Principles of Engineering

Space Technology

MISSION TO MARS – SUSTAINABLE LIFE SUPPORT

Mission 1 – Vertical Farming

Objective:

At the completion of this mission, you will demonstrate how Vertical Farming works. You'll then design a model of a plausible Vertical Farming project.

Briefing:

Nomenclature:

Vertical Farming	Hydroponics	Green Technology
Conventional Farming	Aquaculture	Sustainability
Dry Land Farming		

Research Resources: *Use a search engine to search for information regarding Vertical Farming.*

Institution	Web Site	Description
Popular Science	http://www.popsci.com/environment/gallery/2008-09/inside-vertical-skyscraper	Pictorial guide depicting a possible solution for conserving resources in farm design.
	http://www.popsci.com/node/23573	Shows how vertical farming can solve existing problems with agriculture.
	http://www.verticalfarm.com/PDF/PopSci-Jul-2007.pdf	Popular Science article outlining the concept of vertical farm design.
The Vertical Farm Project	http://www.verticalfarm.com/designs.html http://www.verticalfarm.com/media.html	Nonprofit site containing information from a wide variety of sources regarding vertical farming.
Uni-Aqua	http://www.uni-aqua.com/html/technology_biofilters.htm	Bio-filter data and information.

Questions:

1. Research and develop a detailed definition for each of the terms found in the Nomenclature section of this document. Many words have multiple definitions. Some of which may have nothing to do with the field of Vertical Farming. Make sure your definition falls within the context of this lesson.
2. What is the largest cost regarding today's method of farming?
3. What is the benefit of vertical farming over conventional farming?
4. How can vertical farming alleviate global climate change?
5. List the products that can be produced using a vertical farming technique.
6. List the products that cannot be produced using a vertical farming technique.
7. What are the harmful byproducts of conventional farming as opposed to vertical farming?
8. Where do vertical farms exist… or are being constructed right now?
9. Describe how resources are saved or renewed when using vertical farming technology?
10. Under what conditions would a vertical farm not work?
11. Pencil sketch a design of a vertical farm. Label the component parts while describing their function.

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Procedure: The Vertical Farm Mockup

Required Materials and Equipment: Get these materials and tools from your instructor.

Steps:

1. ( )

Debriefing:

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Space Technology

MISSION TO MARS - AQUAPONICS

Mission 1 – Introduction

Objective:

At the completion of this mission, you will demonstrate how an Aquaponics system works. You'll then assemble a working model of an Aquaponics system.

Briefing:

One of the problems that engineers, scientists, and astronauts will have as they plan bases on our Moon or Mars is coming up with renewable resources for food, water, and air. Launching spacecraft to re-supply these bases will be costly and dangerous. This coupled with the long space flights and a degree of uncertainty make local renewable resources (like Aquaponics) desirable if not essential. Aquaponics systems produce vegetables and fish, as well as, cleanse wastewater and convert CO_2 to Oxygen. They also produce organic material that can enrich otherwise barren soil. Ultimately, fresh vegetables and fish are a healthier choice and Aquaponics may be the only way for those working in space to enjoy them.

Fig 1. Even a small classroom aquaponics systems can produce a lot of food.

As the name implies, aquaponics is the combination of Hydroponics and Aquaculture (Fish Farming). Essentially, it's a delicate balance between meeting the needs of the fish, maintaining the quality of their water, and providing for the growth of the fish and plants. Aquaponics systems are, in fact, closed systems where fish excrete waste into their water, which feeds the plants causing them to grow, bear fruit, and multiply. The plants remove some harmful waste from the water and produce food not only for people but for fish as well. Plants also convert CO_2 into Oxygen… very important on a Moon or Mars base. Unlike soil, the plant cup gravel does not provide nutrition for the plants. All nutrients come from the fish waste in the water. The gravel holds the plant's roots, but its primary function is as a bio-filter. It holds bacteria that metabolize the remaining waste converting it to inert organic material. This maintains the water quality so the fish stay healthy, grow, and reproduce. That's good because fish are not only a great resource for protein, but quite tasty… especially if the only other choice is NASA "food in a tube."

How Does an Aquaponics System Work?

Now that you know what and aquaponics system is… Here's how it works. There are four parts to an aquaponics system. All parts need to be carefully considered and monitored closely to insure not only the health and balance of the system, but to maximize food production and the waste water processing.

- ***Water*** – All living things need water. Plants and animals need it to help metabolize food and flush away waste, but for fish… Water is their environment. Water carries the air they breath and transport waste away. Water can support plant and animal life only if it's relatively free from pollutants and pathogens. That's why it's important to wash everything that comes into contact with the aquaponics system. The smallest amount of soap under a fingernail can kill an entire Culture Tank. Everything that goes into the system is washed with water, and water, only.
  Temperature, water hardness, PH, and dissolved gasses are also important qualities that effect fish health. Different species of fish and plants do better at a different temperature, water hardness and PH levels. Some dissolved gasses like ammonia (NH_3), Carbon Dioxide (CO_2) and chlorine (Cl) are dangerous to fish and need to be monitored and controlled. City utilities often add chlorine to the water supply to kill micro-organisms that can make people sick. However, chlorine also kills fish so let the water stand in a safe water container at least 24 hours before adding it to the system. This allows the chlorine to evaporate away. Water hardness and PH must also be monitored and controlled. Generally speaking, the softer the water

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and the more neutral the PH, the easier it is to control ammonia and pathogens. These conditions are normally optimal conditions for aquaponics systems.

- ***Fish Stock*** – Selecting the best species of fish for an aquaponics system depends upon a many things.
  - Can the fish be consumed by people?
  - What does the fish eat?
  - Does the fish produce waste that can be processed by the selected plant stock?
  - Can the fish thrive and reproduce in the designed aquaponics system?

  It's important that the fish stock matures and grows to an edible size in a relatively short period of time. It doesn't make much sense to choose a fish that can't reproduce quickly enough to harvest or thrive in conditions the system can't support. The species must also eat what's grown as plant stock so obviously we're looking for vegetarian fish. Furthermore, the selection must thrive in the provided water hardness, PH, and temperature. Finally, the fish must produce waste that the plant stock needs to grow and produce. Selecting the appropriate fish stock will require a significant amount of research.

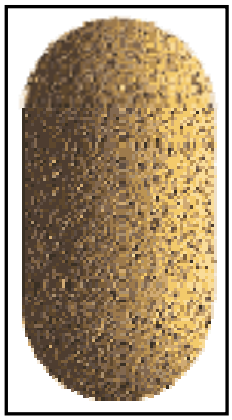

Fig. 2 – Ceramic and Natural Bio-Filter Media. This granules measure only 2x4x6 mm in size but because of all their nooks and crannys, it has a specific surface area of about 4.6 M^2.

- ***Bio-filter*** – Standard mechanical filters cleanse water. They trap particulates and depending on the filter's efficiency, can remove objects as small as a few microns in size. Mechanical filters can make clear water, but do little to control pathogens or the ammonia fish produce in their waste. Bio-filters are designed to host bacteria that breakdown Ammonia into Nitrate in a process called nitrification.

