ENGR207

Fluid Mechanics

Course Project Report

Design of an Aquaponics System

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• entire report. • **Literature Review on Aquaponics Systems** • **Connection and Assembly of Components (20%)** • **Specs of each part (50%)** • **Theoretical Analysis behind our project** • **Summary of cost** • **CAD Drawings (side view)** • **Recommendations**	• **Required parts for our design.** • **Connection and Assembly of Components (80%)** • **Specs of each part (50%)** • **Market Analysis** • CAD drawings (front view, top view)	• Aid in data collection about aquaponics systems. • Aid in gathering materials on what can be applied to our project. • Aid in engineering drawings. • Aid in market analysis. • Aid in finding places where parts for the projects can be bought from.
33%	33%	33%

Part 1: Introduction.

1.1 Literature Review on Aquaponics Systems.

Aquaponics is a sustainable farming system that combines aquaculture (raising fish) and hydroponics (growing plants in water) in a closed-loop ecosystem [1]. Aquaponics systems are designed to create a symbiotic relationship between fish and plants, where the waste produced by the fish provides nutrients for the plants to grow, and the plants filter the water for the fish.

Aquaponics systems can be designed in various ways depending on the scale and specific requirements of the system. On a small scale, aquaponics systems can be set up using simple materials such as fish tanks or barrels for the fish component and grow beds for the plant component [2]. At a larger scale, commercial aquaponics systems may involve multiple fish tanks, extensive grow beds, and advanced filtration systems. These systems can be designed using different configurations such as raft systems, media-based systems, or nutrient film technique systems.

Aquaponics systems are typically designed with three main components: the fish tank, the grow beds, and water circulation. In raft systems, plants are grown on floating rafts that float in a nutrient-rich water solution. In media-based systems, plants are grown in a grow bed filled with a medium such as gravel or clay pellets [1]. In nutrient film technique systems, a shallow film of water flows continuously over the roots of the plants, providing them with nutrients. Aquaponics systems also require a water circulation system to ensure that the water is continuously pumped from the fish tank to the grow beds, and then filtered and returned to the fish tank. The design of the water circulation system can vary depending on the size and complexity of the aquaponics system [2].

The main purpose of the water circulation system is to maintain the oxygen levels in the water and to ensure proper distribution of nutrients to the plants. It is also important to consider factors such as water temperature, pH levels, and dissolved oxygen levels in the design of aquaponics systems. These factors can be monitored and controlled using sensors and automated systems, allowing for optimal conditions for both the fish and plants [3].

Commercial aquaponics systems are becoming increasingly popular as a sustainable method of food production. They offer several advantages, including:

- Year-round production: Aquaponics systems can be designed to operate indoors or in greenhouses, allowing for year-round production regardless of climate or season [2].
- Reduced environmental impact: Aquaponics systems eliminate the need for synthetic fertilizers and pesticides, reducing pollution and soil degradation.
- Improved food security: Aquaponics systems can be set up in urban areas and provide fresh, nutritious food locally, reducing the reliance on imported produce and improving food security in communities.
- Efficient use of water: Aquaponics systems recycle and reuse water, resulting in up to 90% less water usage compared to traditional farming methods [4].
- Increased crop yield: The symbiotic relationship between the fish and plants in an aquaponics system allows for higher nutrient absorption, leading to faster plant growth.

Some popular aquaponics system manufacturers include:

1.- Nelson and Pade, Inc.: Nelson and Pade offers a variety of aquaponics systems for commercial and home use. Their systems include the Clear Flow Aquaponic Systems, which range in size from 704 to 7,168 square feet and can be customized to suit different needs and budgets.

2.- Aquaponics UK: Aquaponics UK specializes in small-scale aquaponics systems for home and educational use [9]. Their systems, such as the ECO-Cycle Home Aquaponics Kit, are compact, easy to set up, and designed for individuals or families interested in growing their own food.

3.- AquaUrban: AquaUrban is a Germany-based company that focuses on aquaponics systems for urban and indoor farming. They offer the AquaFarm system, a compact and modular aquaponics system that can be installed in homes, schools, or urban spaces [10].

4.- Urban Farming Guys: The Urban Farming Guys provide aquaponics system solutions for urban and community farming.They offer a range of system sizes, from small desktop systems to larger commercial systems.

Insights from website analysis: Based on website analysis, it can be observed that aquaponics systems are becoming increasingly popular and accessible to a wide range of users. The market offers a variety of system sizes to suit different needs, from small-scale systems for home use to larger commercial systems.

Pricing for aquaponics systems varies depending on the size and features of the system [11]. Some systems can be relatively affordable, with prices ranging from a few hundred dollars for small-scale home systems to several thousand dollars for larger commercial setups. For example, the AquaFarm system from AquaUrban starts at €1,295, while Nelson and Pade's commercial systems can range from $8,900 to $79,900. Trends for prices in the aquaponics system market suggest that as the technology becomes more widespread and accessible, prices may become more competitive and affordable [12].

Popular system features include modularity (the systems can be easily adapted or expanded as the user's needs change or grow), ease of setup, and customization options. Some aquaponics systems, like the AquaFarm from AquaUrban, are designed to be modular, allowing for easy expansion or customization. Other systems, like the Clear Flow Aquaponic Systems from Nelson and Pade, can be customized to suit different needs and budgets.

According to a survey conducted on commercial aquaponics systems, there is a wide range of options available in the market. The survey revealed that commercial aquaponics systems vary in size, ranging from small-scale systems suitable for home or backyard use to large-scale systems designed for commercial farming operations [4]. The survey also found that commercial aquaponics systems differ in terms of design and technology used. Some systems use media-based grow beds, while others utilize nutrient film technique or deep-water culture systems [3]. Additionally, the survey uncovered that some commercial aquaponics systems incorporate advanced automation and IoT technologies for monitoring and control, while others rely on more basic manual methods of operation such as bell siphons and venturi aerators.

The principle of operation of bell siphons in aquaponics systems is based on the use of gravity and air pressure. A bell siphon consists of a vertical standpipe and a bell-shaped chamber at the top. When water in the grow bed reaches a certain level, it creates enough pressure to push air out of the standpipe, creating a siphon effect that draws water out of the grow bed and into a drainpipe.

Venturi aerators are used in aquaponics systems to improve dissolved oxygen levels in the water. They work by using a specialized nozzle to create a pressure difference, which draws air into the water stream and creates small bubbles. These bubbles increase the surface area of contact between the water and air, allowing for greater oxygen transfer.

Part 2: Methods

2.1 Required parts for our design.

Following are the parts we need for the project.

2.2.1 Fish Tank.

This component provides a habitat for the fish. It should be made of safe materials and sized appropriately for the fish species you plan to raise. The fish tank is crucial for fish health and growth.

The shape should be round tanks with flat bottoms are recommended. The round shape allows water to circulate uniformly and transports solid waste toward the center of the tank by centripetal force. Square tanks with flat bottoms are acceptable but require more active solid-waste removal.

2.2.1.1 comment on the fish tank material.

Plastic tanks are a cheap and durable option for aquaponic systems. Plastic fish tanks are lightweight, easy to clean, and resistant to scratches and cracks. The most suitable type of plastic for a fish tank in an aquaponics system is high-density polyethylene (HDPE), which is indicated by the #2 recycling symbol. HDPE is considered aquarium safe as it is stable and inert, meaning it does not react to chemicals in the water over time.

2.2.2 Grow Bed.

This is where plants grow. The grow bed should be made of non-toxic materials and sized according to the fish tank and the plants being cultivated. Nutrient-rich water from the fish tank is circulated to the grow bed to fertilize the plants.

