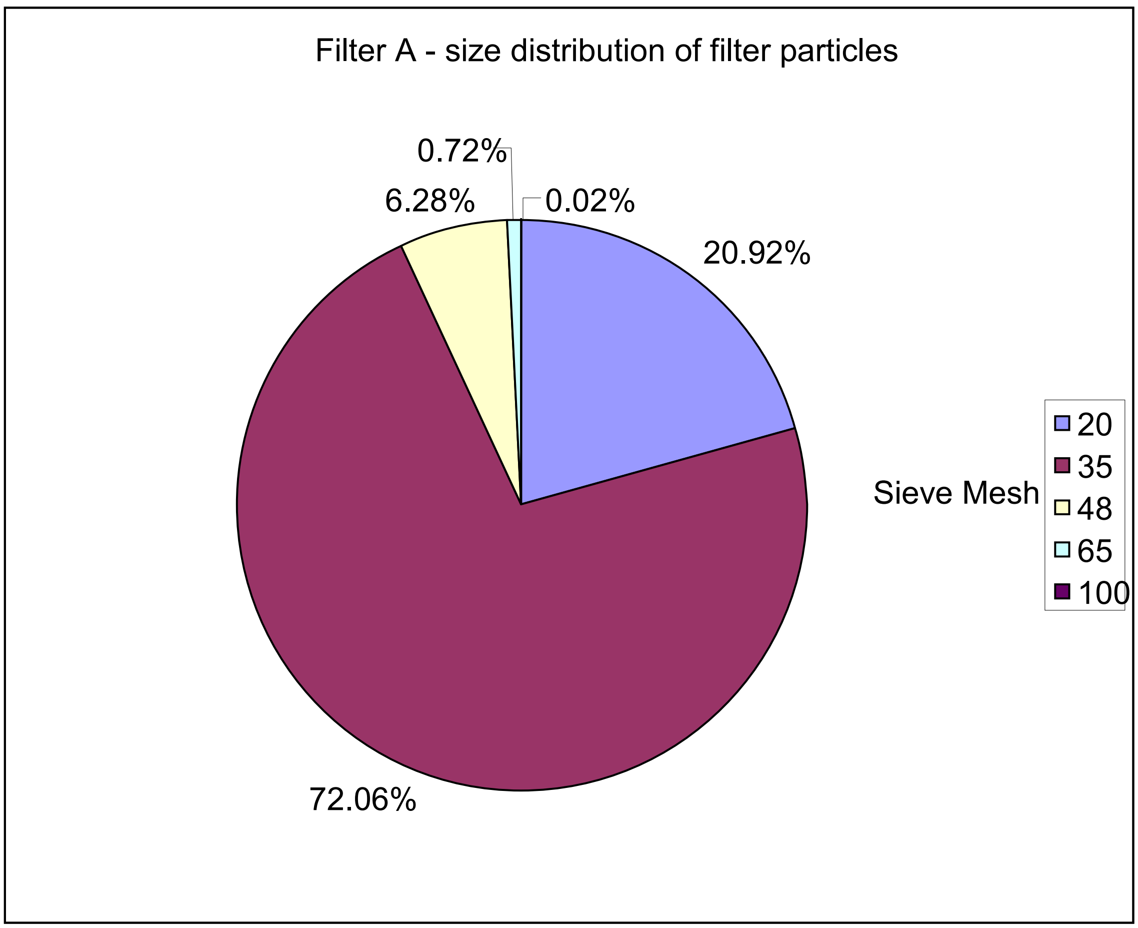
The pH test is one of the most common analyses in water testing and a great indicator of water quality. pH indicates the sample's acidity or alkalinity by measuring the relative amount of hydrogen (H) and hydroxyl (OH) ions in the water. Water that has more H ions is acidic, whereas water that has more OH ions is basic or alkaline. pH measurements runs on a scale from 0 to 14, with 7.0 considered neutral. Solutions with a pH below 7.0 are considered acids and those between 7.0 and 14.0 are considered bases. Values from 6.8 to 7.5 are ideal for drinking water. In our case, the pH value was measured using meter by Thermo Orion (Model 310 PerpHect LogRmeter). The unfiltered water had a pH of 7.43 (slightly alkaline) The sample data below shows how the age of the filter element strongly affects the acidity of the filtered water, emphasizing the need to replace filters after their useful life. This particular aspect can be studied at length over the semester and a plot obtained of effect of number of uses of the filter on the acidity of the filtered water.

Test #	Filter A	Filter B
1	6.35	6.32
2	6.38	6.35
3	6.36	6.33
Average	**6.363**	**6.333**

(iii) Particle size measurement

The carbon and the resin particles present in the filter are not of uniform size, rather the follow a distribution. Students are exposed to the use of In order to have a general idea about the particle size distribution present in the different filters, the filters will be cut open for particle size calculations. There are several different ways of determining particle size. The method used in this experiment is that of dry sieving. The sample (carbon and resin particles) is shaken mechanically through a stack of metal sieves, of decreasing mesh size. The sediment caught in each sieve is weighed and expressed as a percentage of the total weight of the original sample. Students are made to plot pie charts or histograms of the particle size distribution. This is of pedagogical use as the students get exposed to interdisciplinary concepts such as environmental engineering and catalysis.

Sieve mesh size	Weight of particles retained (g)	% wt retained
20	14.56	20.92%
35	50.15	72.06%
48	4.37	6.28%
65	0.50	0.72%
100	0.013	0.02%
Total	**69.593**	**100**



Conclusions

The study on water filter is a simple experiment but the student gets exposed to a lot of information. The experiment gives a basic understanding about the flow rate calculations, pH measurement and the particle size calculations. The flow rate measurement deals with the fluid mechanics while the pH measurement enhances the student's basic chemistry knowledge. The particle size measurement is a common experiment carried out by materials engineer to study the particle size distribution to ensure the properties of the material match the requirements of the applications. Apart from the fundamental understanding, the experiment also helps the student to understand the application of carbon particles and the ion exchange resins in the different industry. In general, this experiment heightens the students' awareness of the high level of technology that go into seemingly innocuous and low-tech kitchen gadgets and gets them to relate fundamentals learned in the classroom to their everyday experiences.

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