The Pump Master
Duke University
EGR190/WERC 2011

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Task Identification

- Task 7: Clean Energy Water Disinfection for Small, Remote, Rural Communities
- Our project must:
  - Harness clean energy (non-fossil based)
  - Be easy to implement, maintain and operate
  - Be portable
  - Be cost-effective
  - Apply to third-world and rural settings
  - Have potential for real-life application

Additional Design Considerations

- Usable by majority of the community
- Easily adapted to different situations
  - Desalination or other water treatments
  - Available construction materials
  - Ability to manufacture versus purchase parts
- Simple design based on concepts that are intuitive or widely recognized

Available Energy Technologies

Potential Energy Sources

- Hydropower
- Wind power
- Biomass
- Solar photovoltaic
- Mechanical (human powered)

Available Treatment Technologies

Chemical Disinfection Methods

- Chlorine
- Iodine
- Hydrogen peroxide
- Ozone

Physical Disinfection Methods

- Ultraviolet (UV) Exposure
- Ceramic filters
- Granular media
- Membrane filtration
- Boiling
- Solar disinfection

Decision

- Technologies were evaluated with a weighted matrix considering:
  - Efficacy
  - Cost
  - Ease of implementation and maintenance
  - Portability
- **Final decision**: human powered stepping mechanism that operates two piston pumps, forcing water through a membrane

	Efficacy	Cost (Initial and O&M)	Ease of Implementation/ Maintenance	Portability	TOTAL
Weighting (5 - most important)	5	4	3	2	
Treatment Methods ($ cost)					
Physical					
UV (450)	5	3	3	5	56
Ceramic Filter (13,000)	5	1	4	4	49
RO Membrane (500)	5	3	3	4	54
Ultrafiltration (250)	**5**	**4**	**5**	**4**	**64**
Porous Media (200)	2	5	5	4	53
Chemical					
Chlorine (50/yr)	5	5	3	1	56
Iodine	2	4	3	3	41
Peroxide	2	3	2	3	34
Ozone	5	2	2	4	47
Themal/Other					
Boiling	5	1	1	3	38
Distillation	5	1	1	3	38
SODIS	4	5	1	1	45
Energy ($ cost)					
Bike (800)	5	4	4	5	63
Stair Step (500)	**5**	**5**	**4**	**4**	**65**
Wind (2500-5000)	3	3	3	1	38
Solar (3100)	3	4	1	4	42
Bio (N/A)	1	1	1	1	14
Hydro (10000)	4	2	1	1	33