  Multi-step filters include both a mechanical and bio-filter. The mechanical filter, typically fiber matt or wadding, removes organic material and other particulates that could keep its bio-filter from working. The bio-filter mechanism is really a bunch of inert, but porous pebbles that trap some very useful bacteria. The pebbles are so porous that each granule's specific surface area (SSA) so large that it's measured in square meters. It's these microscopic nooks & crannies where the good bacteria live. As water is filtered and then circulated through the bio-material, the bacteria feeds on the Ammonia converting in to Nitrate.

  The bacteria that breakdown of these organic compounds require oxygen to do the job. They also produce carbon dioxide as they work so it's important that the water circulating though a bio-filter is sufficiently aerated to get maximum nitrification.

  Generally speaking, the nitrification process can be separated into two processes:

  $NH_4^+ + 1½\ O_2 \rightarrow 2H^+ + NO_2^- + H_2O$

  $NO_2^- + ½O_2 \rightarrow NO_3^-$

  The first process is mainly carried out by a group of bacteria called ***Nitrosomonas***, and the second process by a group of bacteria called ***Nitrobacter***. Essentially, the bacterium uses Oxygen (O_2) to facilitate the separation of NH_4^+ (Ammonia) in Hydrogen, Nitric Oxide (NO_2^-) and Water (H_2O). The second bacterium then combines the Nitric Oxide with Oxygen (O_2) to create Nitrate NO_3^-. Nitrate is much less harmful that Ammonia. It takes about six weeks to grow enough bacteria to start bio-filter operation.

- ***Growing Media*** – The soil found on Earth is quite different than soil that's found on the Moon or Mars. Earth's soil is a combination of different minerals, a few trace metals, and lots of organics (decayed vegetation and animal waste).
  This combination of materials provides plants with nearly everything they need to grow and produce. The soil on the Moon and Mars has no organic base because there are no plants or animals on the Moon or Mars. Although Martian soil may contain important minerals for plant growth, it's missing many elements that can only be provided by an organic base. It's also important to realize that what's in the soil also makes its way into the plant. Moon soil has a lot of Aluminum in it. Therefore, a plant grown in Moon soil would also have a lot of aluminum in it. Even small amounts of aluminum in a person's diet will short-circuit their nervous system. For a Moon Base operation, astronauts would have to bring their own growing media.

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Growing media in an aquaponics system performs two functions. It holds the plant's roots and acts as a bio-filter. The media must be coarse enough to allow water to easily drain but also protect the roots from exposure to air. Fine gravel (1mm to 2mm Diameter) is a good choice. Gravel is also porous enough to act as an adequate home for bacteria that aid in the nitrification process. It's important to note that plants in an aquaponics system receive all of their nutrients from the fish waste in the water. None comes from the growing media as with land farming.

- ***Plant Stock*** – The plants remove the waste from the Culture Tank's water as nutrients, produce Oxygen, and feed the fish and farmer. Selecting adequate plants is a difficult balance between the needs or the plant, fish and farmer. Certain fish produce a particular type of waste… Only certain plants can use that waste to grow and produce a harvest… There's just a few fish that eat vegetation that can be grown in an aquaponics system… Because of the nature and difficulty of bringing a space borne aquaponics system into operation, the vegetation needs to be hearty and produce the highest nutrition possible. Selecting the best plant stock requires a bit of research and a lot of experimentation.

Nomenclature:

Aquaponics	Culture Tank (Stock Tank)	Filter Box
Hydroponics	Growing Media	Bio-filter
Aquaculture	Siphon	Nitrification
	Pump	Nitrosomonas Bacteria
		Nitrobacter Bacteria
Growing Methods (Drip, Ebb & Flow, and Nutrient Film Technique (NFT))		Specific Surface Area (SSA)

Research Resources:

Institution	Web Site	Description
Carolina	http://www.carolina.com/tips/97jan/0197a.asp	Describes how to set up an aquaculture in the classroom
Arizona	http://ag.arizona.edu/azaqua/extension/Classroom/home.htm	Shows how aquaculture and agriculture can be integrated, just as we are doing.
Team Ag Ed	http://www.teamaged.org/aquaculture/	General information on what aquaculture is and how it works.
Univ. of AZ	http://www.b2science.org/	Biosphere 2 closed system experiment.
Uni-Aqua	http://www.uni-aqua.com/html/technology_biofilters.htm	Bio-filter data and information.

Questions:

12. Research and develop a detailed definition for each of the terms found in the Nomenclature section of this document. Many words have multiple definitions. Some of which may have nothing to do with the field of Aquaponics. Make sure your definition falls within the context of this lesson.
13. Explain in detail why an aquaponics system would be desirable for a manned Moon or Mars base?
14. List five (5) water qualities of an aquaponics system that must be closely monitored to insure the health of the fish and plants?
15. What are the two parts of a multistep filter?
16. Explain what nitrification is, how it works, and why it's important.
17. How does a large Specific Surface Area help bio-filters operate more efficiently?
18. Why would an aerator need to be placed in the system's filter box instead of the Culture Tank?
19. Why can't Moon soil be used in a Moon Base aquaponics system?
20. What are the two functions of the growing media in an aquaponics system?
21. What kinds of fish and plants are most often used in fresh water aquaponics farms on Earth?

Procedure: The Aquaponics System Mockup

Required Materials and Equipment: Get these materials and tools from your instructor.

Wood for Base and Supports	Aquarium or Water Tank	Drain Tubing and Fittings
PVC Tube (110mm or 4")	Recirculation Tube and Fittings	Siphon Tube
PVC Fittings	Filter Box, Bucket, or Jug	Gravel
PVC Tube Clamps	Aquarium Heater	Water
PVC Tube (75mm or 3")	Water Pump(s)	Fish
Nylon Wire Ties	Air Pump and Aerator	Seeds

