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# An Inexpensive Recirculating Water Vacuum Pump for the Chemistry Laboratory

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**ABSTRACT:** A recirculating water vacuum pump was constructed from inexpensive materials. The recirculating water vacuum pump has a smaller footprint compared to many commercial models and features a novel, 3D-printed water aspirator pump that also functions with a standard laboratory faucet connection. The performances of both the recirculating water vacuum pump and (faucet) water aspirator pump are comparable to commercial models. The total cost of the recirculating water vacuum pump is approximately $44, excluding the cost of a 3D printer and filament.

**KEYWORDS:** *General Public, Interdisciplinary/Multidisciplinary, Laboratory Instruction, Hands-On Learning/Manipulatives, Laboratory Equipment/Apparatus*



## ■ INTRODUCTION

Laboratory equipment is often expensive and, in turn, is often unavailable at institutions with small budgets. The development of open-source and low-cost alternatives has always been scholarship valued by the *Journal of Chemical Education* (*JCE*), not only as hands-on teaching and learning opportunities, but also as service to the larger chemistry community. In this regard, the impact of the availability of 3D-printing technology has been extraordinary.[1,2] Recent examples of 3D-printed devices or components for the chemistry laboratory include an AIRduino, a dual beam spectrophotometer, a reference electrode shell, a mesoreactor, and a pH sensor for the visually impaired.[3−7]

Water aspirator pumps (Figure 1a) are not uncommon in the teaching laboratory as they provide a reliable source of moderate vacuum for chemistry applications in the absence of a vacuum pump or house vacuum system. These aspirators are typically made from metal or plastic with male 3/8 in. National Pipe Thread Tapered (NPT) faucet connections and include built-in check valves to maintain vacuum pressure when water flow is disrupted and to prevent water backflow. Albeit inexpensive (~$20), water aspirator pumps are water-wasteful and can potentially contaminate wastewater with volatile solvents. Recirculating water vacuum pumps (Figure 1b), often used with rotary evaporators, include a circulating pump, water tank (10−20 L), built-in check valves, and multiple taps/suction nozzles, and they quickly generate a stronger vacuum. Recirculation minimizes water consumption, but vacuum pumps of this type are substantially more expensive ($250−$1300).

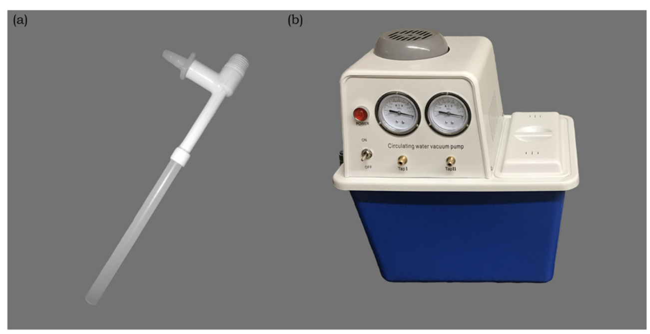


**Figure 1.** (a) Water aspirator pump. (b) Recirculating water vacuum pump.

Low-cost and/or alternative apparatuses for laboratory tasks requiring vacuum have been reported in *JCE*[8−12] and elsewhere.[13] In this paper, we describe the design of a 3D-printable water aspirator pump that functions effectively in a recirculating water vacuum pump or attached to a laboratory

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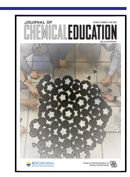

faucet, the construction of a recirculating water vacuum pump, and the performance testing of the recirculating water vacuum pump and (faucet) water aspirator pump against commercial models.