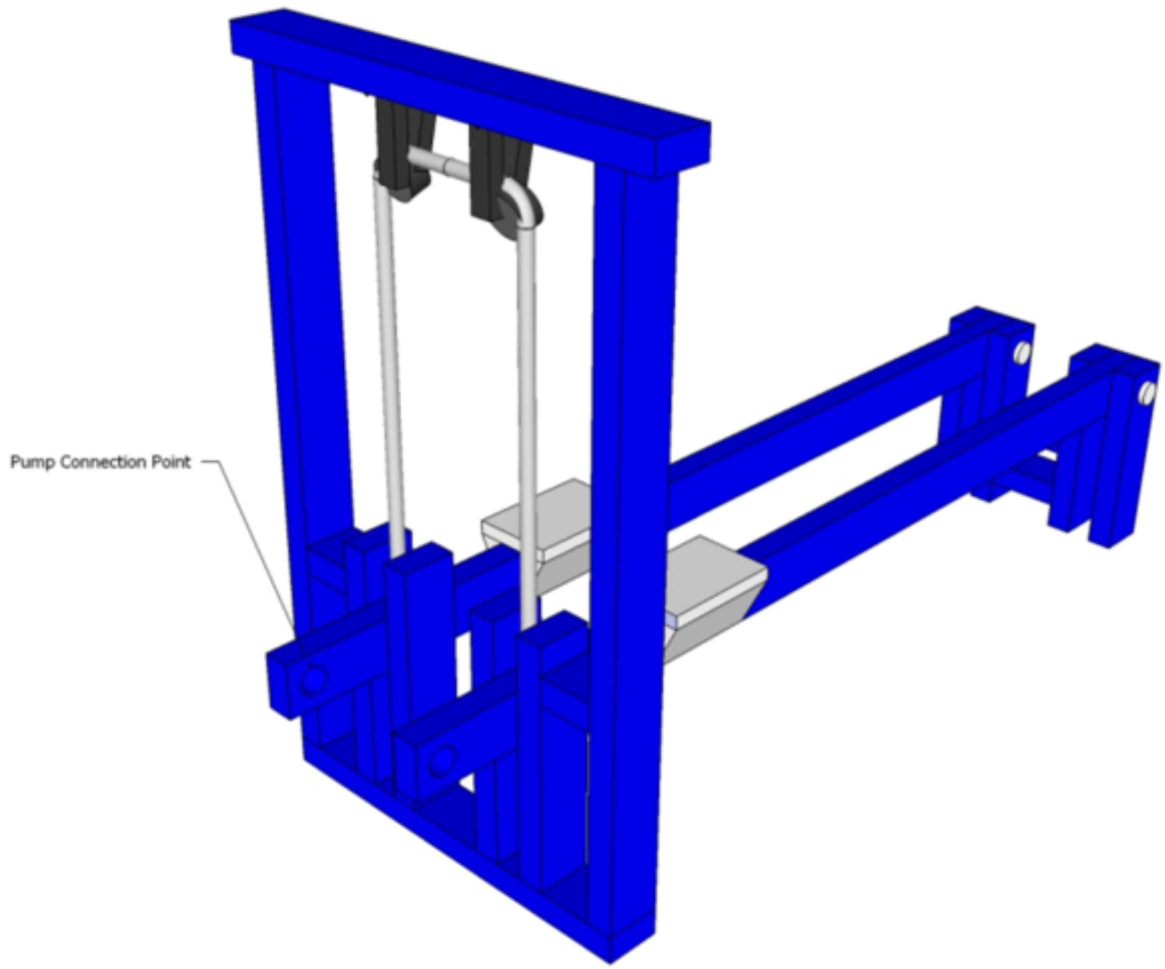
Design Overview

- http://www.youtube.com/watch?v=AsSXa60DtAY

Process-Flow: Human powered filtration

Removing bacterial contaminants from water	via: Human Power
Contaminated water drawn into inflow pipe	via: "Upstroke" of lever
Contaminated water pumped through membrane	via: "Downstroke" of lever
Clean water discharged via outflow pipe	via: "Downstroke" of lever
Clean water discharged into storage	via: "Downstroke" of lever

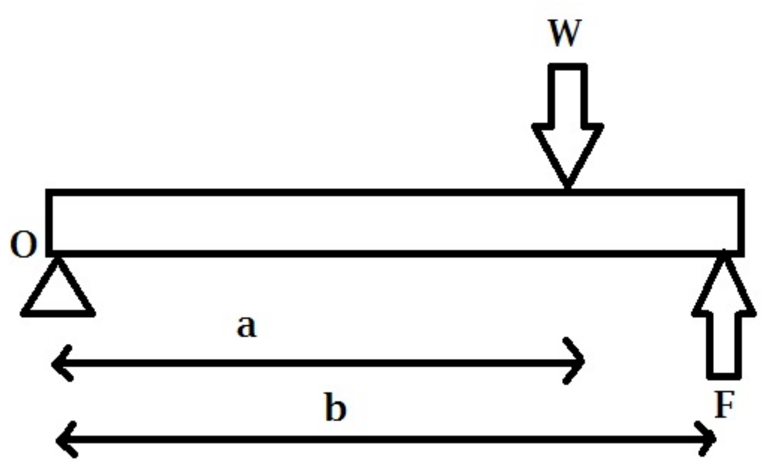
Concept: Mechanical System (Levers and Pulley Mechanism)