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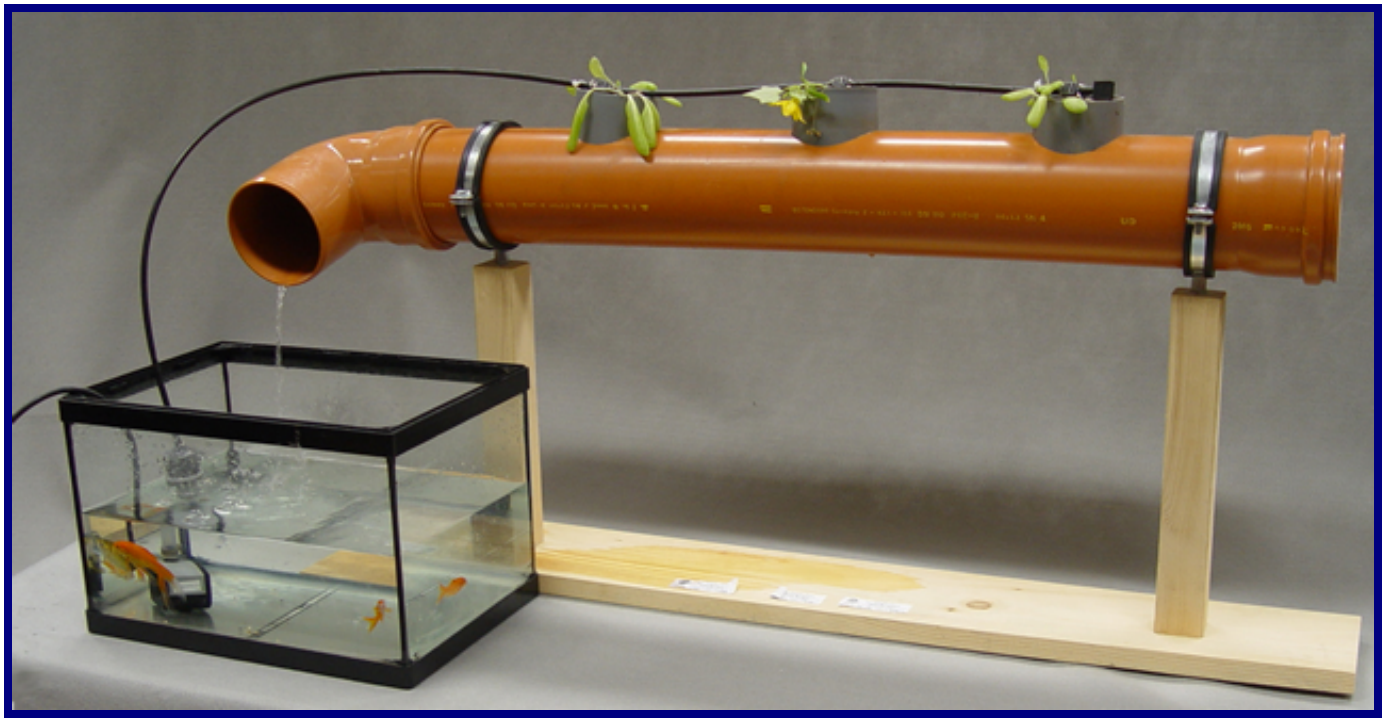

Fig. 3 Aquaponics (Trickle) Mockup - There are many ways to construct a productive aquaponics system. The desired size of system's yield determines the limitations of any specific design. With a few small differences, nearly all designs are functionally the same. Culture tank, bio-filter, growing media and a way to circulate water is all that's needed. Referring to the photographs and drawings in this unit, it would be relatively simple to come up with a successful design. Here are the basic steps for putting together a working aquaponics system.

Important: *Cleanliness is the most important consideration while constructing an aquaponics system. The smallest amount of oil, soap, detergent, or solvent can have a devastating effect on fish and plants. Everything that will come in contact with the water must be washed with water only… Hot water and lots of it… DO NOT USE SOAP and that includes on hands!*

15 Steps: Refer to Figures 3 and 4 as you construct the Aquaponics Mock Up. Complete each of the following steps in the assigned order:

2. ( ) Choose either a Trickle or Ebb and Flow design.
3. ( ) Assemble the Base to support the Channel.
4. ( ) Assemble the Channel to drain water from the plants. PVC tubing (110mm Diameter) and fittings make a good Channel. Cap the ends of the PVC tubing to hold the water.
5. ( ) Assemble the Plant Containers. 75mm PVC tubing is good, but Styrofoam or plastic cups work well too. The Plant Container needs to be designed to accommodate either a Trickle or Ebb & Flow circulating system.
6. ( ) Fill the Plant Containers with gravel to 25mm below the top of the container and install in the channel.
7. ( ) Plant a single seed in the center of each container buried 10mm deep.
8. ( ) Setup the Channel drain so it empties directly into the Culture Tank.
9. ( ) The Culture Tank can be anything that holds water and won't poison the fish. An aquarium is nice, but a plastic tub will work fine. The larger the Culture Tank, the more stabile the system and the larger the fish can grow. Place the Culture Tank so it Channel can empty into it.
10. ( ) Assemble the Filter Box to include both a mechanical and bio-filter. Install the circulating pump so it moves water from the Filter Box up to the Plant Containers. The top of the Filter Box and Culture Tank must be the same height.
11. ( ) Secure the Recirculation Line to each Plant Container so the water will drip over the planted seed.
12. ( ) Fill the Culture Tank with tap water and start a Siphon from the Culture Tank into the Filter Box.
13. ( ) Install an aquarium heater adjusting the temperature to 80 F.
14. ( ) Let the system sit for at least a day for the Chlorine to evaporate and the water temperature to stabilize.

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15. ( ) Install the Aerator in the Filter Box.
16. ( ) Add fish to the Culture Tank, but be sure to allow the fish to acclimate to the Culture Tank for 15 minutes before opening the transport bag into the tank.

Remember… Everything gets washed with hot water only!