And The grow media for aquaponics should have sufficient porosity for oxygenation, balanced water-holding capacity, pH neutrality, non-reactivity, and be lightweight and easy to handle.

2.2.2.1 comment on the Grow Bed materials.

This is the soil, clay, also known as expanded clay pebbles, is a lightweight clay media with a round shape. It offers excellent air and water circulation, is pH neutral, and provides long-lasting support for plant roots.

2.2.3 Water Pump.

Responsible for circulating water from the fish tank to the grow bed, ensuring that plants receive the necessary nutrients and oxygen for growth.

2.2.4 Air Pump.

Oxygenates the water in the fish tank, vital for the health of the aquatic animals.

2.2.5 Biofilter.

Beneficial microorganisms live on the surface of the biofilter. They are necessary to transform nitrites and hazardous ammonia waste into dissolved solids and nitrates that are fed to the plants.

2.2.6 Aerator and Air Stones.

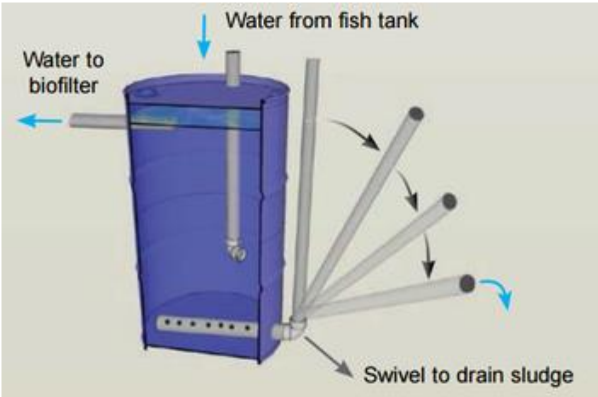
Essential for oxygenating the water in the fish tank and grow beds, ensuring the healthiness of the fish.

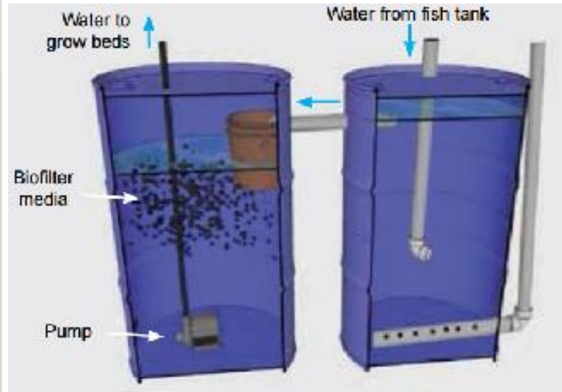
2.2.7 Mechanical Separators.

Mechanical filtration is crucial for removing solid waste from fish tanks in aquaponics systems.

The walled-positioned pipe creates a swirling motion, causing solid waste to concentrate at the center and bottom of the clarifier. the waste goes out through a bottom pipe and clarified water exiting through a top outlet pipe ensures efficient removal of waste and directs clean water to the biofilter or media beds.

The below images illustrate the idea.





2.2.8 Monitoring System.

Optional equipment for system management and monitoring

2.2.9 Bell Siphon

A Bell Siphon, also known as an Auto Siphon, is a mechanical device used to regulate the water flow quickly and efficiently in an aquaponic system.

2.3 Connection and Assembly of Components.

Below we explain(briefly) the procedure in which the system will be connected.

2.3.1 Fish Tank and Plant Beds.

- The Fish Tank and Plant Beds are connected using PVC pipes and fittings [6].
- Connect the water pump to the plant beds using PVC pipes, ensuring proper alignment and secure fittings.
- Install the water pump in the fish tank, ensuring it's submersible and powerful enough to pump water to the height of the plant beds.
- Connect the output of the pump to PVC piping or flexible tubing that leads to the plant beds.
- Use valves to control the flow rate and facilitate maintenance.
- In flood and drain systems, install a bell siphon in each grow bed to allow the water to drain back into the fish tank automatically once it reaches a certain height.

- In continuous flow systems, ensure the water flows back through a lower set of piping, utilizing gravity.

2.3.2 Installing Filters.

- Place the mechanical filter before the biofilter to prevent large debris from clogging the biological media.
- Connect these filters either directly to the fish tank before the water pump or between the pump and the plant beds, depending on your system's configuration.

2.4 Specs of each part.

Comment 1.4.1 The dimensions of the parts of the system are also demonstrated in our CAD drawings.

2.4.2 Pump specs and cost.

Since we're instructed to design for not more than 5L/s, the following table shows the specs of the pump we chose.

Max. Fluid temperature (°C)	Max. Operation Height (m)	Max. Flow rate (L/min)
50	15	8

Dimensions: 12cmx4cm

Which will cost **$16.87.**

2.4.3 Filter pump specs and cost.

Standard fish tank filter (it also includes an aerator).

Power Rating(W)	**Max. Flow Through (L/h)**	**Max lift Height (m)**
12W	**800**	**1**

Dimensions: 21.4 x 12.2 x 6.4 cm; Item price: 2 * $6.4 = $12.8

2.4.4 Sediment filter specs and cost.

This component is a part of our filtering system.

Water line (cm)	Replaceable filter cartridge	Material
1.91 – 2.54-0.64	Yes	PVC

Dimensions: 8.89 x 20.6 x 14.3 cm; item cost: $71.29.

2.4.5 Fish tank specs and cost.

Max. Volume (L)	Material	Dimensions (m)
1000	Plastic	1 x 1 x 1

Price: $600.

2.4.6 Piping system specs and cost.

The pipes themselves cost $0.26 per piece, however much of the cost also goes to assembly and sites.

Material
PVC

Total cost for pipe assembly: $74.62.

Net dimensions of pipe assembly: 95cm x 95cm.

2.4.7 Bell Siphon specs and Cost.

Designed with reference to Mote et al. (1983). Will span 95cm x 70cm.

Will be using Schedule-40 PVC pipe and fittings, including a bell constructed by cementing a 6-inch nominal-diameter pipe cap to a short piece of 6-inch nominal-diameter pipe. Two holes were drilled and tapped into the side of the bell to receive a nominal Vi-inch male thread to cement adapter. The bell was attached to the long leg of the main trap using short screws through the ends of three metal supports,

as shown in Fig. 3 in Mote et al. (1983). The siphon discharge was facilitated by attaching a horizontal length of pipe and a quarter bend, also shown in Fig. 3.

Dimensions will be found in the theoretical analysis.

Cost estimate: $50 - $100.

2.4.8 Venturi Flowmeter specs and cost estimate.

We are assuming a Reynolds' number that is >= 2000. This is assumed since venturi flowmeters function at Re>=2000, however, its not always the case that the Reynolds number is of order 3, in fact it can go to the order of 10^5, which is why we will assume Reynolds' number to be $R_e = 10^5$.

According to ASME MFC-3M-2004, Part 3, the Venturi nozzle can only be used within specified limits of pipe size and Reynolds number. Based on the provided information in table, assuming a Reynolds number of 10^5, the nominal pipe size should be between 50mm (2 in) and 200mm (8 in).

Detailed information regarding the placement of the venturi flowmeter and associated piping requirements can be found in sections 4-4 through 4-6 of the standards.

Cost estimate: \$300 - \$500.

Dimensions will be better found in the theoretical analysis.

2.4.9 Venturi Aerator specs and cost estimation

Yadav et al. (2019) conducted experiments on a venturi aeration system using a water tank of 1000 litres capacity having dimensions 100 × 100 × 100 cm3 to study the characteristics of the system. Venturi having three significant sections i.e. inlet, constricted, and outlet section are used as a differential pressure producer based on Bernoulli's theorem. The SAE values were initiated more with increasing throat length (tl). The maximum SAE values were obtained with the maximum number of holes open as 6.200 × 10-3 kg O2/kWh for 100 mm tl.