Designing the Mechanical System

Lever Design

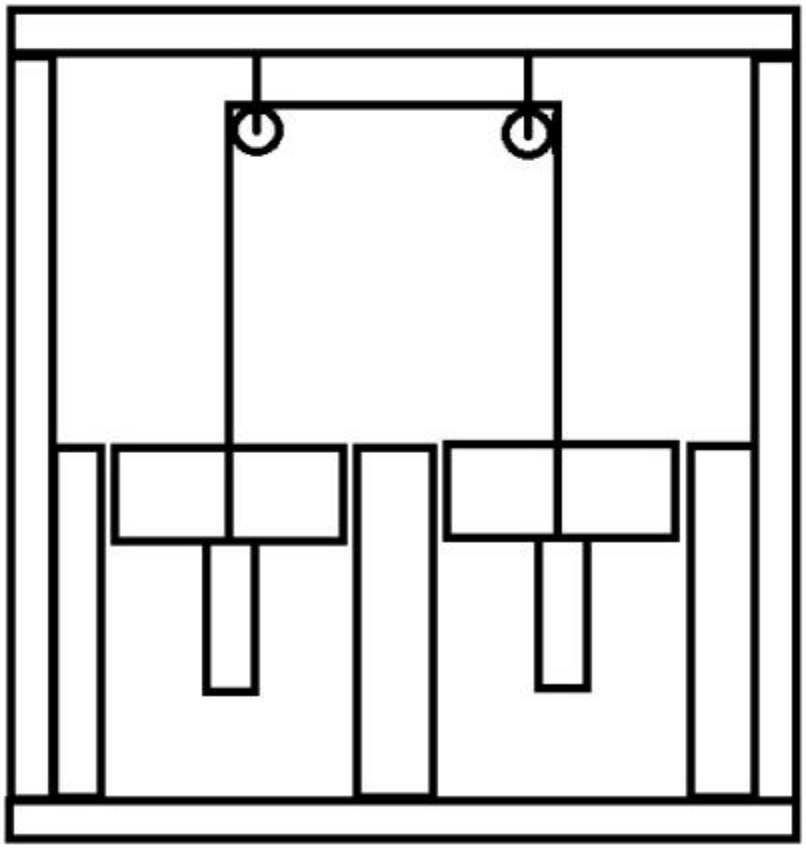
- Calculated ratio of a to b using the minimum and maximum pressure for the filters and the minimum and maximum body weights the system is designed for
- Final dimensions:
  - Length: 6’10’’
  - Applied weight (a): 6’
  - Pump (b): 6’7’’



Designing the Mechanical System

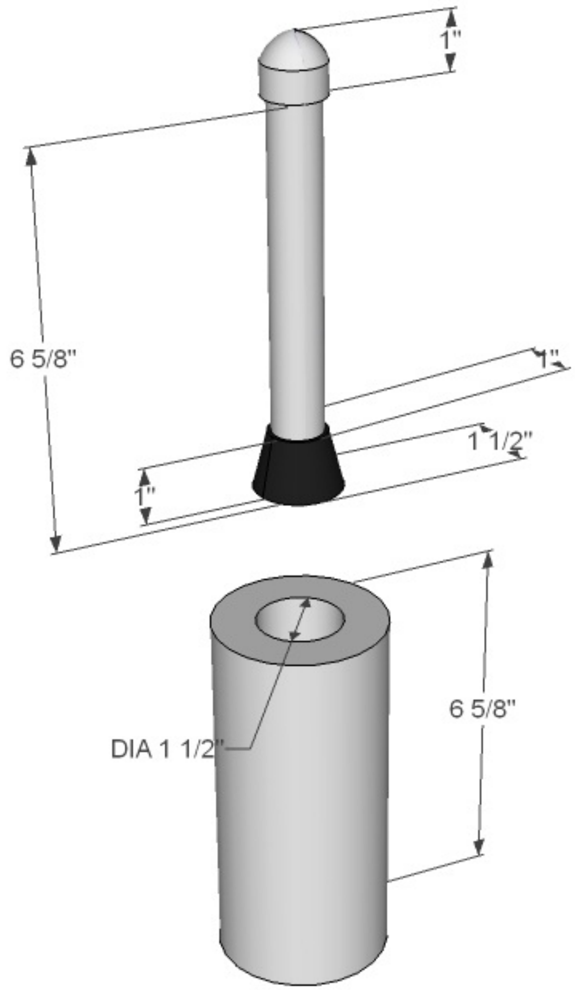
Pulley Design

- Length of cable specified to optimize pump stroke length while minimizing step size
- Ensures continual up-down motion
- Depends on frame construction – trial and error to achieve correct length