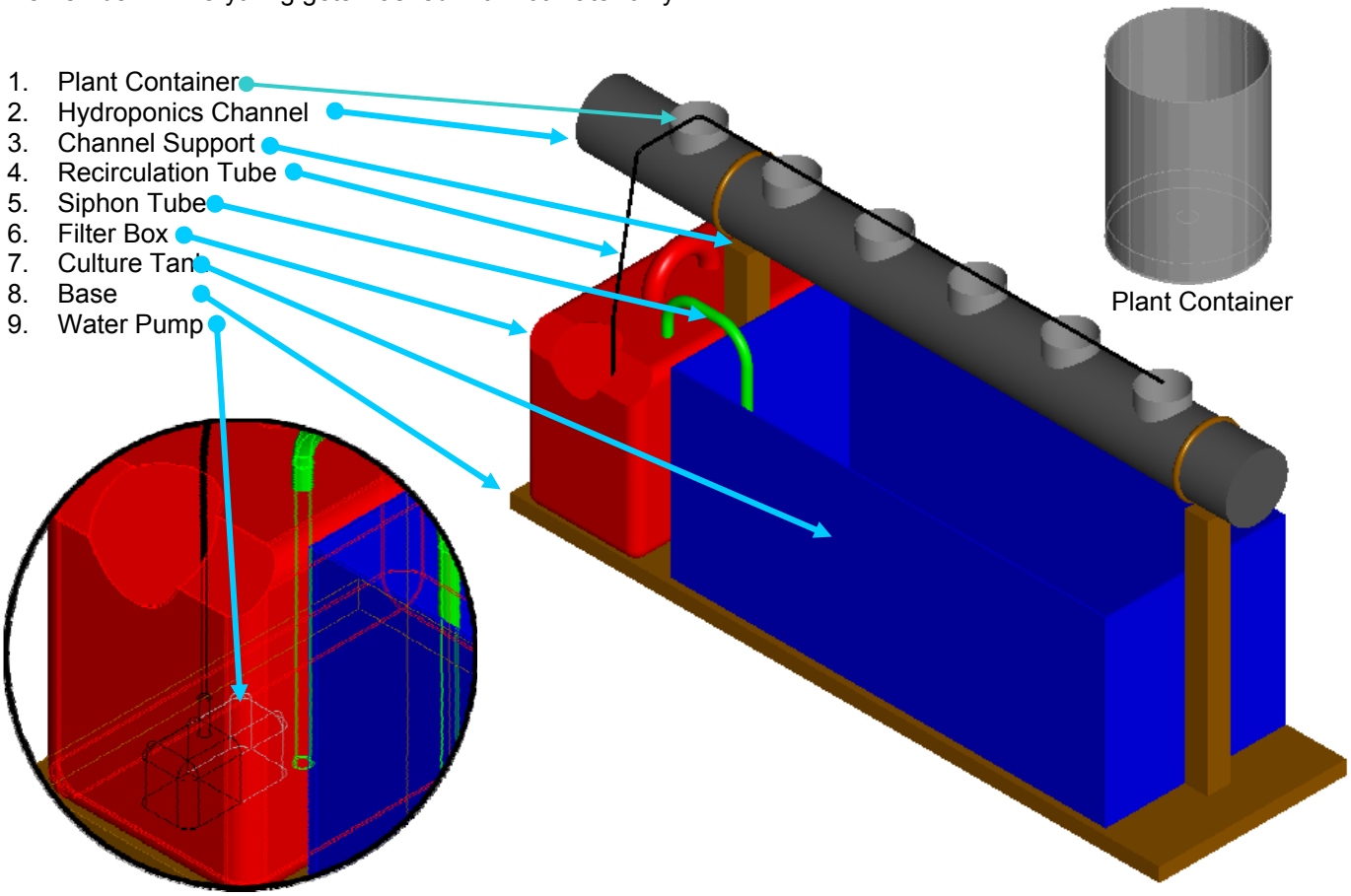

Figure 4. Aquaponics Mockup System

Debriefing:

In completing this mission, you have designed and assembled the essential elements of a working aquaponics system. You have learned that the hydroponics bay, culture tank, bio-filter, fish and plants form a closed system where the waste of one part benefits the other.

You have researched some special terminology used to engineering an aquaponics system and, in doing so, learned that only certain plants and fish are suitable choices. You have also learned how bio-filters use bacterial nitrification to break the Ammonia found in fish waste into nitrates and other gases that can be processed by plants.

Since this is a space technology course, our interests lie in the engineering and design aspects of how an aquaponics system could work on a Moon or Mars base. This mission introduced you to aquaponics technology. In the remaining missions, you'll study and engineer the individual components and you maintain a fully functional aquaponics system.

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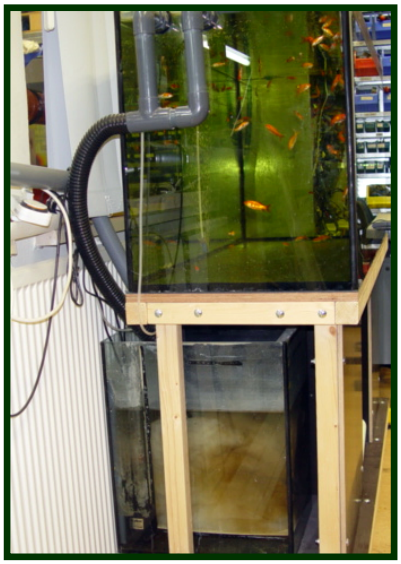
The Working Aquaponics System

Hydroponics Bay: The Hydroponics Bay is the nitrification system for the Culture Tank. It's one long tube which carries water from the plants that are grown in individual Plant Containers. Water from the Culture Tank is used to water and feed the plants. The gravel in the Plant Containers holds the bacteria that breaks down the Ammonia in the waste water and returns clean water to the Culture Tank. Fluorescent lamps are used to provide the light needed to grow the plants. Lighting is controlled by timers giving the plants a normal summer's duration of light. The recirculation tube from the Filter Box constantly drips water into the center of each Plant Container. Water pressure is maintained by a separate pump and water escapes at each T-Fitting in the recirculation tube.

Culture Tank: The fish are fed dry fish food and little bits of lettuce from the Hydroponics Bay. It's important not to overfeed the fish. The excess food on the bottom of the tank promotes the growth of harmful bacteria which removes needed Oxygen from the water. A delicate balance between the number of fish and plants must be maintained. If there are too many fish with a small number of plants, the water isn't adequately cleaned. However, if there aren't enough fish, the plants will not receive the nutrients needed to thrive. It's also important to maintain the proper water level and water temperature in the tank. If the water level is to low, minerals become concentrated in the water. If the temperature in not correct, the fish cannot reproduce. Before adding water, make sure it sits for a day to allow any Chlorine to evaporate.

Plant Container: Because the plants are grown in gravel only, they must rely on the nutrients from the water to thrive. The bacteria in the gravel break down the Ammonia in the fish waste into nitrates and other relatively inert elements. The water pump in the Filter Box forces the filtered water through the Recirculation Tube and to each Plant Container in the Hydroponics Bay.



Filter Box: Solid waste must be filtered away before the water can be pumped to the Plant Containers. Otherwise, the organic material will clog the pores in the bio-filter material. The mechanical filter in this photo is aquarium filter wadding. The Recirculation Pump and Tube forces water through the filter wadding up into the Plant Containers. Gravity brings the water back into the Filter Box for pumping to the Culture Tank.

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Principles of Engineering

Space Technology

MISSION TO MARS - RENEWABLE RESOURCES

Mission 2 – Aquaponics: Water Quality Assessment

Objective: In this mission, you will complete a series of tests (temperature, ammonia, hardness, alkalinity, pH, nitrite and nitrate) on the water used in an aquaponics system. You will demonstrate how each measurement determines water quality and how to adjust water quality for optimum conditions.

Briefing: Fish and plants are open biological systems meaning… whatever is in the water, through the process of osmosis and digestion, is also part of them. That's why it is very important that chemical and mineral levels in the water stay at a safe level. If water conditions are not correct, fish will not grow or breed, and could in fact, get sick or die. Since the goal of an aquaponics system is to produce fish and plants for consumption, frequent monitoring of water quality is essential. Bacteria grow on the surface of the biological filter media where they feed on the toxic soluble waste products that are produced by fish. Although over 400 species of microorganism have been identified as feeding on these soluble waste products, most can be divided into two main groups: those that consume ammonia and those that consume nitrite.

Fig. 1 – Here's an example of a complete water test kit used to evaluate a freshwater aquarium.

Algae are plants that feed off of excess Nitrate. The presence of excessive algae indicates a poor water quality or water maintenance. There are 4 types of Algae - Brown, Green, Blue, and Red. Brown Algae are generally considered harmless algae. It looks like a brown coating on the glass. Green Algae looks like light green threads of algae growth on tank hardware. These algae are also considered harmless and actually indicate that water conditions are good. Blue Algae is blue greenish in color and indicates an excess of nitrates and/or phosphates in the water. As the nitrate and phosphate levels are lowered this algae should disappear. Red Algae is a not easy to get rid of usually appears on plant leaves. The balance of an aquaponics system is key to production success. I all cases… It the nutrients that Algae require to grow are kept at low levels, the Algae growth will remain controllable.

The Water Test Kit

Each water test kit contains its own instructions for use and is specifically designed to test the water quality for fish. Follow the instructions that come with the kit. ***Always test water in a clean test vile. Never apply testing solution directly into the culture tank.*** This will harm the fish. What follows are sample instructions:

pH Test -*Tests the Water's Acid/Base Level*

1. Fill a clean test tube up to the white line with water from the aquarium.
2. Making sure you are holding the bottle straight upside down, add three drops of pH Indicator Solution (not High Range pH).
3. Cap the test tube and invert it a few times to mix it.
4. Determine the pH reading by matching the color of the solution against those on the **pH color chart** card. The tube should be viewed against the white area beside the color chart. Color comparisons are best made in a well-lit area. The closest match indicates the pH of the water sample.
5. Rinse the test tube with clean water.