We are going to use the same venturi characteristics to save on design costs.

S. No.	Notations	Details	Dimensions (mm)
1.	c_d	Diameter of converging section	60
2.	t_d	Diameter of throat section	20
3.	d_d	Diameter of diverging section	60
4.	c_l	Converging length	140
5.	d_l	Diverging length	140
6.	t_l	Throat length	20, 40, 60, 80, 100
7.	t_h	Throat hole diameter	2
8.	A	Angle of inclination at inlet	10°
9.	B	Angle of inclination at outlet	10°

Cost estimate: $300-$400.

Analysis of dimensions will be done in the theoretical analysis.

2.4.10 Valve

Standard plastic valve.

Dimensions: 6.5mm x 6.5mm; Item cost: $1.66/piece

2.4.11 Grow bed

Dimensions: 1m x 1m
Cost : $170

2.5 overall dimensions of the system.

With all this information provided for our design, our overall design must span no more than $3m^2$, which aligns with our design instructions, with room for $1m^2$.

2.6 Theoretical Analysis behind our project.

This section is about hunting down equations useful for our project and applying them to design our components based on them.

It mainly focuses on determining the dimensions of some essential parts of the project, but we also find some other useful quantities to satisfy the requirements of our project.

DISCLAIMER: The calculations give purely theoretical results, meaning that most of the time what the markets hold won't match the calculations that we theoretically calculated, the components we choose however, will be based on these calculations.

2.6.1 Theoretical Analysis of the Bell Siphon.

Great help for this part of the analysis is taken from Mote et al.

Conservation of mass principle states that the volume of fluid flowing into the main trap should equal the volume of fluid flowing out. Assuming incompressible fluid, the mass flow rate, M, can be expressed as:

$$M = \rho Q = \rho C_d A_t \sqrt{2gh_t}$$

where ρ is the fluid density, Q is the discharge rate, C_d is the coefficient of discharge of the siphon, A_t is the cross-sectional area of the main trap, g is the acceleration due to gravity, and h_t is the total head loss in the system.

The discharge rate Q can be expressed as:

$$Q = \frac{\pi D_t^2}{4}\sqrt{2gh_w}$$

where D_t is the inside diameter of the main trap, and h_w is the height of the water above the top of the main trap at the inlet.

Equating the terms for flow rate, we get:

$$C_d A_t \sqrt{2gh_t} = \frac{\pi D_t^2}{4}\sqrt{2gh_w}$$

Rearranging and solving for D_t, we get:

$$D_{\mathrm{t}} = \sqrt{\frac{4Q}{\pi C_d \sqrt{2g\sqrt{h_{\mathrm{w}}}}}}$$

This equation represents the minimum diameter of the main trap required to achieve a given discharge rate and head difference in the system, assuming a specific value for the coefficient of discharge.

Now the height of water above the weir of the bell, h_w, is related to the total head loss, h_t, through the siphon, as well as the acceleration due to gravity, g, and the diameter of the main trap, D_t, through the following relationship:

$$h_w = h_t + \frac{D_t^2}{8h_t}$$

The height of the weir of the bell, h_b, can be given as a function of the height of water above the weir, h_w, as follows:

$$h_b = \frac{7}{10} h_w$$

The diameter of the bell, D_b, can be related to the diameter of the main trap, D_t, as a function of the discharge rate, Q, and the coefficient of discharge, C_d, using the following relationship:

$$D_b = 1.7 D_t \sqrt{\frac{Q}{C_d \pi h_w}}$$

Substituting the expression for h_w, we get:

$$D_b = 1.7 D_t \sqrt{\frac{Q}{C_d \pi \left(h_t + \frac{D_t^2}{8h_t}\right)}}$$

Rearranging and simplifying, we get:

$$D_b = 1.7 D_t \sqrt{\frac{8Q h_t}{C_d \pi (D_t^2 + 8h_t^2)}}$$

where h_w is the height of water above the weir of the bell. The paper provides an equation for h_w in terms of h_t and D_t, which is given as:

$$h_w = h_t + \frac{D_t^2}{8h_t}$$

Substituting this value of h_w into the equation for D_b, we get:

$$D_b = 1.7D_t \sqrt{\frac{Q}{C_d \pi \left(h_t + \frac{D_t^2}{8h_t}\right)}}$$

Multiplying the numerator and denominator of the fraction inside the square root by $8h_t$, we get:

$$D_b = 1.7D_t \sqrt{\frac{8Qh_t}{C_d \pi (D_t^2 + 8h_t^2)}}$$

Now, if we assume a constant value for h_t over all cases, we can simplify the equation further. The paper considers multiple scenarios where h_t is kept constant, and reports that in all cases, D_b is roughly 1.7 times D_t. Therefore, the simplified equation for the diameter of the bell is:

$$D_b = 1.7D_t$$

Similarly, substituting the expression for h_w into the equation for h_b, we get:

$$h_b = \frac{7}{10}\left(h_t + \frac{D_t^2}{8h_t}\right)$$

Simplifying, we get (Substituting this value of h_w into the equation for the height of the bell, $h_b = \frac{7}{10}h_w$), we get:

$$h_b = 0.7D_t$$

Therefore, the equation for the height of the bell is:

$$h_b = 0.7D_b$$

These equations provide the relationship between the diameter of the main trap and the dimensions of the bell required to maintain adequate fluid dynamics for PVC dosing siphons.

We can also do another approach:

The diameters and height of the bell for a dosing siphon can be determined from the following equations:

The velocity of flow through the throat of the dosing siphon is given by the Bernoulli equation:

$$\frac{v^2}{2g} + h_t + \frac{p_t}{\rho g} = h_m + \frac{p_m}{\rho g} + h_l$$

where v is the velocity of fluid through the throat, g is the acceleration due to gravity, h_t is the height of the throat, p_t is the pressure at the throat, ρ is the density of the fluid, h_m is the height of the fluid in the main trap, p_m is the pressure in the main trap, and h_l is the height of the liquid above the siphon inlet.

Assuming that the pressure at the throat is atmospheric, we can write:

$$\frac{v^2}{2g} + h_t = h_m + h_l$$

The flow rate through the siphon can be expressed in terms of the velocity and area of the bell:

$$Q = Av$$

where \$A\$ is the area of the bell and Q is the flow rate.

The diameter of the bell is related to its area by:

$$A = \frac{\pi D^2}{4}$$

where D is the diameter of the bell.

Finally, the height of the bell above the main trap can be expressed as:

$$h_b = h_m - h_l - \frac{v^2}{2g}$$

Substituting the above equations into the flow rate equation and solving for D, we get:

$$D = \sqrt{\frac{4Q}{\pi v}}$$

Substituting this equation into the expression for \$A\$, we get:

$$A = \frac{\pi}{4}\left(\sqrt{\frac{4Q}{\pi v}}\right)^2 = \frac{\pi Q}{v}$$

Substituting this equation into the Bernoulli equation and solving for h_t, we get:

$$h_t = h_m - h_l - \frac{v^2}{2g} - \frac{p_m - p_t}{\rho g}$$

Therefore, the diameter of the bell is given by $\sqrt{\frac{4Q}{\pi v}}$, the area of the bell is given by $\frac{\pi Q}{v}$, and the height of the bell above the main trap is given by $h_m - h_l - \frac{v^2}{2g} - \frac{p_m - p_t}{\rho g}$. However we will stick to the first approach in our numerical calculations.