Concept: Pumping System

Designing the Pump



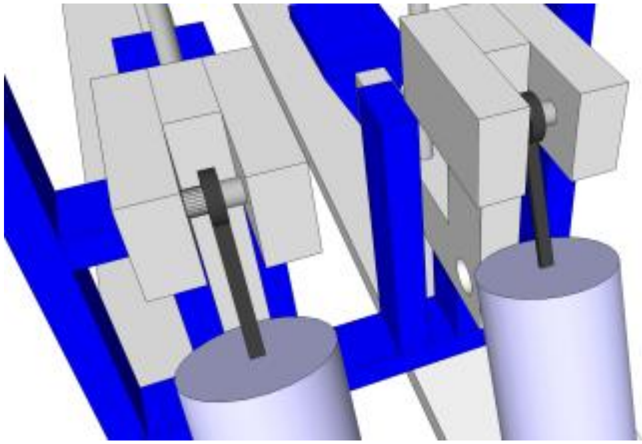
Simple Piston Pump

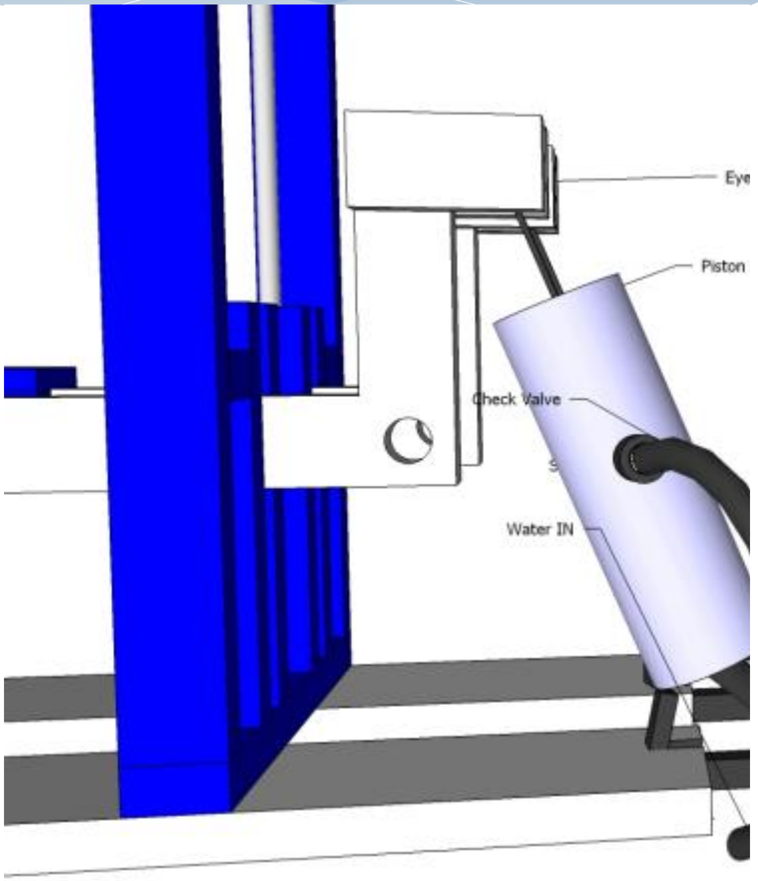
- Possible to manufacture a simple piston pump from steel or plastic, or whatever materials are locally available
- Design pressure 30-100 psi (fails at 150 psi)
- $P = F/A$, where $A = \pi r^2$

