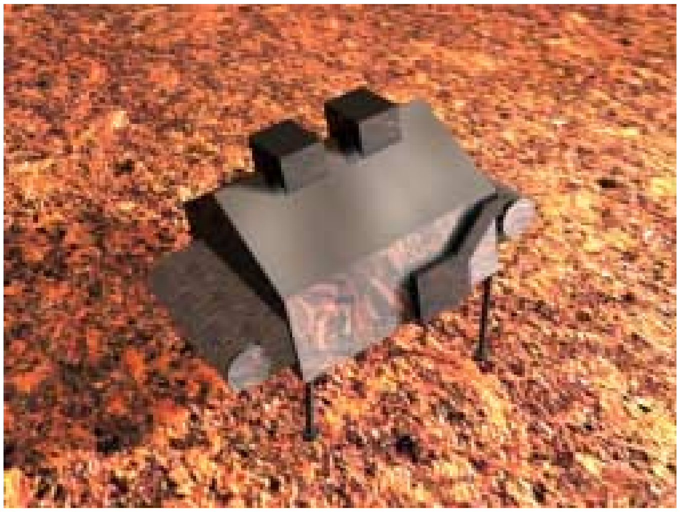
Water Extraction from Martian Soil

Colorado School of Mines



TEAM JFEET

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1. ABSTRACT

With the projected growth in space exploration, several milestones have been set for future space programs. One milestone in particular is the landing of a human on the planet Mars. However, one major barrier to the successful placement of persons on Mars is a lack of water on the Martian surface. Because of the massive quantity of water that would be necessary for a mission to Mars, it is not possible to transport the amount necessary from Earth to Mars. Water would be necessary for human consumption as well as a base for jet propulsion fuel. Past unmanned missions to Mars, such as the Viking missions of the 1970's, have revealed the presence of small quantities of water in Martian soil. Research has determined that the water in the soil can be recovered when the soil is heated to a temperature between 200˚C and 500˚C. Team JFEET has designed a system with the capability to extract water from the soil of Mars, and then meter and deliver the water to a storage tank for later use.

The system uses simple concepts with few moving parts, creating a design that is reliable, efficient, and semi-autonomous. C.R.A.T.E.R., another design team from Colorado School of Mines, has designed a system that will provide the Martian soil necessary for process. This soil is placed on a conveyor belt that runs into a pressurized casing. A small motor attached to a sprocket on the belt's bearing, and placed at a downward angle in order to maximize gravitational assistance will automate the belt. The sand is transported into the casing where it is exposed to microwaves. These microwaves are emitted from two magnetrons attached to the roof of the casing. Microwaves are used to most efficiently free bound water molecules from the soil. From there, the vaporized water molecules will collect and condense on the roof of the casing. Once the water condenses, it runs down the roof into a gutter system that transports the water into a metering device. After the water is metered, it is siphoned into a storage unit. Power necessary for this process is provided by a silicon solar cell. The designed system meets NASA's and our physical and operational constraints, such as maximum mass and minimum water production rate (Table 1).

Team JFEET began in the spring of 2000 by evaluating several possible furnace systems to recover water from the Martian soil. The array of furnace systems devised had various energy sources, such as: the use of focused light, the thermal heating of soil in an oven apparatus, and the use of microwave energy. Each evaluated system had its own benefits, but most were outweighed by factors such as complexity or project specifications. After inspecting the various systems, it has been determined that a microwave energy based system presents the best possibility for success.

For the spring of 2001, team JFEET has continued to explore the potential of the original design. The microwave system provides the greatest efficiency, applies energy directly to the water, and has few moving parts. In addition to this, microwave energy based systems have a history of reliability. The efficiency of the system lies in the utilization of microwaves and internal power sources. The internal motor will be isolated from the harsh Martian environment thereby increasing its reliability. The appeal of microwaves is that they transfer energy almost entirely to the water molecules wasting little energy on the soil.