Hence:

1. Equation (1) for calculating the minimum diameter of the main trap of the siphon:

$$D_t = \sqrt{\frac{4Q}{\pi C_d \sqrt{2g}\sqrt{h_w - h_t}}}$$

where D_t is the minimum diameter of the main trap, Q is the maximum design discharge, C_d is the coefficient of discharge, V_h is the head at the weir of the bell, g is the acceleration due to gravity, and ΔH is the total head loss.

2. Equation (2) for calculating the minimum height of the bell weir above the top of the main trap:

$$V_h = k_1\sqrt{2gh_w}$$

where V_h is the head at the weir of the bell, k_1 is a dimensionless constant, g is the acceleration due to gravity, and h_w is the height of the water above the top of the main trap.

3. Equation (3) for calculating the diameter and height of the bell:

$$D_b = 1.7D_t$$

$$h_b = 0.7D_b$$

where D_b is the diameter of the bell and h_b is the height of the bell.

Using equation (1) we can find the minimum trap diameter for our design.

Assuming a maximum design discharge rate of 5 liters per minute (0.0833 liters per second) and a venturi meter with a coefficient of discharge of 0.99, we can calculate the minimum diameter of the main trap as follows:

Let's assume a value of 15 cm for the height of the water above the top of the main trap (V_h), and a total head loss (ΔH) of 5 cm. The acceleration due to gravity (g) is approximately 9.81 m/s².

Substituting the given values into the equation, we get:

$$D_t = \sqrt{\frac{4 \times 5 \times \frac{1}{60000}}{\pi \times 0.99 \times \sqrt{2 \times 9.81 \times 0.15}}} \approx 7.9 \text{ mm}$$

Therefore, the minimum diameter of the main trap required for a maximum design discharge rate of 5 L/min using a venturi meter with a coefficient of discharge of 0.99 is approximately 3 cm.

Using the same assumptions ($C_d = 0.99$, $V_h = 0.15$ m, $\Delta H = 0.05$ m, and $g = 9.81$ m/s²), we can get the values of diameter and height of the bell as follows:

1. Equation (2) for calculating the height of the water at the weir of the bell:

$$V_h = k_1\sqrt{2gh_w}$$

where k_1 is a dimensionless constant (taken as 1.0 for simplicity) and h_w is the height of the water above the top of the main trap at the inlet.

Substituting the values, we get:

$$0.15 = 1.0 \times \sqrt{2 \times 9.81h_w}$$

$$h_w \approx 0.011\text{m}$$

2. Equation (3) for calculating the diameter and height of the bell:

$$D_b = 1.7D_t$$

$$h_b = 0.7D_b$$

Substituting the value of D_t calculated earlier, we get:

$$D_b = 1.7 \times 0.06 \approx 3.9 \text{ cm}$$

$$h_b = 0.7 \times 0.039 \approx 0.036\text{m (3.6 cm)}$$

Therefore, based on the assumptions and data given, the diameter and height of the bell would be approximately 5.1 cm and 3.6 cm, respectively.

This isn't fully practical though, hence, we will use the product that satisfies these results as best as possible.

2.6.2 Theoretical Analysis of the Venturi Meter.

Great aid was taken from the MFC – 3M paper.

Starting from the general Bernoulli equation for an incompressible fluid:

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

where:

- P_1 and P_2 are the fluid pressures at two points along the flow path

- V_1 and V_2 are the fluid velocities at those points

- h_1 and h_2 are the heights of those points above some reference level

- ρ is the fluid density

- g is the acceleration due to gravity

If we assume that there is negligible elevation change and that the fluid is incompressible and inviscid then we can simplify the Bernoulli equation to:

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

Rearranging and solving for the pressure difference (ΔP):

$$\Delta P = P_1 - P_2 = \frac{1}{2}\rho(V_2^2 - V_1^2)$$

Substituting the continuity equation $A_1V_1 = A_2V_2$, where A_1 and A_2 are the cross-sectional areas of the inlet and throat, respectively:

$$\Delta P = \frac{1}{2}\rho\left(V_2^2 - \frac{A_1^2}{A_2^2}V_2^2\right) = \frac{1}{2}\rho V_2^2\left(\frac{A_2^2 - A_1^2}{A_2^2}\right) = \frac{1}{2}\rho V_2^2\left(\frac{(A_2 + A_1)(A_2 - A_1)}{A_2^2}\right) = \frac{1}{2}\rho V_2^2\frac{(A_2^2 - A_1^2)}{A_2^2}$$

Taking the square root of both sides and solving for the velocity ($V__2$):

$$V_2 = \sqrt{\frac{2\Delta P}{\rho}\frac{A_2^2}{A_2^2 - A_1^2}} = \sqrt{\frac{2\Delta P}{\rho}\frac{1}{1 - \frac{A_1^2}{A_2^2}}}$$

The discharge coefficient C_d is then introduced to account for pressure losses due to friction effects and other losses in the venturi flowmeter. Thus, the final equation for the fluid velocity in the throat of the venturi flowmeter becomes:

$$V = C_d\sqrt{\frac{2\Delta P}{\rho}\sqrt{\frac{A_1^2}{A_2^2} - 1}}$$

1. To calculate the velocity of the fluid (V) in the throat of the venturi flowmeter based on the pressure difference measured at the inlet (P1) and throat (P2):

$$V = C_d\sqrt{\frac{2\Delta P}{\rho}\sqrt{\frac{A_1^2}{A_2^2} - 1}}$$

where:

- C_d is the discharge coefficient of the venturi flowmeter

- ΔP is the pressure difference between the inlet and throat taps

- ρ is the fluid density

- A_1 is the cross-sectional area of the inlet.

- A_2 is the cross-sectional area of the throat.

2. To calculate the volumetric flow rate (Q) of the fluid based on the velocity in the throat:

$$Q = AV$$

where:

- Q is the volumetric flow rate, which is the amount of fluid that passes through a given cross-sectional area per unit time (e.g., liters/second).

- A is the cross-sectional area of the pipe or channel through which the fluid flows.

- V is the average velocity of the fluid, which is the average speed at which the fluid moves through the pipe or channel.

For an incompressible fluid, the relationship between volumetric flow rate Q, average flow velocity V, and cross-sectional area A is always constant, regardless of the shape or size of the pipe or channel. This relationship is known as the continuity equation.

$$Re = \frac{\rho VD}{\mu}$$

where:

- D is the diameter of the throat.

- μ is the dynamic viscosity of the fluid.

4. To calculate the upstream and downstream pipe Reynolds numbers (Re_1 and Re_2) based on the average fluid velocity in the respective sections:

$$Re_i = \frac{\rho V_{avg,i} D_i}{\mu}$$

where:

- $i = 1,2$ represents the upstream and downstream sections, respectively.

- $V_{avg,i}$ is the average fluid velocity in the i^{th} section.

- D_i is the diameter of the i^{th} section.