Designing the Pump

Pump Attachment

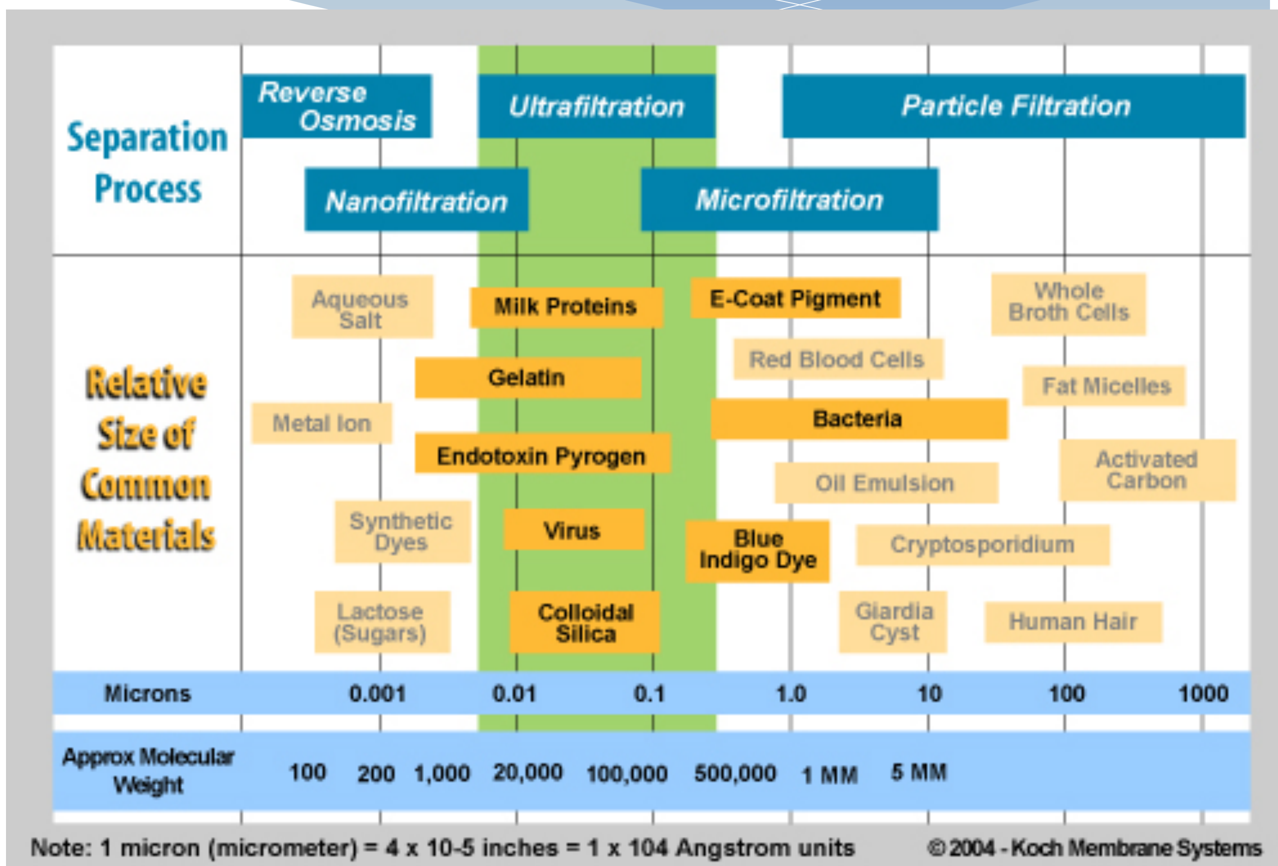
- Elevates pumping system so that levers remain close to ground
- Utilizes eye-hooks to allow for pivoting





Choosing a Membrane

- MUST remove bacteria
- Options:
  - micro-
  - ultra-
  - nano-
  - reverse osmosis
- Ultrafiltration has "**absolute** bacteria and virus removal from surface waters"* with less pre-treatment and lower pressures than nanofiltration or RO