## ■ WATER ASPIRATOR PUMP DESIGN AND 3D-PRINTING

Aspirators, also called eductors, Venturi pumps, or jet pump ejectors, have three basic components: a nozzle, a throat, and an exit tube/diffuser (Figure 2). Water forced through the

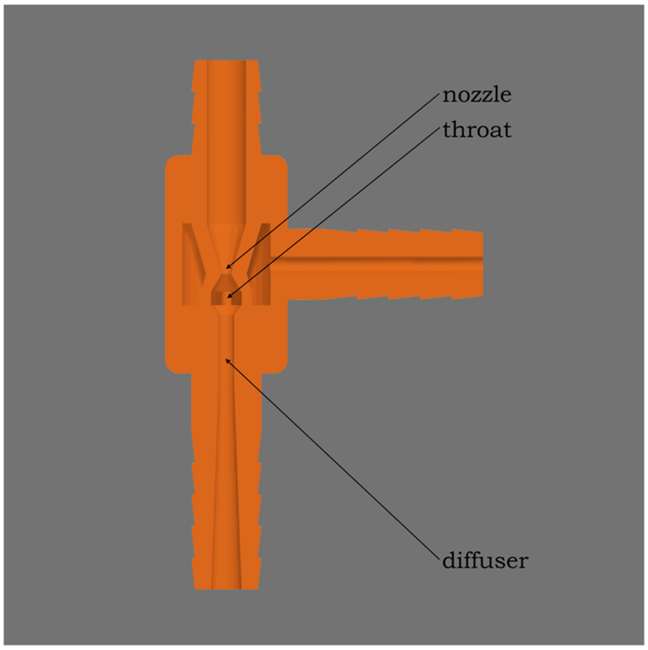


**Figure 2.** Water aspirator pump model.

nozzle into the throat creates a differential pressure, drawing air from the side arm connected to the air space in the throat in order to equalize the pressure (the Venturi effect). Consequently, the depth of vacuum is limited by the vapor pressure of water.[14] In a commercial water aspirator pump, the side arm includes a ball or diaphragm check valve to maintain vacuum pressure when water flow is disrupted and to prevent water backflow. Our water aspirator pump design does not incorporate a built-in check valve. Exclusion of a check valve simplified the design, expediting the prototyping process, and yielded a fully functional 3D-printed water aspirator pump that does not require assembly. However, our water aspirator pump does require a trap in the event of water backflow or an inline check valve (e.g., a fuel check valve) to prevent water backflow *and* to maintain vacuum pressure if water flow is disrupted.[15]

The water aspirator pump model was designed in FreeCAD 0.17 (open-source computer-aided design (CAD) software, https://www.freecadweb.org/), sliced with Ultimaker Cura 4.1.0, (open-source 3D-printing software, https://ultimaker.com/), and printed on a fused deposition modeling (FDM) 3D printer (Wanhao Duplicator i3 mini, https://www.wanhaona.com/). Although a stereolithography (SLA) 3D printer would print with higher dimensional accuracy, FDM printers are more common and more affordable. The i3 mini (~$200) is a hobbyist-level 3D printer that accommodates polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), poly(vinyl alcohol) (PVA), polyethylene vinyl acetate (PEVA), and high-impact polystyrene (HIPS) filament. The water aspirator pump was printed in PLA with support structure and with a fine resolution (0.06 mm layer height) to reduce dimensional inaccuracies (a byproduct of the tolerance(s) of the 3D printer and/or filament). At this resolution, the dimensions of the 3D-printed water aspirator pump were within ±0.03 mm of the CAD model dimensions (i.e., within the uncertainty of the digital calipers). Although PLA was ideal for prototyping a functional water aspirator pump (inexpensive, easy to print, and high dimensional accuracy when 3D-printing), PLA has only modest chemical resistance and mechanical strength.[16] Consequently, an alternative plastic should be considered for long-term use, e.g., polypropylene (PP). However, printing with a different plastic, such as PP (which warps when cooled), or with a lower resolution may require adjustments to obtain a working model. Adjustments can be made with the "Horizontal Expansion" setting in Ultimaker Cura, or the equivalent of this setting in the preferred 3D-printing software.

