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Modular On-Demand Water Purification for Developing Countries

2020-2021 ChemE Cube Problem Statement

Document Revision History

Version (Date)	Comment
1–7 (2020)	Pre-release drafts
8 (January 2021)	Initial release

Business Objective

Water is essential for human life in more ways than just drinking and is often taken for granted by those with ready access to clean and safe water supplies. Not everyone in the world is fortunate enough to have direct access to a clean and safe water—your cube design may have an impact here.

Limited access to clean water is seen in many places in the developing world and at times also in the developed world (e.g., during a disaster). An example is Ethiopia, the second-most populated country in Africa[1]. While having made significant progress in economic development over the past decade, Ethiopia remains among the poorest nations in terms of GDP per capita in 2019[2] and with only 39% of the population having at least basic access to water in 2015[3]. This leaves an estimated 70 million people without enough clean water to drink, to wash clothes, and to use for cooking and cleaning without having to make a 30 minute (or more) round trip for clean water. Multiple trips for water are typically required per day for an average family of 5 as of 2017[4]. According to the UN, the average person carries 50 to 100 L per day[5]. This means that an average household can haul 250-500 L of water per day. Time taken to make trips for water leaves less time for education and other pursuits, and often disproportionately impacts women and children. Similar statistics have been found in other places in sub-Saharan African and around the world.

The competition will focus specifically on drinking water, as it requires the highest purity and is the most basic need. According to the UN[5], a lactating woman has a recommended daily intake of 7.5 L of water. An adult male and female are recommended to consume 3.7 L and 2.7 L of water per day, respectively, according to Mayo Clinic[8], meaning an average household could require approximately 14–22 L per day, assuming up to one lactating woman and 4 men or women.

You are tasked with creating a modular, on-demand surface water treatment mini-plant that can fit inside a 1-foot cube and can purify at least 25 L of surface water per day, meeting the relevant drinking water standards (e.g., EPA's national primary drinking water standard[6] and others), with cost for materials of 1500 USD or less for your first-of-a-kind prototype.

It is expected that such a cube could be built in a developed country and deployed as part of a humanitarian effort or built in the developing world using artisanal factories as part of an enterprise solution to poverty. In either case, the design will be sensitive to cost, as the cube is intended primarily for users living in moderate to extreme poverty. Profitability of the cube is important for its economic sustainability along the value chain (e.g., an artisanal factory being able to turn a profit selling cubes, or a cube purchaser being able to achieve a reasonable payback time by offering on-demand clean water to customers).

Technical Objectives and Data

Cubes will be supplied with DC current only as to allow for the use of off-grid power sources such as solar or wind power. Each team must include their required electrical current (not to exceed 10 Amps) in their team's Engineering Design Package (EDP). Regulated 12 V DC power will be provided for the competition.

The teams must purify the challenge water to produce 90 mL of water within 5 minutes that satisfies the requirements listed in Table 2 to meet the required flowrate of 25 L per day, or approximately 18 mL per minute.

The challenge water, which represents a worst case scenario for collected fresh, surface water, can be assumed to contain the following microbial pathogens:

1. Bacteria (e.g., E. coli) ≥ 10^7 cfu (colony forming units) per 100 mL
2. Virus (e.g., MS2 coliphage) ≥ 10^7 pfu (plaque forming units) per L
3. Oocyst (e.g., Cryptosporidium or Giardia) ≥ 5 x 10^4 per L

In addition, the challenge water can be assumed to have these other properties:

4. Background chlorine: ≤ 0.1 mg/L
5. pH: 7.0 ± 0.5
6. Total Organic Carbon (TOC): 10–15 mg/L
7. Turbidity: 50–100 NTU
8. Temperature: 20 ± 5°C
9. Total Dissolved Solids (TDS): 1500 ± 300 mg/L

<u>Challenge Water for Competition</u>

Table 1 lists the challenge water specifications that will be used for the competition. Several substitutions will be made based on safety considerations. Brewer's yeast will be used as a surrogate for bacteria, and 6-micron polymer microspheres be used as a surrogate for oocysts.

A virus simulant will *not* be used in the challenge water recipe, but potential for virus contamination must be addressed in the cube design.

In addition, the challenge water will include sodium chloride to adjust the TDS, an ISO standard fine test dust to adjust turbidity, tannic acid to adjust TOC, a nearly neutral pH, and near ambient temperature. Table 1 lists the recommended amounts of additives for testing your ChemE Cube. **Please use deionized or distilled water** to prepare the challenge water for testing purposes. Organic carbon, dissolved solids and turbidity are added to simulate real world constituents of surface waters that can affect taste and make removal or deactivation of pathogens more challenging. Challenge water will be provided on the day of the competition.