To achieve the goal of usable water on Mars, NASA requires a system capable of removing water from the soil. This system must be capable of operating reliably and maintenance free for at least 500 hours, storing the water, and must be powered by solar energy. The microwave system designed by Team JFEET presents the best chance for achieving this goal.

2. INTRODUCTION

The exploration of deep space is the final frontier for humankind. A plan to settle Mars is being researched at great lengths, but any human missions to Mars will require a water source for both process and human consumption. Due to the absence of free water on the Martian surface, NASA has expressed the desire to develop a unit capable of extracting water from Martian soil (Duke). This proposed design is capable of extracting water from Martian soil, metering the quantity of extracted water, and then delivering the water to a storage system for later use. The extraction system must operate autonomously with no on-site maintenance and be able to withstand acceleration forces of up to 5G. This system will operate in conjunction with a previously designed soil collection system, which will provide soil to the extraction system. A design that presented the best possibility for success under the constraints given in Table 1 was chosen after considering and evaluating several potential solutions. Team JFEET has developed a system that incorporates microwave energy in conjunction with a conveyor belt mechanism to process soil and extract bound water. The system is referred to by code name: Microwave Pizza Oven (MPO).

Table 1: Specifications

SPECIFICATION	CLIENT REQUIREMENT
Maximum Mass	20 kg
Temperature Range	200°C to 500°C
Water Extraction	200g/hr
Operating Period	500hrs
Power Source	Solar Energy

Previous exploration missions to Mars, such as the Viking missions, have determined that water can be extracted from the soil if the soil temperature is increased to between 200°C and 500°C. These same missions also determined that water is present in the soil at approximately 2% by mass. Therefore, a system such as the MPO which is capable of heating the soil, collecting the water, and finally providing the water for storage is necessary if any future missions, especially manned missions, to the Red Planet are to be successful.

In continuation of our work in EPICS 151, Team JFEET has explored the potential of our previous reactor design. We previously researched various possibilities for accomplishing the required mission. Some possibilities included systems that utilized solar heating and/or conventional thermal heating. While these two methods of heating are simple and effective, they are also extremely inefficient when compared to a microwave unit. During the development of the various systems, the anticipated surface conditions in Table 2 were used in all calculations.

Table 2: Anticipated Surface Conditions (Hamilton, Williams)

SURFACE CONDITION	Range	
	Low	High
Temperature (C)	-123	37
Wind Speed (m/s)	0	30
Atm. Pressure (kPa)	0.60	0.81

The initial design, as seen on the cover page, contains five major subsystems: power source, conveyer belt, casing, magnetrons, and water metering. When continuing this research, we have focused on three subsystems (conveyor belt, casing, and magnetrons) in order gain a greater understanding of the overall design.

3. TECHNICAL PLAN

3.1 Description of Potential Designs

Several different designs were considered as possible solutions for the extraction of water when originally launching the project in the spring, 2000. All designs were analyzed and evaluated on the grounds of overall advantages, disadvantages, feasibility of design, durability of product, and ability to meet given design restrictions. During the evaluation of the designs, a numeric value was assigned to each category for each design on a scale of one to ten (with one indicating worst possibility for success and ten indicating best possibility for success). Tabulated results can be found in Appendix. Further details for each potential design are outlined below.

Inclined Pipe:

Electrical heating elements would heat the soil as it passes through a rotating inclined pipe. Similar to a commercial kiln, soil is heated to release water. The released vapor would rise from the soil, travel along the inside surface of the inclined pipe then exit out the top of the pipe. The dehydrated soil would pass out the bottom of the pipe for disposal.

Kettle/Pot:

An enclosed vessel to heat the soil via conventional electric heating. Soil is placed into the kettle/pot where electric heating would increase the temperature of the soil to release water vapor. The released vapor is then collected and condensed into liquid water. The liquid water would then be measured and stored for later use.

Sifter:

Combination sieve and heating element that is used to heat soil. A bin above a sifting screen collects holds the soil. As the soil passes through the sifting screen, which is electrically heated, the soil temperature is increased to the point where water vapor is released.