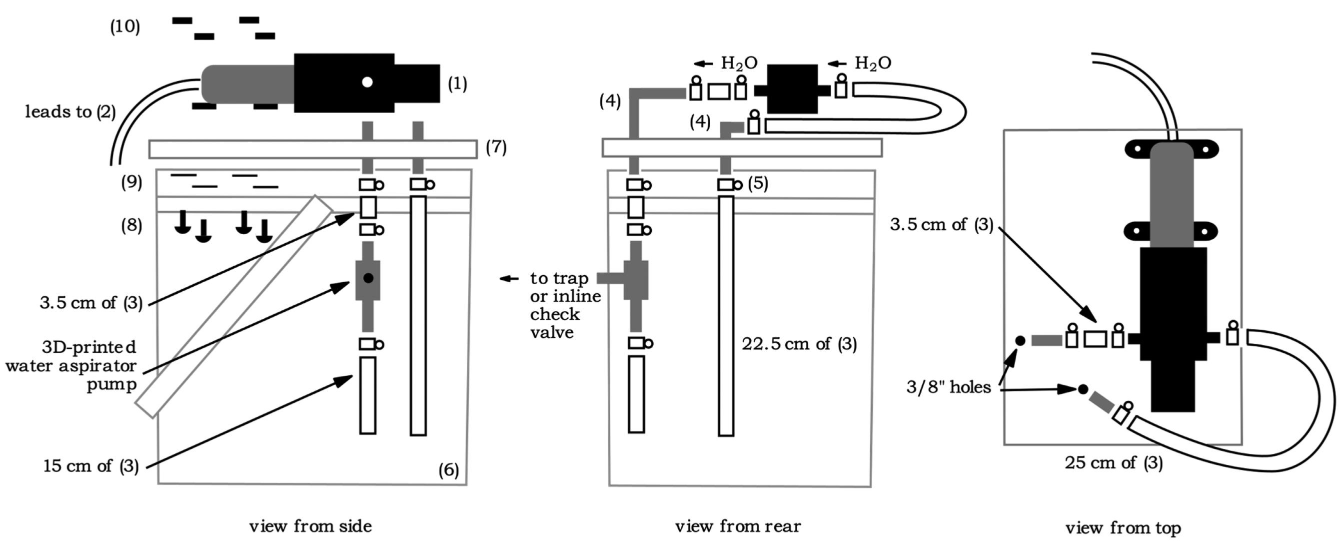


**Figure 3.** Recirculating water vacuum pump construction diagram.



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**Table 1. Recirculating Water Vacuum Pump Parts**

| Item | Source | Part (Number) | Cost[a] |
|---|---|---|---|
| 1 | Amazon https://www.amazon.com | Bayite Pump (BYT-7A102) | $17.99 |
| 2 | Amazon https://www.amazon.com | LEDMO 12 V 5A 60W AC DC Power Supply Adapter (43207-895) | $9.99 |
| 3 | Menards https://www.menards.com | Sioux Chief 5/8 in. o.d. × 3/8 i.d. × 10 ft Braided Vinyl Tubing (42142612) (69.5 cm @ $2.30/m) | $1.60 |
| 4 | Menards https://www.menards.com | Sioux Chief 3/8 in. i.d. × 3/8 i.d. Nylon Hose Barb (17100350) (2 @ $1.79 each) | $3.58 |
| 5 | Menards https://www.menards.com | Breeze 1/4 in.−5/8 in. Hose Clamp (3704MEB) (8 @ $0.72 each) | $5.76 |
| 6 | US Plastic Corp. https://www.usplastic.com | Gallon Super Kube White Pail with Handle (5486) | $2.60 |
| 7 | US Plastic Corp. https://www.usplastic.com | Super Kube White Lid for 1 Gallon Pails (5489) | $1.13 |
| 8 | Local hardware store | 6-32 × 1/2 in. Philips Pan Head Machine Screws (4 @ $0.08 each) | $0.32 |
| 9 | Local hardware store | No. 6 Flat Washers (4 @ $0.07 each) | $0.28 |
| 10 | Local hardware store | 6-32 Hex Nuts (4 @ $0.08 each) | $0.32 |
| | | | $43.57 total cost |

[a]Costs correct as of February 2020 and do not reflect state and local sales tax or shipping cost. Costs reflect construction cost, not bulk cost (e.g., braided vinyl tubing).