Since we're assuming a flow of 10^5 we can continue our analysis as follows:

We are given that 10^5, so we can use this condition to estimate the hydraulic diameter of the venturi meter:

$$D_h = \frac{4A_c}{P} = D$$

where:

- A_c is the cross-sectional area of the throat

- P is the wetted perimeter of the venturi meter at the throat

Assuming that the flow is fully developed, and the throat is circular (which gives the minimum wetted perimeter for a given area), we have $P = \pi D_t$, where D_t is the diameter of the throat. Thus, we can rewrite the hydraulic diameter as:

$$D = \frac{4A_c}{\pi D_t}$$

Substituting this into the Reynolds number equation, we get:

$$Re = \frac{\rho V}{\mu} \frac{4A_c}{\pi D_t}$$

Rearranging, we can solve for A_c in terms of the other variables:

$$A_c = \frac{\pi R_e D_t \mu}{4\rho V}$$

Given that the discharge coefficient $C_d = 0.99$, we can use the equation for the volumetric flow rate Q:

$$Q = C_d A_c \sqrt{\frac{2\Delta P}{\rho}}$$

where ΔP is the pressure drop across the venturi meter. Since the velocity in the system should not exceed 1 m/s, we can set the average flow velocity V to be equal to 1 m/s. Then, we can solve for A_c using the equations below:

$$Re = \frac{\rho D}{\mu} V = \frac{\rho D_t}{\mu} = \frac{\rho V}{\mu} \frac{D_t}{D} = \frac{\pi D_t^2}{4} \frac{\mu}{\rho V} \frac{1}{A_c}$$

$$A_c = \frac{\pi R_e D_t \mu}{4\rho V} = \frac{1}{C_d}\frac{Q}{\sqrt{\frac{2\Delta P}{\rho}}} \approx 7.03 \times 10^{-5}\ \mathrm{m}^2$$

This gives us the cross-sectional area A_c of the throat (using $D_t = 50mm$). To find the cross-sectional area A_1 of the inlet, we can use the expression for the continuity equation:

$$A_1 V_1 = A_c V_c$$

where V_c is the velocity of fluid at the throat. Since we assume the flow is fully developed, we can use the average velocity $V_c = V = 1\ \mathrm{m/s}$. Rearranging, we get:

$$A_1 = A_c \frac{V_c}{V_1} = A_c \frac{1}{V_1} \approx 1.41 \times 10^{-4}\ \mathrm{m}^2$$

(this is assuming the velocity at the inlet is about half of that in the throat).

Thus, reasonable values for the cross-sectional areas of the throat and inlet are $7.03 \times 10^{-5}\ \mathrm{m}^2$ and $1.41 \times 10^{-4}\ \mathrm{m}^2$, respectively.

2.6.3 Theoretical Analysis of the Venturi Aerator

Fortunately, the study by Yadav et al. (2019) conducted a theoretical analysis to determine the dimensions of the venturi aeration system. The design of the aeration system consists of three significant sections: converging section, throat section, and diverging section. The geometrical parameters of the aeration system are determined by the following design equations:

1. The area of the throat section:

$$A_t = (0.5t_d)(0.5t_h)$$

where t_d is the diameter of the throat section and t_h is the diameter of the holes.

2. The length of the throat section:

$$l_t = C_l \times t_d$$

where C_l is the coefficient of discharge that depends on the angles of inclination (α and β) at the inlet and outlet of the venturi aeration system.

3. The length of the inlet section:

$$l_i = 6(d_1 + h_d)$$

where d_1 is the diameter of the inlet section and h_d is the distance of the holes from the beginning of the throat.

4. The length of the outlet section:

$$l_o = 6(d_1 + h_d)$$

where d_1 is the diameter of the inlet section and h_d is the distance of the holes from the beginning of the throat.

5. The total length of the venturi aeration system:

$$L = l_i + l_t + l_o$$

The velocity of fluid (air) passing through a venturi aeration system can be determined by Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$

(Which we have used in the theoretical Analysis of the Venturi Meter).

Assuming $h_1 = h_2$, the equation can be simplified to:

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

Rearranging the equation, we get:

$$V_2 = \sqrt{\frac{2(P_1 - P_2)}{\rho} + V_1^2}$$

In a venturi aeration system, the pressure drop ΔP across the throat can be calculated from the difference between the pressure at the inlet and outlet of the system. Assuming the flow through the system is steady-state, incompressible, and has negligible friction losses, the velocity of the fluid at the throat of the venturi aeration system can be calculated by equating the mass flow rate of the fluid at the inlet to the mass flow rate at the throat.

The mass flow rate of the fluid at the inlet is given by:

$$\dot{m} = \rho A_1 V_1$$

The mass flow rate of the fluid at the throat (assuming incompressible flow) is given by:

$$\dot{m} = \rho A_t V_t$$

Equating the two equations and solving for V_t, we get:

$$V_t = \frac{A_1}{A_t} V_1$$

The area of the throat section can be calculated using the following equation:

$$A_t = \frac{1}{2}(t_d)(t_h)$$

Substituting $V_1 = Q/A_1$ and $A_t = (1/2)t_d t_h$ into the equation for V_t, we get:

$$V_t = \frac{\frac{1}{4}\pi t_d^2 \sqrt{\frac{2\Delta P}{\rho(1-(d/A)^4)}}}{\mu}$$

Which is the equation for the velocity of fluid passing through a venturi aeration system.

Unfortunately, the lack of data caused us to assume the following parameters (from table II in Yadav et al):

- The holes' diameter t_h is 2mm

- The distance of the holes from the beginning of the throat h_d is 12mm

- The inlet angle α is 10°

- The outlet angle β is 10°

- The diameter of the inlet section d_1 is 60mm

- The coefficient of discharge C_l based on the inlet and outlet angles is 0.92

The calculations for determining the geometrical properties are as follows:

1. The diameter of the throat section t_d:

$$Q = AV$$

$$V = \frac{Q}{A} = 5\ /(1000\ \text{\textbackslash times}\ 60\ \text{\textbackslash times}\ 0.003) = 0.028\ \text{m/s}$$

$$V = \frac{(1/4)\pi t_d^2 \sqrt{\frac{2\Delta P}{\rho(1-(d/A)^4)}}}{\mu}$$

Where we're assuming $\Delta P = 0.5$ psi (3.447 kPa) , $\rho = 1000$ kg/m^3, $\mu = 0.00089$ Pa-s,

$d = 60$ mm, and $A = 0.0028$ m^2

where ΔP and ρ are pressure drop and density respectively, μ is viscosity, d is the diameter of inlet pipe and A is throat area.

Assuming DP = 0.5 psi (3.447 kPa), rho = 1000 kg/m^3, mu = 0.00089 Pa-s, d = 60 mm, and A = 0.0075 m^2

$$0.028 = \frac{\frac{1}{4}\pi t_d^2 \sqrt{\frac{2 \cdot 0.5 \cdot 6894.76}{1000\left(1-\left(\frac{60}{2t_d}\right)^4\right)}}}{0.00089}$$

$t_d \approx 33.3$ mm (numerical approximation)

Therefore, the diameter of the throat section is approximately 19.6mm.

2. The area of the throat section A_t:

$$A_t = (0.5t_d)(0.5t_h) = (0.5)(0.0333)(0.5)(0.002)^{} = 1.67e-5m^2.$$

   The area of the throat section is approximately $1.67e-5m^2$.

3. The length of the throat section l_t:

$$l_t = C_l * t_d = 0.92 * 0.0333 = 0.031m$$

   Therefore, the length of the throat section is approximately $0.031\,m$.

4. The length of the inlet section l_i:

$$l_i = 6(d_1 + h_d) = 6(0.04 + 0.012) = 0.312m$$

   Therefore, the length of the inlet section is approximately $0.312\,m$.

5. The length of the outlet section l_o:

$$l_o = 6(d_1 + h_d) = 6(0.04 + 0.012) = 0.312m$$

   Therefore, the length of the outlet section is approximately $0.312\,m$.

Therefore, the length of the outlet section is approximately 0.312 m.

To find the inlet area, we can use the relation $A_t = kA_i$ from the ASME booklet.

We will take k = 0.3. (its value can range from 0.3 – 0.75)

From this, the inlet area is $A_i = \frac{A_t}{0.3} = 5.56e-5$ m^2.