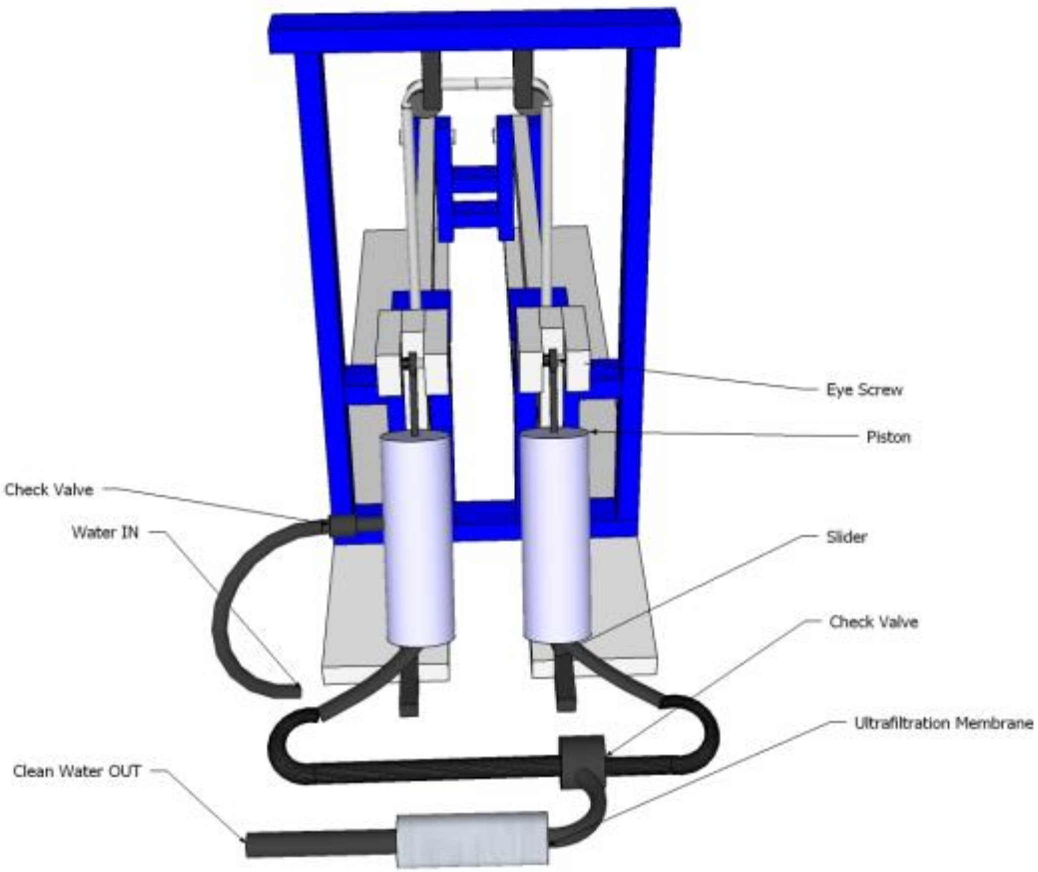
*From Applied Membranes http://www.appliedmembranes.com/polyethersulfone.htm

Choosing a Membrane

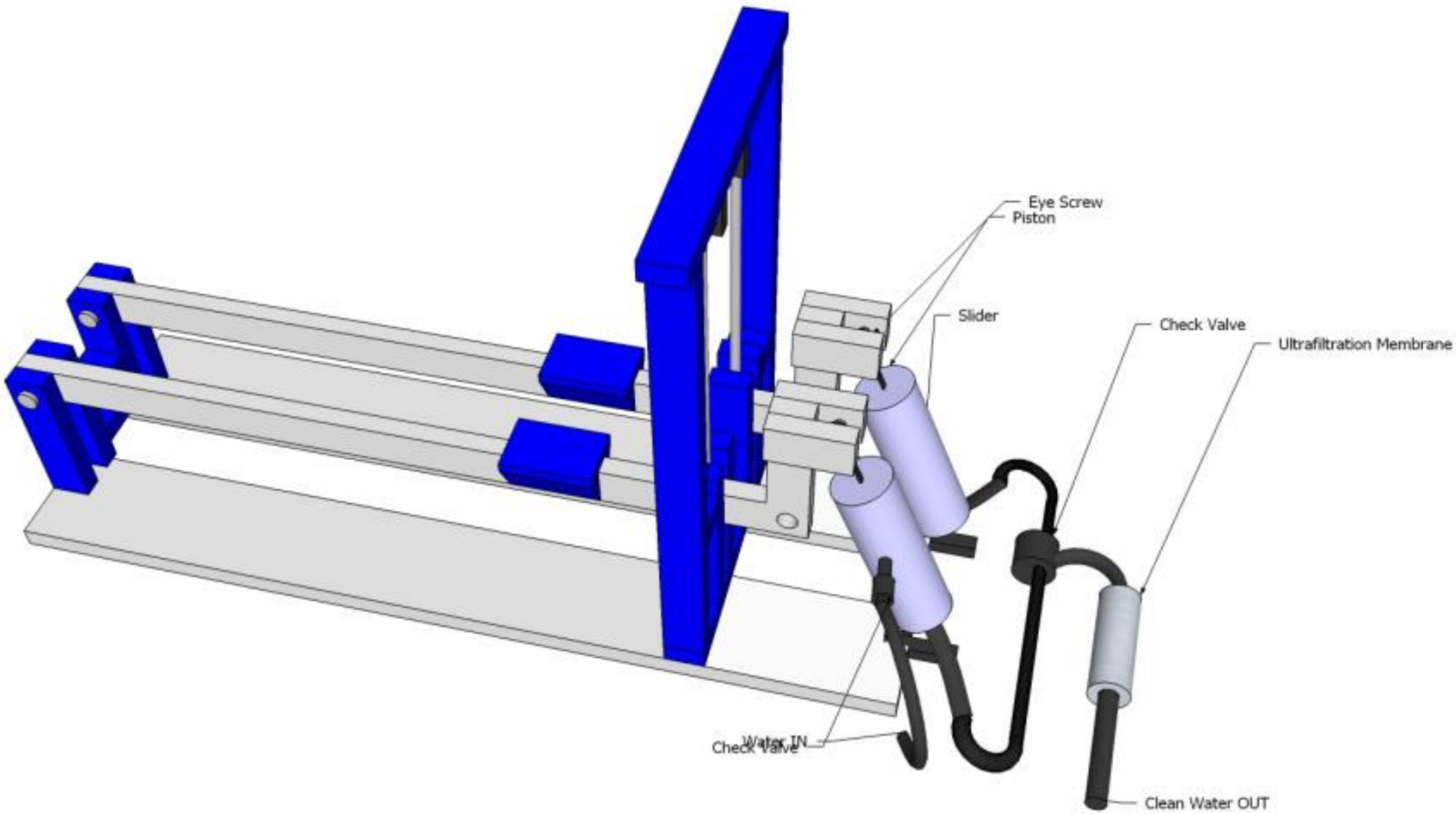
- Membrane selected: AMI Membranes, Polyethersulfone Ultrafiltration Membrane Model No. M-U4040PES
  - Maximum flow rate of 20 GPM, able to meet 3000 GPD requirement
  - ~10,000 MWCO (.01 micron pore size)