## RECIRCULATING WATER VACUUM PUMP CONSTRUCTION

The recirculating water vacuum pump was constructed as shown in Figure 3 using parts outlined in Table 1. The one gallon pail (6) has a compact footprint and a lid (7) with a flat surface area that accommodates the pump and hardware. The diaphragm water pump (1) is bolted to the pail lid using machine screws (8), washers (9), and nuts (10) via the four rubber mounting feet. Hose clamps (5) secure the braided vinyl tubing pieces (3) to the pump, nylon elbows (4), and aspirator. (The tubing lengths can be adjusted to facilitate construction.) The two holes (3/8 in. each) in the lid accommodate the nylon elbows. The hole (3/8 in.) in the side of the pail accommodates the side arm and stabilizes the 3D-printed water aspirator pump when connected to the vacuum hosing leading to the trap. The pump leads are connected to the power supply (2) via the power plug connector included with the power supply.

## HAZARDS

Always wear eye protection when using any water aspirator pump or recirculating water vacuum pump. Never leave any apparatus connected to a vacuum source unattended.

Exercise standard electrical safety practices when using the recirculating water vacuum pump. Caution should be taken while operating electrical components (diaphragm water pump and power supply) near water. Address any leaks before using the recirculating water vacuum pump for the first time since leaks can result in pooling of water on the lid of the pail near the water diaphragm pump motor. Protect exposed wires with heat shrink tubing or electrical tape when applicable. Alternatively, place a fuse in line with one of the water diaphragm pump motor wires to protect the circuit in the event of a power supply or motor failure.

Fluid pressure at the 3.5 cm output line of the diaphragm pump (Figure 3) is approximately 55 psi. The suggested maximum working pressure of the braided polyvinyl tubing is 55 psi at 21 °C. Consider replacing the braided polyvinyl tubing at the output line with polyethylene tubing as polyethylene tubing has a higher maximum working pressure (100 psi at 21 °C).

The maximum working pressure of the PLA 3D-printed water aspirator pump is untested. Water in the tank should be free of any debris that may obstruct the nozzle of the aspirator and overpressure the aspirator and/or water diaphragm pump. (The water diaphragm pump has a default cutoff pressure of 80−85 psi.) Consider adding an inline strainer to the input line of the pump.

Use a trap when using any water-based vacuum source. When working with solvents and other volatile liquids, use an additional cold trap of sufficient size to avoid the contamination of wastewater and to protect the water diaphragm pump and polyvinyl tubing from corrosion.

## PERFORMANCE TESTING

The evacuation rate and depth of vacuum of the constructed recirculating water vacuum pump was compared to a commercial model (Mophorn Lab multi-purpose water circulating vacuum pump) utilizing the setup shown in Figure 4. Standard rubber laboratory vacuum hosing (1/4 in. i.d.) was used to connect the recirculating water aspirator pump to the trap. The constructed recirculating water vacuum pump was filled with 1 L of tap water. The commercial model was filled with roughly 12 L of tap water, and both taps/suction nozzles were connected to the trap via a plastic t-shaped vacuum tubing connector. The trap was connected to a Vernier gas