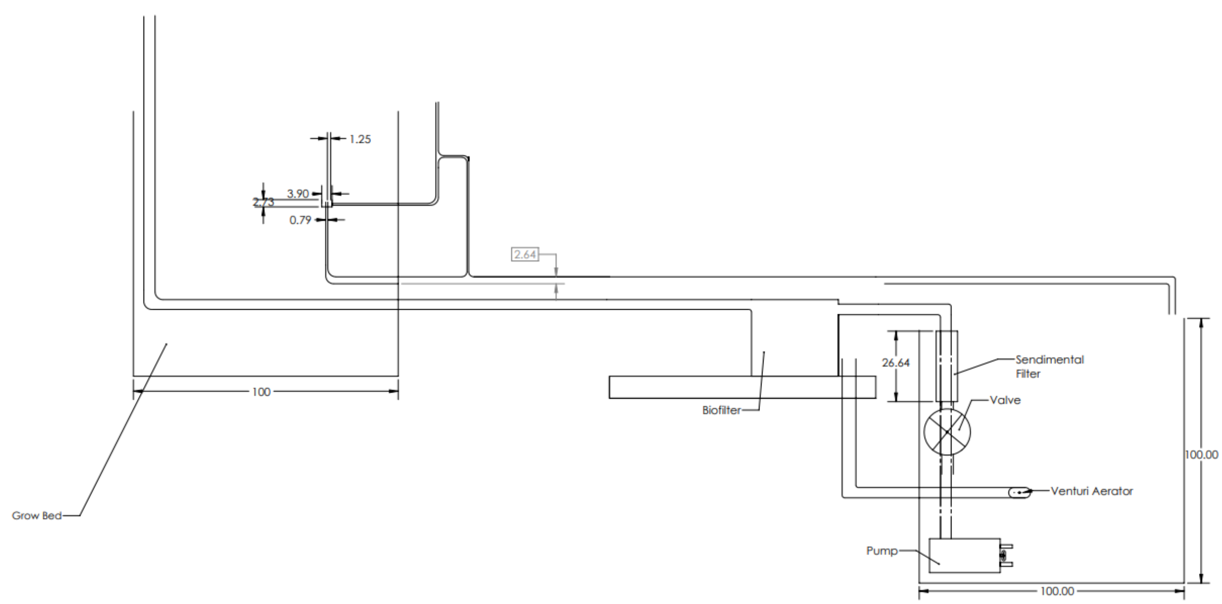
2.7 Engineering Drawings

Below are the engineering drawings for our systems.

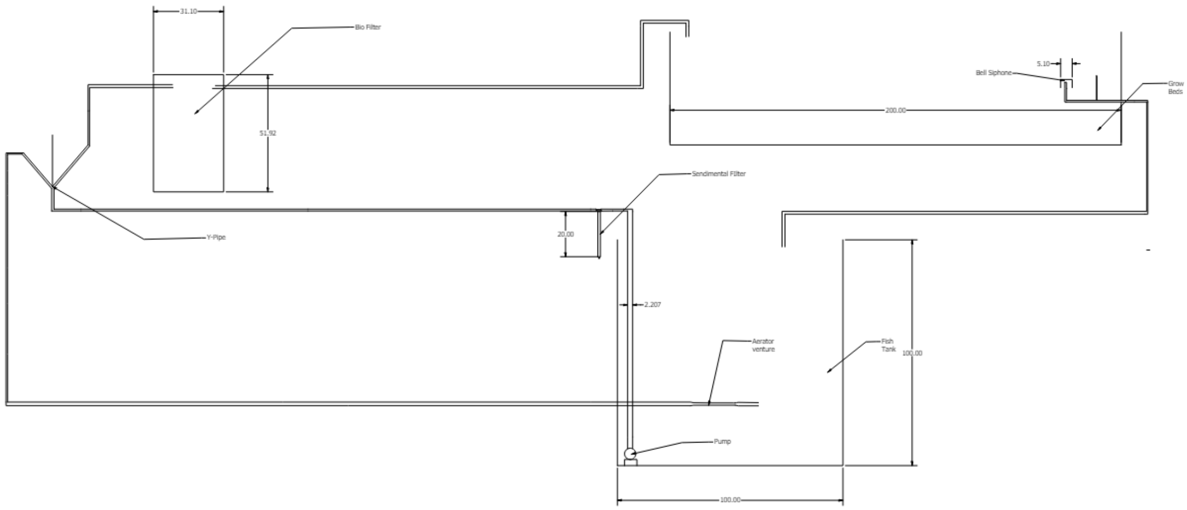
DISCLAIMER: just like with the theoretical calculations, we can't find products in the market that match exactly the characteristics of our parts. Hence, while these drawings are purely based on theoretical calculations, the actual sizes and parameters will depend on what's available in the local market.

Also, for the side view, some components have been replaced with simple shapes which would otherwise be too complicated to draw.

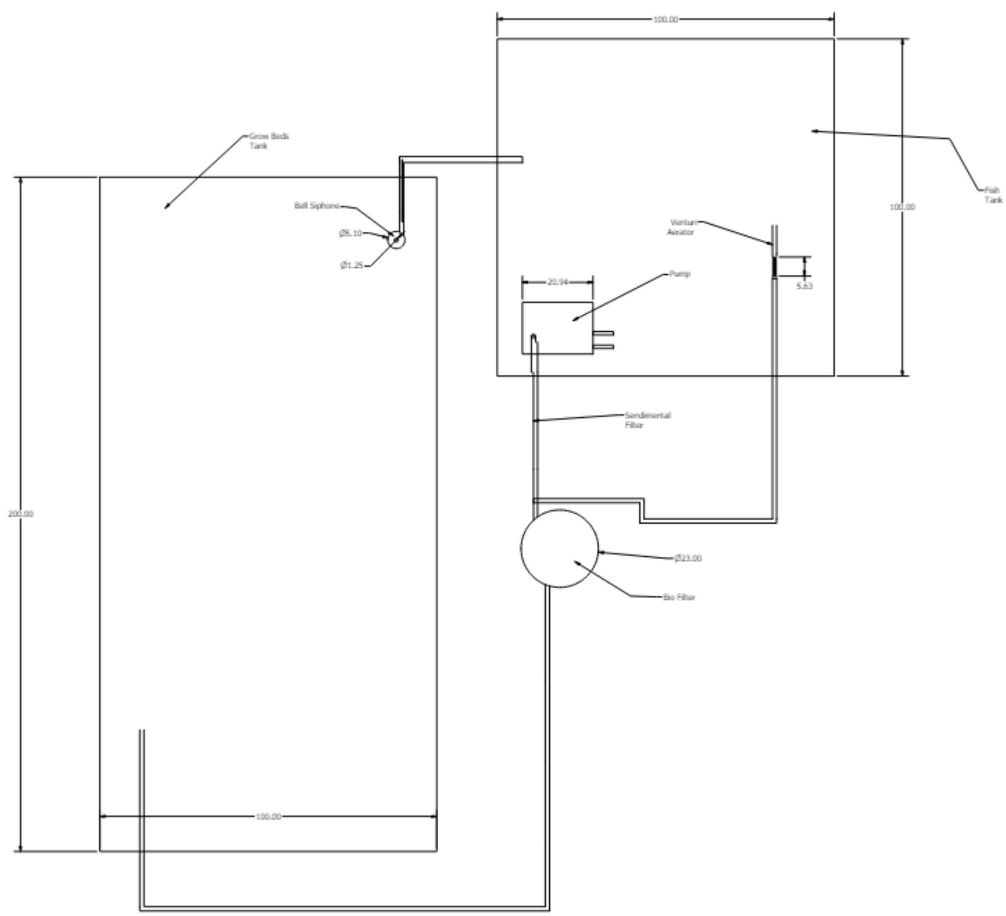
2.7.1 Side View



2.7.2 Front View



2.7.3 Top View



2.8 Market Analysis

1. Fish Tank

Size:

.5m*1m*1m

Where to Buy and Prices:

- Nelson Pade:
  - 55-gallon cone-bottom round tank: $262.50
  - 150-gallon flat-bottom rectangular tank: $475.00
  - 200-gallon flat-bottom round tank: $477.50
  - Available at [Nelson Pade](https://www.aquaponics.com)
- Regatta Tanks:
  - Custom aquaponics fish tanks available upon request.
  - Contact via [Regatta Tanks](https://www.regattatanks.com)

2. Grow Bed

Material and Size:

2 * 2* 2.5

Where to Buy and Prices

- Nelson & Pade: Custom grow beds and media available. Contact for specific prices on their [website](https://www.aquaponics.com)

- Amazon: Various DIY aquaponics kits include grow beds and media.