Model No.	L		I		D	
	Inches	Cm	Inches	Cm	Inches	Cm
M-U4040PES	40	1016	38	96	3.9	9.9

Market Product

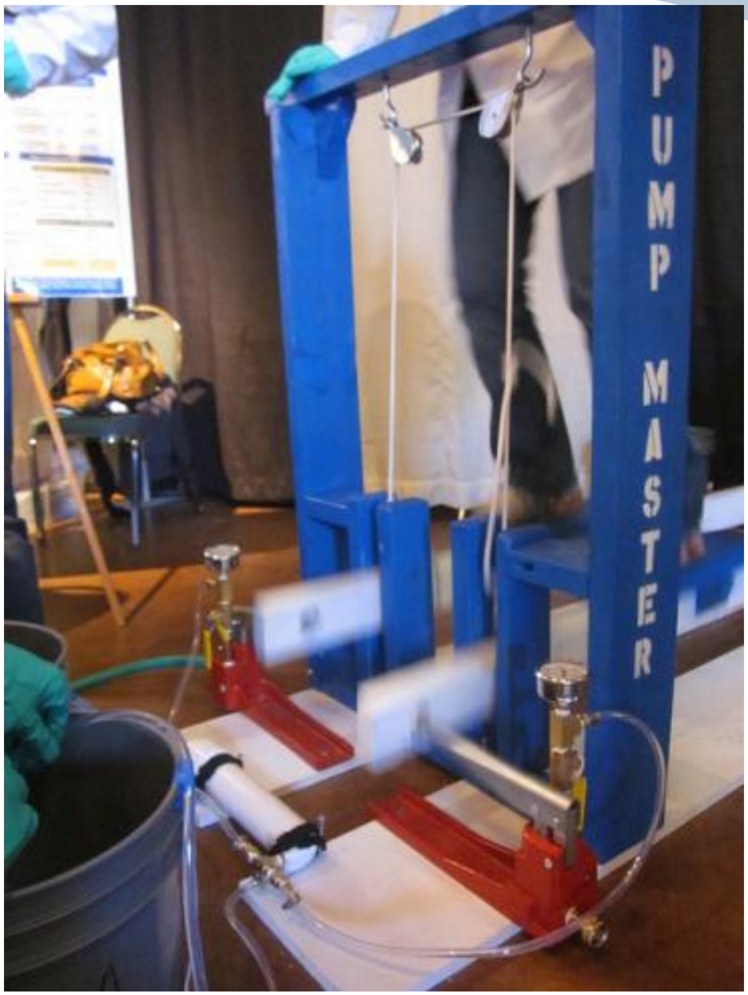


- Mechanical System: levers and pulley
- Pump: simple piston pump
- Membrane: large ultrafiltration membrane (max flowrate: 20 GPM)