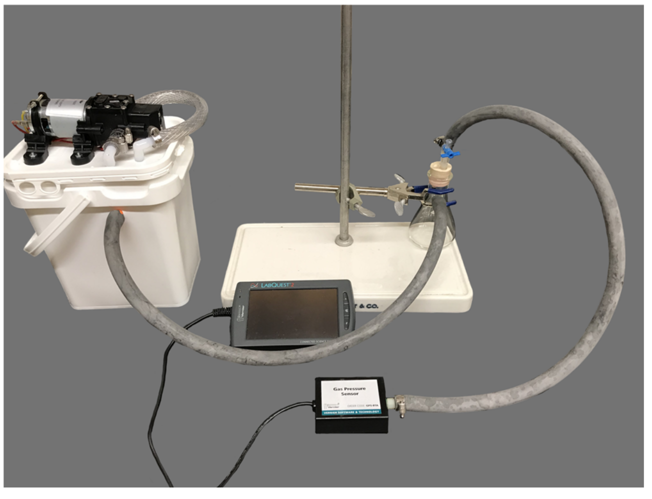

**Figure 4.** Performance testing apparatus shown with constructed recirculating water vacuum pump.



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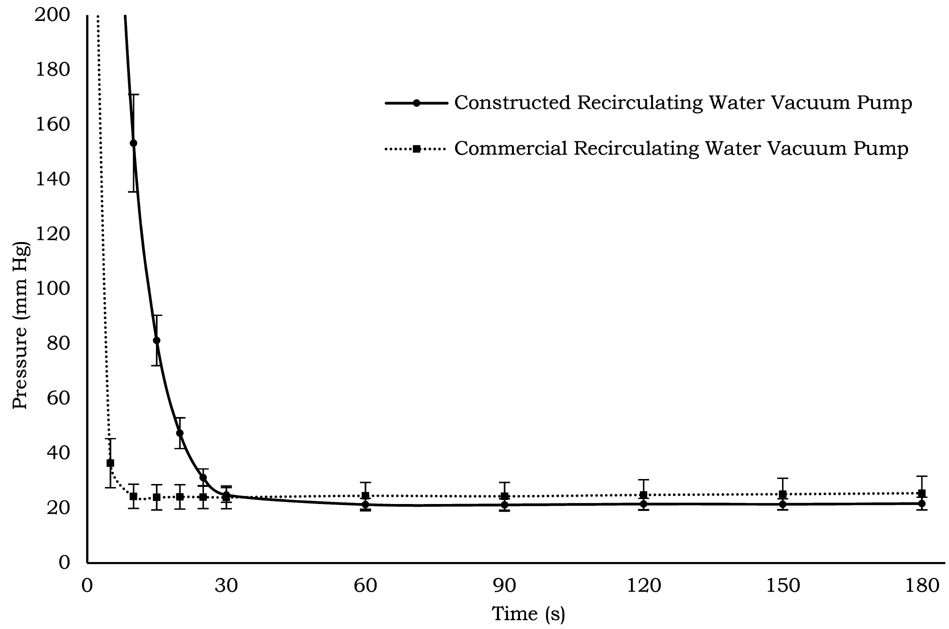


**Figure 5.** Recirculating water vacuum pump performance testing. Data points at 5, 10, 15, 20, 25, 30, 60, 90, 120, 150, and 180 s ≤200 mm Hg. Error bars indicate 95% confidence intervals ($N$ = 5).