-Aqua Sprouts Garden ($170), VIVOSUN Aquaponic Fish Tank ($80)

Water Pump

Where to Buy and Prices:

- Amazon: Prices range from $20 to $150 depending on capacity and brand.

: Offers water pumps specifically designed for aquaponics systems, available on their [website](https://www.theaquaponicsource.com)

3. Biofilter

Where to Buy and Prices:

- https://www.theaquaponicsource.com).

- Nelson & Pade:(https://www.aquaponics.com)

4. Mechanical Filtration

Where to Buy and Prices

- Nelson & Pade Included in their Clear Flow Aquaponic Systems® packages, available on their [website](https://www.aquaponics.com

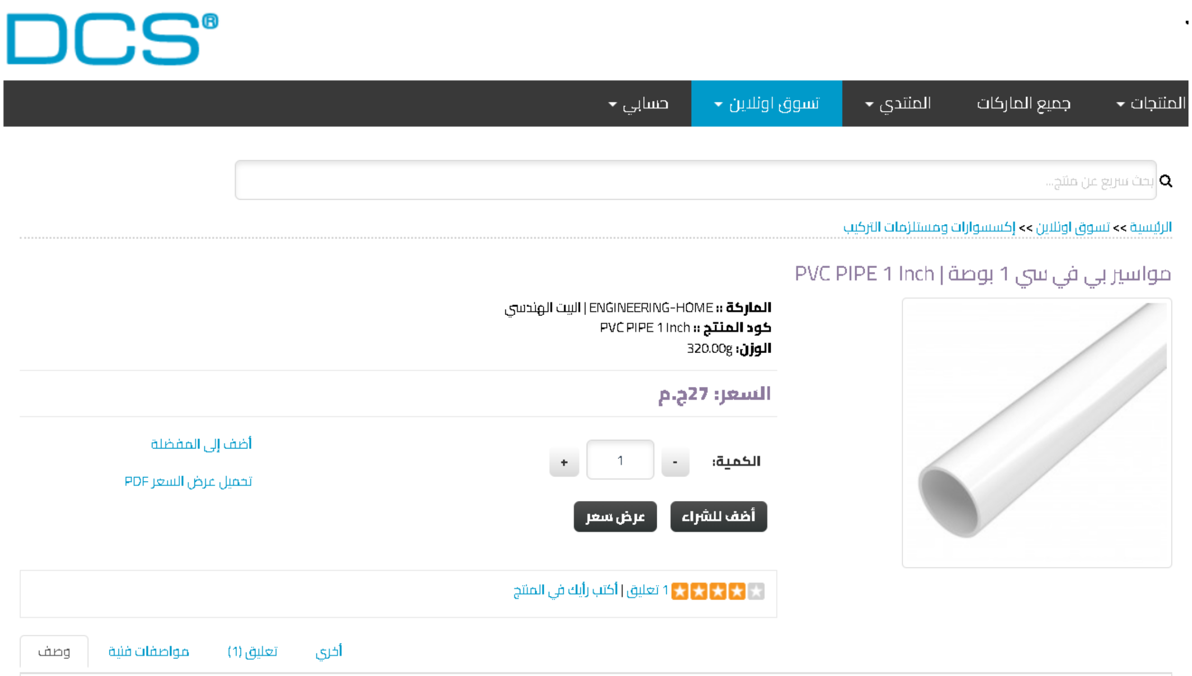
5. Bell Siphon

.

Where to Buy and Prices

- Stores and Online : Bell siphons can be purchased from various online retailers, including Amazon, with prices ranging from $10 to $50 depending on size and design.

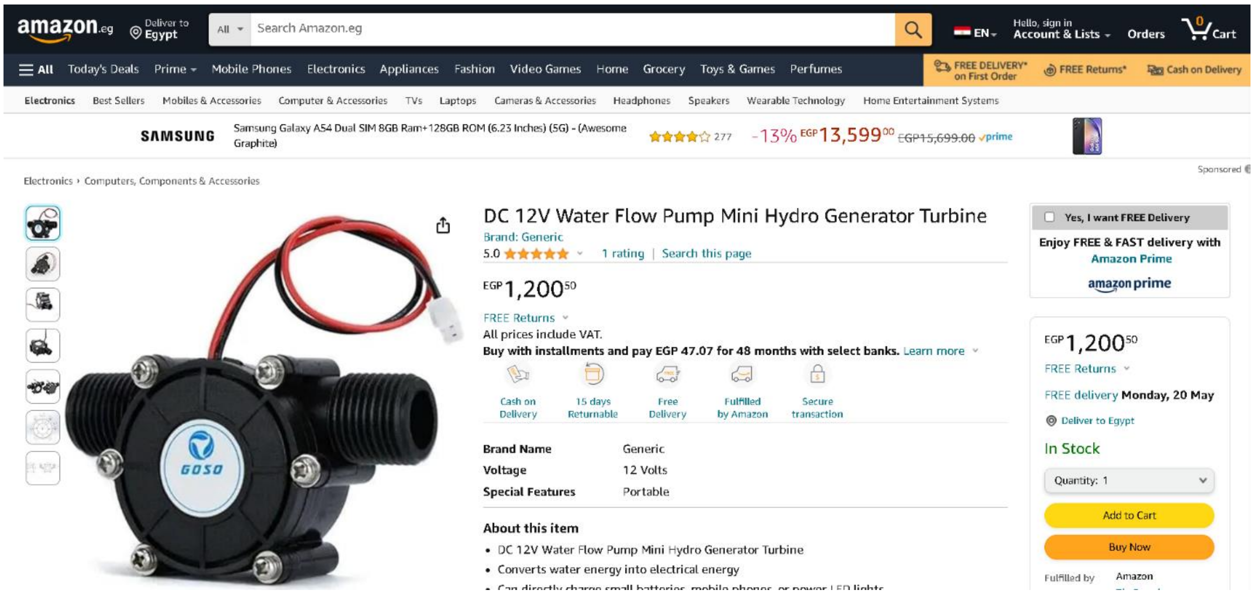
Pvc :
https://www.dcsmisr.com/%D8%B4%D8%B1%D8%A7%D8%A1-%D9%85%D9%88%D8%A7%D8%B3%D9%8A%D8%B1-1-%D8%A8%D9%88%D8%B5%D8%A9-%D8%A7%D9%84%D8%A8%D9%8A%D8%AA-%D8%A7%D9%84%D9%87%D9%86%D8%AF%D8%B3%D9%8A-%D8%A8%D8%A7%D9%84%D9%85%D8%AA%D8%B1.html