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Ammonia Test – *Tests the Water's Fish Waste Level*

1. Fill a clean test tube up to the white line with water from the aquarium.
2. Add 8 drops from **Ammonia test Solution Bottle #1,** holding the bottle upside down in a completely vertical position.
3. Add 8 drops from **Ammonia Test Solution #2,** holding the bottle upside down in a completely vertical position.
4. Cap the test tube and shake vigorously for 5 seconds.
5. Wait 5 minutes while the color develops.
6. Read test results by matching the test solution against the **Ammonia Color Chart** card. The tube should be viewed against the white area beside the color chart. The closest match indicates the ppm (mg/L) of ammonia in the water sample.
7. Rinse the test tube with clean water.

Nitrite Test – *Tests the Water's Fish Waste Level*

1. Fill a clean test tube up to the white line.
2. Add 5 drops of Nitrite test solution
3. Cap the test tube and shake for 5 seconds.
4. Wait 5 minutes for color to develop.
5. Read test results by matching color against those on the **Nitrite Color Chart**.

Nitrate Test– *Tests the Water's Fish Waste Level*

1. Fill a clean test tube up to the white line with water from the aquarium.
2. Add 10 drops from **Nitrate test solution bottle #1.**
3. Cap test tube and turn upside down several times to mix.
4. Shake **Nitrate test solution bottle #2** for at least 30 seconds.
5. Add 10 drops from **Nitrate test solution bottle #2.**
6. Cap test tube and shake vigorously for 1 minute.
7. Wait 5 minutes for color to develop.
8. Read test results by matching the test solution against the **Nitrate test Color Chart.** Rinse the test tube with clean water.

Microorganisms – *Indicates the Presence of Protozoa in the Water.*

1. Fill a test tube with tank water, and using a Pipette place 1 drop of water on a microscope slide.
2. Place a cover slip on the drop of water on the slide and place the slide on the viewing stage of the microscope.
3. Using a magnification of 40x, count the number of microorganisms that enter the view field within two minutes. Identify the types of microorganisms you observe.

Algae – *Measures the Amount of Algae Growth in the Culture Tank*

1. Draw a 4 inch test circle on the Culture Tank.
2. Examine the test circle and estimate amount and density the coverage of the algae in the circle in percentage. If the algae are closely packed together, they will block more light, and therefore, more opaque. If the algae are spread out, it will allow more light to pass through.

Nomenclature:

Aquaponics	Nitrate	Temperature
Water Hardness	PH	Evaporation
Alkalinity	Ammonia	Nitrite
Microorganisms	Algae	Opaque

Research Resources:

Institution	Web Site	Description
Hanna Inst.	http://www.hannainst.co.uk/acatalog/Optimum_Aquarium_water_quality_levels.html	Aquarium Water Quality
Wikipedia	http://en.wikipedia.org/wiki/Aquarium#Water_conditions	Basic Aquarium Operation
Fishlore	http://www.fishlore.com/Disease.htm	Freshwater Fish Diseases
Hobbyist	http://fins.actwin.com/mirror/disease-fw.html	Freshwater Fish Diseases
Univ. of FL	http://edis.ifas.ufl.edu/FA002	Dissolved Oxygen for Fish

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Questions:

1. Research and develop a detailed definition for each of the terms found in the Nomenclature section of this document. Many words have multiple definitions… Some of which may have nothing to do with the field of aquaponics. Make sure your definition falls within the context of this lesson. Each definition should be two sentences or more.
2. How does evaporation affect water quality in an aquaponics system? How can evaporation be prevented?
3. Create a chart listing each optimum measurement of water quality for fish.
4. What is the best way to control algae growth in an aquaponics system?
5. Name one type of protozoan that is harmful to fish?
6. What is the minimum amount of dissolved oxygen considered acceptable for fish growth?
7. What types of algae are harmful to an aquaponics system?
8. Which freshwater fish diseases are caused by poor water quality?
9. What qualities of the water are determined by what comes out of the tap?
10. What is the best water temperature range for fish?

Required Materials and Equipment:

Aquaponics System – Culture Tank Water Test Kit Water Test Strips
Thermometer

Procedure:

1. Follow the instructions in the water test kit completing the following table over 5 consecutive class periods.
2. Transfer the data to the Water Quality Assessment spreadsheet and generate a graphic model of the system's water quality. Save and print your data.
3. Compare your results with the established norms and report any discrepancies to the instructor recommending corrective action if necessary.

Water Quality Analysis Record
Culture Tank

Day	Date	Temp C°	Ammonia	Hardness	Alkalinity	pH	Nitrite	Nitrate	Micro-organisms	Evaporation
1										
2										
3										
4										
5										

Established Norms for Most Fresh Water Fish						
Temp	Ammonia	Hardness	Alkalinity	PH	Nitrite	Nitrate
30 C	0	200	120	7	0	20

Debriefing: Optimum Water quality promotes good fish health and helps encourage breeding. In completing this mission, you have demonstrated how to identify various measurable qualities of water and how to test and maintain water quality in an aquaponics system. As engineers design and build bases on the Moon and Mars, renewable food sources, as well as, an air and water purification systems are essential elements to life support operations. In fact, the aquaponics system may ensure the very life of astronauts. Therefore, periodic, accurate and reliable water quality monitoring and maintenance is a key skill required of any mission specialist.

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Space Technology

MISSION TO MARS - RENEWABLE RESOURCES

Mission 3 – Aquaponics: Automated Laboratory

Objective: In this exercise you'll set up a Microcomputer Based Laboratory (MBL) equipment and software to automatically monitor water quality.

Briefing: The LabPro is an MBL interface connecting various sensors to the Logger Pro software. The MBL equipment gathers data from a sensor probe and converts it to information the Logger Pro software understands. The data is then displayed in tabular and graph form. The LabPro can record single or multiple sensor probes on demand or run unattended over very long periods of time. Different sensor probes are used to measure different qualities and there are specialized probes for nearly every characteristic of water quality assessment.

Research Resources:

Web Site	Description
http://www.vernier.com/mbl/labpro.html	Contains all of the LabPro links and user manuals.
http://www.vernier.com/soft/lp.html	Logger Pro Software information and guides.

Required Materials:

If you don't have MBL equipment or software, check with you school's science department. They may have items you can borrow.

Data Collection Software – Vernier Logger Pro Software
MBL Interface – Vernier LabPro
Temperature Probe
Light Sensor
Dissolved Oxygen Probe

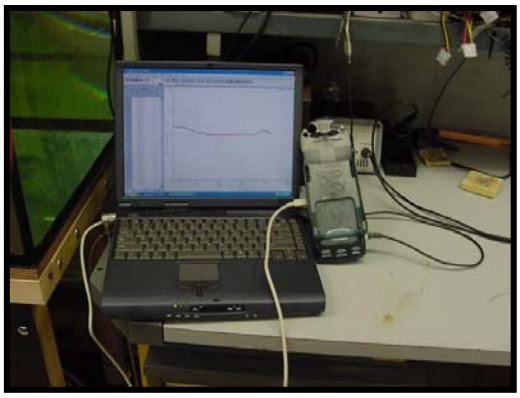

Fig. 1 Here's a MBL setup that's measuring water temperature automatically over weeks.