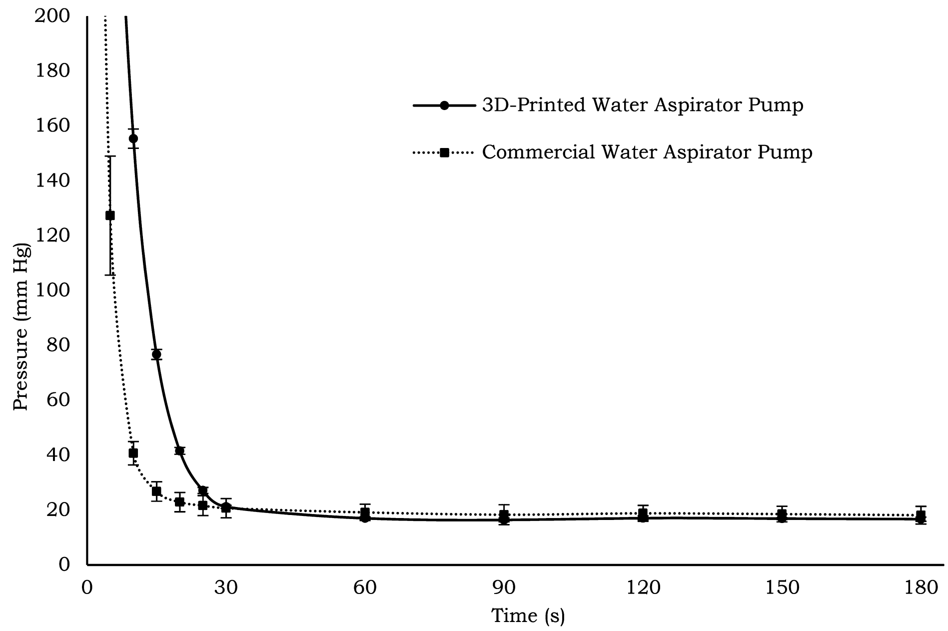


**Figure 6.** Faucet aspirator performance testing. Data points at 5, 10, 15, 20, 25, 30, 60, 90, 120, 150, and 180 s ≤200 mm Hg. Error bars indicate 95% confidence intervals ($N$ = 5).

pressure sensor (pressure range 0−210 kPa; accuracy ±4 kPa) and LabQuest interface. Pressure was collected every second over 180 s.

The results of the performance testing are shown in Figure 5. As expected, the evacuation rate of the commercial recirculating water vacuum pump (120 V AC motor 180 W) was faster than the constructed recirculating water vacuum pump (12 V DC motor 36 W). However, the depth of vacuum of the constructed recirculating water vacuum pump was indistinguishable from the depth of vacuum of the commercial model at 30 s and beyond ($p > 0.05$).

Performance testing of the 3D-printed water aspirator pump modified with a 3/8 in. NPT faucet connection and a commercial model (polypropylene water aspirator, Flinn Scientific) utilized the setup shown in Figure 4. The 3D-printed (faucet) water aspirator pump or the commercial model was connected to a laboratory faucet (65−70 psi).[17] A length of standard rubber laboratory vacuum hosing (1/4 in. i.d.) was added to extend the exit tube of the water aspirator pump into the sink drain.

The results of the performance testing are shown in Figure 6. The depth of vacuum of the 3D-printed (faucet) water aspirator pump was indistinguishable from the depth of vacuum of the commercial model at 30 s and beyond ($p > 0.05$).

Water consumption of the 3D-printed (faucet) water aspirator pump and the commercial model was assessed separately and calculated to be 2.17 ± 0.01 and 8.59 ± 0.03 L/min, respectively.[18] Although the faster flow rate of the commercial water aspirator pump provides a marginally faster evacuation rate, the 3D-printed water aspirator pump was 74% more water efficient and noticeably quieter.

## ■ CONCLUSION

In summary, a recirculating water vacuum pump was constructed from inexpensive materials (~$44) and features a novel, 3D-printed water aspirator pump that also functions with a standard laboratory faucet connection. Although the vacuum performance of the constructed recirculating water vacuum pump is comparable to, if not indistinguishable at times from, a more expensive commercial model (~$200), it is important to note that

- the constructed recirculating water vacuum pump requires a trap or inline check valve;
- the flow rate of the water diaphragm pump is insufficient to achieve maximum attainable vacuum of the commercial water aspirator pump; and
- the mechanical longevity of a polylactic acid water aspirator pump is unknown.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.9b01123.

Aspirator pump 3D model files and faucet aspirator pump 3D model files (ZIP)

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### Notes

The authors declare no competing financial interest.

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(17) The 3D-printed aspirator pump connection to the laboratory faucet should be hand-tight. Threading leaks were not uncommon with 3D-printed NPT threads and could be stemmed with polytetrafluoroethylene (PTFE) thread seal tape.

(18) Flow rates were calculated once the aspirator achieved a stable vacuum pressure by measuring the time to fill a 4 L graduated cylinder. The uncertainty in the flow rate indicates the 95% confidence interval ($N$ = 5).