Table 1: Challenge Water Characteristics/Components

Component	Amount/Value	Purpose	Notes
Brewer's Yeast	$\geq 10^7$ per 100 mL	Surrogate for bacteria	Champagne yeast recommended. Deactivated with heat prior to competition to stabilize concentration.
—	$\geq 10^7$ per L	Theoretical virus loading	Virus not included in challenge water, but must assume it is present
Polymer microspheres	$\geq 5 \times 10^4$ beads per L	Surrogate for oocysts	6 µm polystyrene microspheres; from source 12 w/ modification
Chlorine	≤ 0.1 mg/L	Background chlorine	Adjustment should not be necessary if using DI/distilled water
NaOH/HCl	Adjust for pH of 7.0 ± 0.5	Adjust pH	Adjustment should not be necessary if using DI/distilled water
Tannic Acid	10-15 mg/L	Adjust TOC	From source 12
Test Dust	Adjust to 50-100 NTU	Adjust Turbidity	Use ISO 12103-1, A2 fine test dust
Temperature	20 ± 5°C	Simulate typical ambient	Effectiveness of some disinfection methods depend on temperature
NaCl	1500 ± 300 mg/L	Adjust TDS	From source 12

Requirements of Purified Water

Table 2 lists the purity standard that your cube's treated water should attain per the EPA's national primary[6] and secondary[9] drinking water regulations, the NSF P248 standard[12], and other related guidelines and standards. Your cube will be judged on the ability to meet or exceed this purity standard at a flow rate of 25 L per day, or approximately 18 mL per minute, and other criteria defined in the judging rubric. Specifically, your cube must reduce turbidity and microbiological pathogens by the amounts listed in Table 2, while maintaining acceptable concentrations of disinfectant and a neutral or near-neutral pH.

Typical methods for water purification include pathogen removal (e.g., filtration) and pathogen deactivation (e.g., chemical or other method of disinfection to render the pathogen not viable). Different types of pathogens respond differently to these treatment methods; for example, virus particles tend to be small (~100 nm) and more difficult to remove by filtration. Meanwhile, oocysts are larger but more robust and difficult to deactivate with chemical means. Because inactive surrogates will be used in the competition (microspheres for oocysts and deactivated yeast for bacteria), treatment methods must focus on removal rather than deactivation for these pathogens. Regarding viruses, because of difficulties enumerating viruses in the treated water and lack of a suitable surrogate, teams should devise and implement a strategy for deactivating viruses, which may reasonably be present in real-world collected, surface waters. If chemical disinfection is used, teams must show that the chemical disinfectant is dosed properly. If teams select a chemical disinfectant other than chlorine, the teams must provide the judges a fast, inexpensive test kit for use during the competition. The test kit should be described in the EDP. If non-chemical disinfection is used, teams should provide suitable evidence of its efficacy as part of the Poster presentation.

Table 2: Purified Output Water Requirements

Contaminant	**Reduction/ Maximum Level**	**Notes**
Bacteria (Brewer's yeast surrogate)	Log reduction of 6	99.9999% removal[12]
Virus (no surrogate)	Log reduction of 4	99.99% deactivation[12]
Oocyst (Polymer microspheres surrogate)	Log reduction of 3	99.9% removal[12]
Chlorine (if applicable)	4.0 mg/L; 0.8 mg/L; 250 mg/L	As Cl_2 or chloriamines; as chlorine dioxide[6]; as chloride[9] (see text if other disinfectant is used)
pH	7.0 ± 0.5	Secondary water regulation[9]
Turbidity	5 NTU	Recommendation from the Sphere handbook[11]

Other Criteria

In additional to these water quality performance metrics, size, weight, and power (commonly SWaP) are important for small, deployable systems like the cube. While size is fixed by the 1 × 1 × 1 ft cube constraint, power consumption and weight will also be criteria judged head-to-head in the duel. Also note that cubes smaller than 1-ft^3 are undesirable due to a preference for standardizing to a common form factor for stacking and transport. If possible, rather than make the cube smaller, it is preferred to increase the throughput (within a reasonable range up to *ca.* 2X the spec), and this will also be judged head-to-head. See the cube demo rubric for more details.

Sources

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