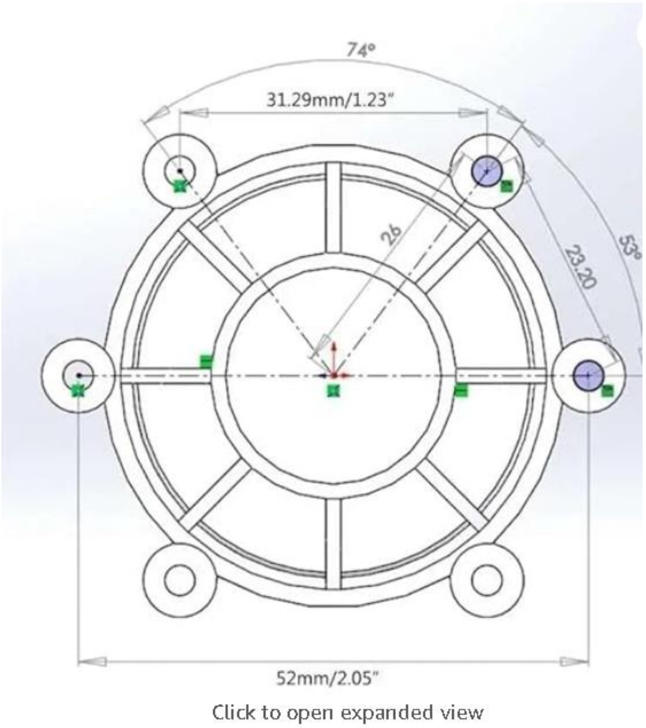


Pump :

https://www.amazon.eg/%D9%83%D9%87%D8%B1%D8%A8%D8%A7%D8%A6%D9%8A-%D8%A8%D8%AA%D8%AF%D9%81%D9%82-%D8%A7%D9%84%D9%85%D9%8A%D8%A7%D9%87-%D8%A8%D8%AA%D9%8A%D8%A7%D8%B1-%D9%85%D8%B3%D8%AA%D9

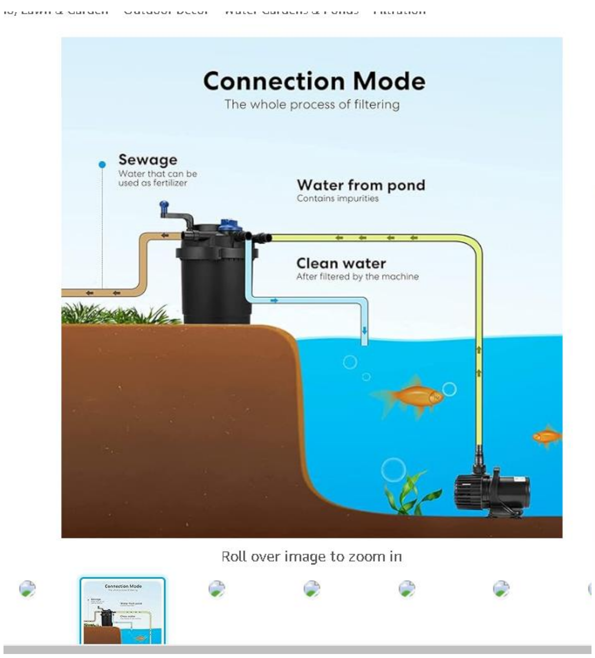
%85%D8%B1%D8%8C/dp/B0CHWM4W6W/ref=asc_df_B0CHWM4W6W/?tag=egoshpaddear-21&linkCode=df0&hvadid=545103391899&hvpos=&hvnetw=g&hvrand=12205362672943661887&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9112388&hvtargid=pla-2237533227071&psc=1&mcid=1892d7a4c5d5326a82868fa9a5c153f7





Bio filter

https://www.amazon.com/VIVOHOME-Pressure-13-watt-Sterilizer-Gallons/dp/B07Y1FYJGC/ref=sr_1_1_sspa?dib=eyJ2IjoiMSJ9.8E458HokM6olqNFigIhLNAkIG67eCqfVyLwlvmDgrzH88XRrmGgyqz7L_hNy6Xf1wovAevi8JiFRZqbKUjI1JDRBFszxOCxrWD7MHspeKQr4-YtIPvsd67uI-R8rYzO-7BfLC0flo0o0HHjMVXIKK-0WLnamR1z1Ou5nyKFwy64JLaYPb5yvItzT5qpmTv_cMez5V97OOBwT1pPyZHxHbxOCK4G5sXGpS0HbXEEc3r2IlLy6X-1_dPsaSz1RCAVPaqRHB4xtA1AU5frlNV3ky8vOwUDNeRebaV_dWeUJQfU.ys4Kfh_0vFVAFQZphdmIgl6_enV0HpXihBWkgFZgMkw&dib_tag=se&keywords=Bio%2BFilter&qid=1715550644&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&th=1



Sendiment filter

https://www.ebay.com/itm/253259612188?chn=ps&norover=1&mkevt=1&mkrid=711-166974-028196-7&mkcid=2&mkscid=101&itemid=253259612188&targetid=2274564709393&device=c&mktype=pla&googleloc=9112388&poi=&campaignid=21266539599&mkgroupid=162443905415&rlsatarget=pla-2274564709393&abcId=9414513&merchantid=118868255&geoid=9112388&gad_source=1&gclid=CjwKCAjw0YGyBhByEiwAQmBEWn3xvt1jY7DgkJZVZKJCnoDrS2oEIy7dMHChAlSGUGPlcaZAkHtewBoCYa0QAvD_BwE

Bell Siphon for Grow Bed

Cost: $110

Available on: https://www.eppinghydroponics.com.au/products/bell-siphon-for-grow-beds

Suitable for 225mm grow beds.

2.9 Summary of cost

With all the information above, the estimated cost (by adding up the prices listed above) for designing and building a small-scale aquaponics system is approx. **$1900**.

Part 3: Results

After conducting extensive research and calculations, a small-scale aquaponics system design has been proposed. The aquaponics system is designed to create a symbiotic relationship between fish and plants, where the waste produced by the fish provides nutrients for the plants to grow, and the plants filter the water for the fish. The proposed system has three main components: the fish tank, the grow beds, and the water circulation system.

The fish tank is designed to be cubic and span $1m^2$, with a capacity of no less than 1000 liters. To maintain optimum water conditions, the tank contains a filtration system consisting of a radial flow separator and a submerged pump. The radial flow separator separates the solid waste from the water, while the submerged pump pumps the water to the grow bed.

The grow bed is designed to be rectangular and X meters in length, Y meters in width, and Z meters in height, with a capacity of U liters. The grow bed is filled with gravel and will be used to grow vegetables. The water is pumped from the fish tank to the grow bed, and the plants absorb the nutrients and filter the water before it is returned to the fish tank.

The water circulation system consists of a pump, pipes, and valves. The pump is used to circulate the water from the fish tank to the grow bed, and the pipes transport the water from the fish tank to the grow bed and back. To maintain the oxygen levels and proper distribution of nutrients to the plants, the circulation rate is designed to be 300 liters per hour.

Part 4: Conclusion

In conclusion, the proposed design of a small-scale aquaponics system provides an affordable and sustainable source of fresh food production. The estimated cost for designing and building the system is $1900, and it has several advantages such as increased crop yield, reduced environmental impact, year-round production, improved food security, and efficient use of water.

Part 5: Recommendations

- The theoretical analysis part could be done much better, finding balance between factors to neglect (such as in the bell siphon part for the trap and bell diameters) would contribute much better for the project.
- Regular maintenance of the aquaponics system to ensure it is functioning optimally. This would include cleaning filters, aerators, and testing the chemical balance of the water.
- Consideration of the initial and ongoing costs of the system, including fish, plants, and equipment upkeep.
- Implementation of a system to monitor water quality parameters on an ongoing basis, as this will ensure the health and well-being of the fish and plants.
- Consideration of the appropriate fish and plant species for the local climate and other environmental conditions.
- A focus on sustainability and energy conservation, such as selecting a solar-powered air pump and reducing the amount of waste produced by the system.
- Continuous education and awareness-raising within the community about the benefits and methods of aquaponic systems to promote food security and sustainability for future generations.

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