Procedure:

MBL Setup and Test

1. If necessary, install the LabPro device driver and Logger Pro software. Double click the Logger Pro icon to launch the program.
2. Connect the LabPro MBL interface as follows:
   - Power Adapter to the LabPro
   - Computer USB port between LabPro and Computer
   - CH1 - Stainless Steel Temperature Probe
   - CH2 - Light Probe
   - CH3 - Dissolved Oxygen Probe
3. When the **Connect to LabPro** window is displayed, click on **Connect to Port** and select **LabPro-USB** from the drop down list.
4. Select **File… New**
5. Select **Experiment… Sensors** and setup Channels 1, 2, and 3 with the corresponding sensors.
6. Select **Experiment… Data Collection** and set the **Time Base** to **5 Minutes** and the **Sample Rate** to **4 Samples per Minute.**
7. Select **Experiment… Start Collection.** Adjust the position of the Light Sensor and Grasp the Temperature Probe to warm it. Observe the results over time.
8. Select **Experiment… Stop Collection**

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9. Select **Experiment… Clear Latest Run**
10. Select **File… Save As… WaterQualityAssessment**

Extended Culture Tank Water Assessment –

IMPORTANT NOTE: Nothing goes into the Culture Tank unless it is free of contaminants. Soap, oil, cleaners, and chemicals can harm or kill fish and plants. Wash the Temperature and Dissolved Oxygen Probes in hot water (only) before placing them into the Culture Tank.

1. Adjust the Culture Tank's heater to 27° C.
2. Relocate the computer, LabPro, and Sensor Probes in close proximity to the Culture Tank. Situate the equipment for a two day test.
3. Place the Light Sensor on top of the Culture Tank in a dry location with full exposure to ambient light.
4. Suspend the Temperature and Dissolved Oxygen Probes into the Culture Tank so only the sensor portion of the probes is in the water.
5. Setup the LabPro interface and configure the Logger Pro software to measures Light, Temperature, and Dissolved Oxygen levels every 30 minutes over a 2-day period.
6. Save and Print your data.
7. Present the results to your instructor for verification.
8. Return the Culture Tank's temperature to 22° C.

Nomenclature:

Microcomputer Based Laboratory	Sensor (Probe)
Interface	Time Base
Dissolved Oxygen	Sample Rate

Questions:

1. Research and develop a detailed definition for each of the terms found in the Nomenclature section of this document. Many words have multiple definitions… Some of which may have nothing to do with the field of aquaponics. Make sure your definition falls within the context of this lesson. Each definition should be two sentences or more.
2. Regarding fish, plant, and filtering capacities… What is the optimal level of dissolved oxygen in an aquaponics system?
3. According to your collected data… What is the relationship between light and temperature levels in an aquaponics system?
4. What happens to the Culture Tank's ability to hold oxygen as the water temperature rises? Speculate how this would affect protozoan, fish, and plant health.
5. What other probes are needed to completely assess water quality for an aquaponics system?

Debriefing:

Have you ever noticed that cold water tastes better than warm water? As water warms, its molecules absorb more energy allowing soluble gases to escape. Cold water holds more oxygen and other gases which improves the taste of this essential liquid. There is a definite relationship between water temperature and its ability to hold oxygen. Far beyond taste, the level of dissolved oxygen in water affects plant and fish health. Water temperature, and therefore, the level of dissolved oxygen also have a profound affect upon levels of the bacteria that are required for water filtering (nitrification).

In this mission you demonstrated how to set up and use Microcomputer Based Laboratory (MBL) equipment. You also used data collection software (Logger Pro) to continually assess water quality over an extended period of time. Although this task focused on temperature, light, and dissolved oxygen qualities, probes are available to measure nearly every water characteristic that can be tested with a typical chemical water test kit.

Continuous monitoring of water quality using MBL is an important tool giving technicians greater control over complex systems.

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Principles of Engineering

Space Technology

MISSION TO MARS - RENEWABLE RESOURCES

Mission 4 – Aquaponics: Aquaculture

Exercise Objective: In this mission, you will research aquaculture and then demonstrate how to manage a productive farm fish.

Discussion of Fundamentals: Fresh water fish are farmed in ponds or tanks. Aquaculture is complicated work focused upon the production and breeding of fish stock. In ponds, fish over breed and have to compete for food causing stunted growth. When fish are grown in culture tanks, fish stop breeding when numbers reach a certain density. In tanks, fish don't have to compete for food but the confinement creates stress and increases the risk of transmitted diseases. Culture tanks also allow fish farmers to easily manage fish stock. Tanks also provide for a high degree of environmental control over water quality such as water temperature, Dissolved Oxygen (DO), pH, and waste management. The culture tank method also makes it easier to adjust water quality for maximum fish production.

Fig. 1 – *Oreochromis niloticus or Nile Tilapia are among the most adaptable fish used in aquaculture. The can grow from egg to 2 Kg in 10 months*

With tanks, feeding and harvesting is much easier than with ponds. Newly-hatched fry can be captured with a dip net and transferred to an isolation tank or nursery. It's important to remove all fry and juvenile fish from the brood tank because they prey on spawn and reduce production. Fish are protected with a thin layer of mucus that protects them from fungi, bacteria, and other harmful microorganisms. Capturing fish removes this protective slime making them more susceptible to disease. For this reason, always use care when capturing specimens. Some culture tanks include net enclosures, allowing easy removal of all fry and eliminates the need for draining the brood tank. Male and female brood fish should be kept in separate enclosures until its time to breed. It's important to consider the breeding habits of the stock fish as some species carry their fry in their mouths.

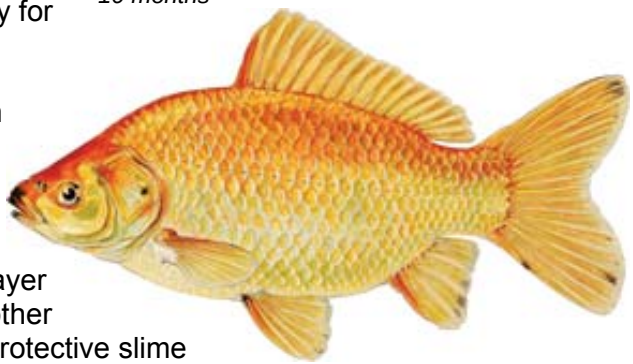

Fig. 2 – *Carassius auratus or the common Goldfish are cheap and readily available at most pet stores.*

Fig. 3 – *Ictalurus punctatus or the* Channel Catfish is also a popular product raised in fish farms.

Fig. 4 – *Oncorhynchus mykiss* or Rainbow Tout go from fish farms to restaurant kitchen by the tons each day.