Eye Screw
Piston
Slider
Check Valve
Ultrafiltration Membrane
Water IN
Check Valve
Clean Water OUT

Bench-Scale Product



- Mechanical System: levers and pulley
- Pump: Reed HTP300 hydrostatic pump
- Membrane: small ultrafiltration membrane (max flowrate: 2 GPM)

Testing and Evaluation: Bench-Scale Product

- Functional pumps
  - Hand-tested, achieved >300 PSI with upper body strength
- Operational mechanical system
  - Tested with variety of team members
- Off the shelf membrane
  - Rated for absolute bacterial removal
  - Flow rate achieved at WERC: ~0.167 GPM
  - Flow rate <2 GPM, so pressure <150 PSI
    - Boundaries: (30-150 PSI) and (0 GPM, 2 GPM)
    - Linear interpolation: for 0.167 GPM, operating at 40 PSI

Additional Testing and Evaluation: Market Product

- Functional pumps
  - Would need to ensure proper seal - test independent of mechanical system
- Operational mechanical system
  - Test with a verity of team members (done)
- Off the shelf membrane
  - Similar calculations using the larger membrane
  - Boundary conditions: (30-150 PSI), (0-20 GPM), (60-290 lbs)
  - Design conditions: (30-100 PSI), (0-11.67 GPM), (60-180 lbs)

Potential Design Improvements

- Pre-treatment
  - Granular media to remove large particles and prevent membrane fouling
- Post-treatment
  - Chlorination to prevent bacteria regrowth
- Pressure checks
  - Pressure gauges in-line to monitor pressure in front of membrane
- Periodic water sampling
  - Plating to test for bacteria in treated water
- Pulley system materials
  - Use steel cable and low friction pulleys

Economic Analysis: Market Product Estimated Cost

Component	Unit Cost	Quantity	Total Cost
Membrane Housing	$50	1	$50
Membrane	$240	1	$240
Manufactured Pump System	$175	1	$175
Frame Materials	$150	1	$150
Piping Materials	$20	1	$20
Testing Equipment	$10	2	$20
Installation	$12/hr	6	$72
Total Initial Capital			$727
Maintenance (Annual Filter Replacement, Pump Maintenance, and Miscellaneous Cost)	$240	2	$480
	$12/hr	25	$300
	$12/hr	25	$300
Annual O & M			$1,080
Expected Lifetime in Years		10	
Annual Lifetime Cost			$1,153
Annual Water Cost		3000 G/d	$0.001 /G

Economic Analysis: Bench-Scale Product Cost

Component	Unit Cost	Quantity	Total Cost
Membrane Housing	$20	1	$20
Membrane	$40	1	$40
Hydrostatic Pump	$210	2	$420
Frame Materials	$150	1	$150
Piping Materials	$20	1	$20
Testing Equipment	$10	2	$20
Aesthetics	$25	1	$25
Total Initial Capital			$695

Economic Analysis:
Market Entry and Product Distribution

- Set up as a non-profit corporation
- Partner with international organizations for deployment
  - Microfinance
  - Focus on local ties
  - Ex: The Water Project
- Assess and construct on site
- Roll-out Plan
  - 3rd World Countries
  - Disaster Zones
    - current example: Haiti

Public Involvement and Education

- Educate community about project: purpose and benefits
  - Seminars targeted to specific demographics within a community
- Community input
  - How to adapt the design for the community
  - Financial plans
  - Long-term partnership

Safety

- Concerns: minor physical injury during construction, maintenance and operation
  - Addressed by proper training on use and maintenance of the system
  - Appropriate security measures and safety mechanisms
- Health benefits from disinfected water outweigh any potential negatives

Environmental Considerations

- Marine and terrestrial habitat
  - Minimal disturbance
- Byproducts of the Pump Master
  - Concentrate
    - Use as fertilizer
      - Long Term Storage Treatment
      - Heat Treatment
    - Pit Disposal

Conclusions

- Recent events have necessitated a system that is:
  - Simple
  - Affordable
  - Adaptable
  - Easy to maintain
  - Portable

- The Pump Master IS this system!

Thank You!

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