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Research Resources:

Web Site	Description
http://en.wikipedia.org/wiki/Fish_farming	Intro to Fish Farming
http://www.fishbase.org	Fish Classification Site
http://aquanic.org/publicat/usda_rac/efs/srac/282fs.pdf	Tank Culture or Tilapia
http://www.fao.org/figis/servlet/static?dom=culturespecies&xml=Oreochromis_niloticus.xml	Information on Nile Tilapia

Required Materials:

Culture Tank, Fish, Fish Food
Camera, Measuring Tape, Beaker, Scale

Procedure:

1. Feed the fish an appropriate amount so that they can eat it all in two minutes. Remember it is easier to add more than to take away.
2. Perform a complete water quality assessment and report your results to the instructor.
3. Photograph three fish for a health study as you record data regarding your specimens.
4. Enter are required data in the spreadsheet FishStock.xls .
   - **a.** Photograph 3 specimens. Edit and enhance the images and then insert them in the spreadsheet.
   - **b.** Enter a detailed description of the specimen including distinctive markings.
   - **c.** Identify the specimen by common and scientific name.
   - **d.** Estimate the age of the specimen and its sex.
   - **e.** Examine the specimen for damage or diseases and then rate the heath of the fish.
   - **f.** **Weighing the Specimen:** Fill a suitably sized container (washed) with enough water for the fish. Weigh the container and water (without the fish) and record your results. Use a dip net to collect the specimen gentility placing it into the container. Weigh the container again and subtract the two measurements to obtain the weight of the fish.
   - **g.** **Measuring the Specimen:** This step must be done very carefully and quickly to ensure the welfare of the specimen. Although they'll survive, fish will suffocate if out of water for much longer than a minute. Have everything clean and setup for measuring before you remove the specimen from the stock tank.
     - i. Layout a flat metric ruler close to the stock tank.
     - ii. Layout a clean sheet of wax paper on top of the ruler.
       1. Remove a specimen from the stock tank and gently place in on top of the wax paper and ruler.
     - iii. Without Touching the Specimen…
       1. Take an accurate measurement of the specimen's length.
       2. Cradle the specimen in the wax paper and return it to the stock tank.

Nomenclature

Brood Fish	Nile Tilapia *(Oreochromis Niloticus)*
Nursery Tank	Rainbow Trout (*Oncorhynchus Mykiss*)
Fry	Channel Catfish (Ictalurus Punctatus)
Fingerlings	*Goldfish (Carassius Auratus)*

Questions:

1. Research and develop a detailed definition for each of the terms found in the Nomenclature section of this document. Many words have multiple definitions… Some of which may have nothing to do with the field of aquaponics. Make sure your definition falls within the context of this lesson. Each definition should be two sentences or more.
2. How often and how much food should adult fish be fed? What do juvenile (fry) fish eat? What are the problems with over-feeding fish?
3. What conditions must exist for fish to breed? Describe the difference between the reproduction habits of Tilapia and other aquaculture stock.
4. Why are fish slimy?
5. What breed of fish is best suited for an aquaponics system?

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Debriefing:

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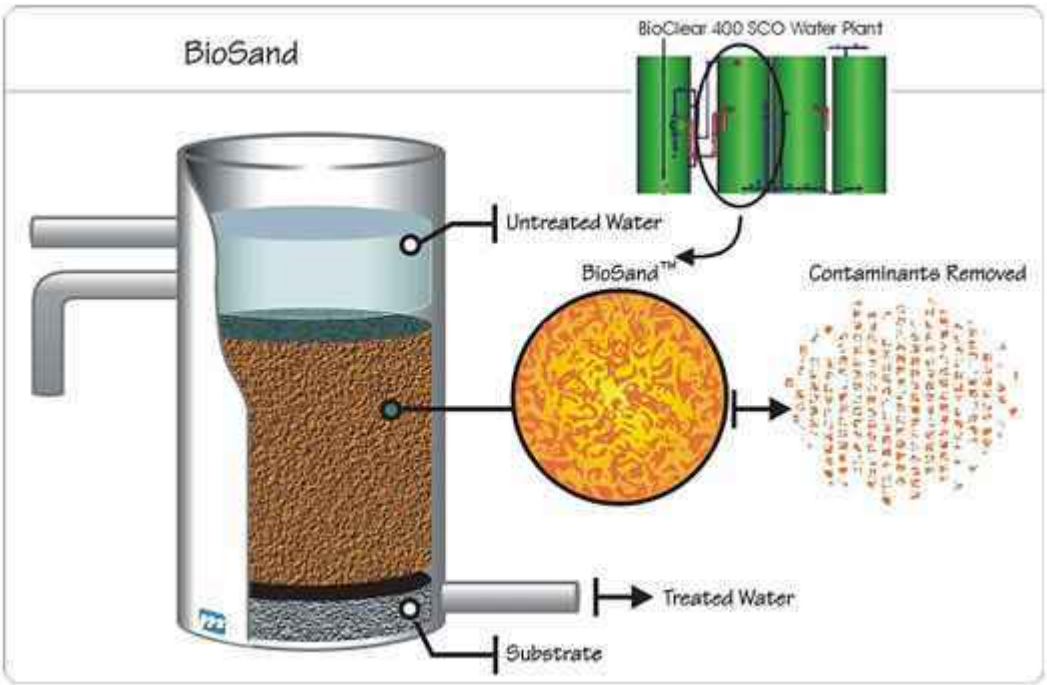
MISSION TO MARS - RENEWABLE RESOURCES

Mission 5 – Aquaponics: Water Filtration

Conclusion: In this mission you learned how to care for and breed Tilapia. With proper care, they will grow big and provide more food for the astronauts. This is what the tank should eventually look like with proper care.

Objective: To demonstrate how to construct and use a bio-filter, a filter system made from gravel and other micro-porous solids to help keep the water quality ideal for fish to thrive.

Briefing: Fish require acceptable water quality to grow and procreate. The fundamental objective in designing a filtration system for off-world missions was to keep the water quality ideal for the fish to thrive. A bio filter uses gravel and other micro-porous solids to break down bacteria and other organic wastes into less harmful bacteria and organic waste.



Nomenclature:

Micro-porous	Procreate
Bio-filtration	
Bacteria	
Organic waste	

Research Resources:

Web Site	Description
http://www.wetwebmedia.com	Details a Bio-filtration system
http://www.watertiger.net/mainstream/mainstream.htm	Details Bio-filtration systems

Questions:

1. What do bio-filters remove from water?
2. How do bio-filters work?

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3. Research and develop a detailed definition for each of the terms found in the Nomenclature section of this document. Many words have multiple definitions… Some of which may have nothing to do with the field of bio-filtration. Make sure your definition falls within the context of this lesson.

Required Materials:

- Cotton Wadding
- Gravel

Procedure:

1. Place cotton wadding in filtration tank.
2. Place gravel in planting cups.
3. Pump water from filtration tank through the gravel into the main fish tank.

Conclusion: Bio-filtration systems promote good water quality for fish and other organisms to thrive on off world missions and in a common household.

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MISSION TO MARS - RENEWABLE RESOURCES

Mission 6 – Aquaponics: Hydroponics

Objective: In this mission you will design and build a working hydroponics system. You will design a prototype Plant Container for the two different methods of plant feeding. You'll also engineer the channel and pump system used to deliver and drain nutrients to and from the Plant Containers. Finally, you will research and select the appropriate plants to grow.

Fig. 1 – Nearly all Off-season strawberries are grown using hydroponics techniques.

Briefing:

Hydroponics is a method of growing plants without soil. There are 6 basic ways to grow plants in a hydroponics system but each requires that all nutrients are delivered to the plants through a solution delivered to their roots. It's the way in which the nutrients are delivered to the plant's roots that sets these methods apart. The methods are…

Wick – Just like a candle, this method uses fiber material to wick nutrients from the nutrient tank up into the growing bed.
Water Culture
Ebb and Flow (Flood & Drain)
Drip (recovery or non-recovery)
NFT (Nutrient Film Technique) -
Aeroponic – There is no growing medium used in this system. The roots of the plants are suspended in the air. Nutrient solution is frequently sprayed roots to keep them wet. The excess solution is collected and pumped up to the spray nozzle.

Variations (or combinations) of these methods form the basis of all hydroponics systems.

Fig. 2 – Commercial nutrient solutions are concentrated mixtures of chemical compounds engineered to feed plants (Bio-Grow).

The saying, "You are what you eat" applies to plants as well. When you grind up plants and analyze what they're made of, they're pretty much made of just 16 elements. Those elements are C, H, O, N, P, K, Ca, Mg, S, Zn, Cu, Fe, Mn, B. Mo and C1. Plants normally get these elements from the air or the minerals in the soil. Plants need these elements to thrive so in soil-less farming, these nutrients must be added to the water that's circulated through the hydroponics system.

Commercially produced hydroponics solutions are engineered to meet the nutritional requirements of specific types of plants. For instance, tomatoes have different nutritional requirements than lettuce. The solution is mixed with the water and circulated throughout the system. As the plants absorb the nutrients, more solution is periodically added to replenish the system. Here's a sample formula of the compounds found in a typical hydroponics nutrient solution.

0.4 $NH_4H_2PO_4$; 2.4 KNO_3; 1.6 $Ca(NO_3)_2$; 0.8 $MgSO_4$; 0.1 Fe as Fe-chelate; 0.023 B as $B(OH)_3$ [boric acid]; 0.0045 Mn as $MnCl_2$; 0.0003 Cu as $CuCl_2$; 0.0015 Zn as $ZnCl_2$; 0.0001 Mo as MoO3 or $(NH4)_6Mo_7O_{24}$; Cl as chlorides of Mn, Zn, and Cu (all concentrations in units of millimoles/liter). Sounds Yummy!

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Hydroponics systems go back as far as the 17th century. The earliest published work on growing terrestrial plants without soil was the 1627 book, *Sylva Sylvarum* by Sir Francis Bacon. Subsequently, water culture has become a very popular research technique. In 2003, 528,078 million metric tons of tomatoes were grown in hydroponics green houses. Although this is only 4% of the total market, advances in hydroponics technology and the increased cost of terrestrial farming could make hydroponics a more desirable alternative to terrestrial farming. Currently, NASA has done extensive hydroponic research for their Controlled Ecological Life Support System CELSS for the preparation of extraterrestrial farms on the Moon or Mars.

How do pumps work?

Nomenclature:

Hydroponics
Diminutive
Terrestrial

Research Resources:

Web Site	Description
http://en.wikipedia.org/wiki/Hydroponics	History and description of hydroponics
http://www.simplyhydro.com/system.htm	Basic Hydroponics Systems
	Lab-Volt Pumps
http://ider.herts.ac.uk/school/courseware/design/index.html	The Blue Print

Questions:

1. Research and develop a detailed definition for each of the terms found in the Nomenclature section of this document. Many words have multiple definitions. Some of which may have nothing to do with the field of hydroponics. Make sure your definition falls within the context of this lesson. Each definition should be two sentences at least.
2. What did plant physiology researchers discover in the 1800's about how plants absorb needed nutrients?
3. Create a table measuring the plant heights; you should take measurements once weekly.
4. List the different parts of a recirculation pump.

Required Materials and Equipment:

Gravel	plant seeds	75mm PVC Tubing
Drip tubing	Water Pump	110mm PVC Tubing
	Pump Adapter	Silicone Cement
	16 mm PVC Tubing	Hole Saw

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Procedure:

The Design Process

The Design Process – The engineering industry generally accepts the following 5-Step design process as the preferred method for solving design problems. An additional step might include marketing or sales. However, we'll focus our efforts on the "Big 5" listed here. You'll need to use this process as you work on any design mission.

1. Define the Problem
All design work is based upon solving a specific problem. After all… It would be hard to go about solving a problem if you don't know one exists or what it might be. In most organizations, the problem is identified and data is collected in the Research and Development (R&D) phase of manufacturing. Once scientists and engineers have determined the need for a product, certain design limitations, and other relevant specifications the design process begins.

2. Find Solutions and Ideas
Brainstorming is the key to this phase in the design process. Ideas are offered and examined while concepts of the overall design are developed. Sketches and bullet statements are used to document possible designs. All possible solutions are scrutinized to be sure they address design limitations and actually solve the defined problem. It's important to note that there may be many solutions to the problem, but usually there's one best solution once design limitations are considered.

3. Document Ideas
Documentation is perhaps the most important phase in the design process. Properly documented ideas convey solutions to all participants and create the continuity that's required in today's global workplace. Complex design problems are attacked by teams of people sometimes spanning time zones or even continents. In this phase, all sketches are converted to Computer Aided Design (CAD) and notes are polished up as word processed documents to allow easy editing as the solution takes shape. Detailed drawings and notes are required to build a prototype that may solve the problem.

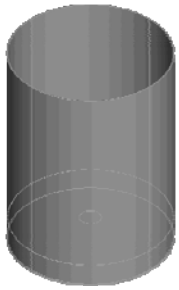
4. Test and Refine
Proposed solutions must be tested using realistic circumstances. Sometimes a prototype, scale model, or even a virtual model is constructed to test a solution before it actually goes into production.

5. Production
All aspects of the design problem have been examined and the best solution has surfaced and a tested prototype. It's time to go into production. Using production software, manufacturing, Computer Automated Design (CAD), or Computer Aided Manufacturing (CAM) tools the technicians and craftsmen turn the design into product.

Hydroponics Channel Design and Construction - Use the 5-Step design process to engineer and construct a hydroponics channel for an ebb-and-flow system. Your design must conform to the following criteria:

1. Required Material – 110mm OD PVC Tubing, 13mm Hose Connector, and End Caps
2. Required Adhesive – Silicone Cement
3. Maximize the Number of Plant Containers
4. Include Support and Base for Hydroponics Channel
5. The Channel Must Drain Into the Culture Tank

Plant Container Design – Use the 5-Step design process to engineer and construct a plant container for an ebb-and-flow hydroponics system. Your design must conform to the following criteria:



1. Required Material – 110mm OD, 75mm OD, 16mm OD PVC Tubing
2. Required Adhesive - Silicone or PVC Solvent Cement
3. Receptacle Orifice – 76mm Diameter - Round
4. Required Volume – 550cm^3 to 600cm^3 (pi * radius^2 * height)
5. Must be able to secure the Recirculation Line at Center of Container

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Recirculation System Design and Construction - Use the 5-Step design process to engineer a recirculation system for an ebb-and-flow hydroponics system. Your design must conform to the following criteria:

1. Required Material – 10mm OD Drip Line, Water Pump, 13mm to 10mm Line Adapter
2. All Plant Containers Must Receive Sufficient Saturation
3. Setup a Test Culture Tank to Verify the System Works

Conclusion: In this mission you have learned how to

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