Funnel:

Similar concept to that of the sifter method. A funnel design meters the flow of soil onto a conveyor belt. Conventional heating elements within the belt then heat the soil to release the water.

Conveyor Belt (Pizza Oven):

Used in conjunction with a soil metering system, such as the funnel, would carry the soil near heating elements that would heat the soil to release water vapor.

Focused Light:

Incorporates focused sunlight to concentrate the application of energy. The focused light would heat a portion of the soil to release water vapor.

Microwaves:

This design, unlike the other designs, does not rely upon the use of conventional thermal heating or the concentration of sunlight to heat the soil. High power radio waves (microwave energy) are used to apply sufficient energy to the soil to increase the temperature of the water, and thus generate water vapor. This method heats the water contained within a uniformly distributed flow of soil. The microwaves apply energy to the water directly, and don’t require the direct heating of the soil unlike conventional heating methods.

3.2 Limitations of Designs

The pipe and pot options were eliminated based on the projected number of moving parts and total mass. The greater number of moving parts lead to a greater chance of mechanical failure, in addition to increased time for engineering and development. Also, both design options used a conventional heating method (electrical). Conventional heating presents a much higher energy requirement than would be necessary with a non-conventional method, such as microwaves.

The team eliminated the sifter and funnel options because of the high potential for blockage, making the required one-year of maintenance free operation very unlikely. An additional subsystem to remove blockages would only create further complexity of the system. Again, both systems were dependent upon the use of conventional heating, which as stated above, has a lower efficiency than that of microwave heating.

Based on the complexity of the system to perform reliably for the required amount of time without on-site maintenance and adjustment, we eliminated the focused energy option as a possible solution. Team JFEET felt that the research and development necessary to design a system that could reliably deploy a solar collector and continuously adjust the position of the collector was prohibitive at this time.

Ultimately, Team JFEET chose the design that incorporated microwave energy for the energy source in combination with a conveyor belt mechanism to move the soil. Microwave energy has higher efficiency, and unlike the other systems, has the ability to heat the water independently of the soil (Bloomfield). Some energy applied to the water will be lost to the soil through conduction, however this loss is minimal when compared to the energy that would be required to heat the soil then heat the water. The MPO will compensate for the energy losses by increasing the energy output of the microwaves. The conveyor belt method allows for a continuous flow of soil, and is not as susceptible to blockage, like the sifter or funnel methods. The primary energy source for the generation of microwave energy and part-time driving force of the conveyor belt will be solar energy. Though Martian days are a few minutes longer than Earth days, day light times are approximately equal therefore calculations can be based on Earth days. Because of the requirement that the system use solar power all calculations for MPO operation were performed assuming 12 hours per day of operation, along with 12 hours per day of idle time when the MPO will be in darkness.

Past research has shown microwave energy as a possible solution for the generation of water on Mars. Microwaves, unlike conventional thermal heating methods, have the advantage of being tunable, so that most of the energy is used to heat the water and not the soil. Microwave ovens have been determined to be quite reliable, having the potential of operating for ten years or more without requiring maintenance (Zurbin).

The major drawback encountered in project continuation is the hazard of microwaves. The primary health effect of microwaves is thermal effects. Microwave frequencies produce skin effects; however the radiation may penetrate the body and be absorbed in deep body organs without skin effect, which is the warning sign. Without a warning sign prolonged exposure to microwaves could prove dangerous, if not fatal (OSHA). Because of the potential safety hazards that come from working with microwaves, it has been decided that a working magnetron is not a priority of team JFEET, at this stage in our design. After inspection of the initial design it was determined that focus should be placed on the design of the microwave energy unit, the belting apparatus and the water collection subsystems. Table 3 below is a decision matrix outlining the different methods of evaluation for each subsystem.

Table 3: Decision Matrix

	PROS	CONS
Microwave: Theory	Low cost, less work, build off of proven knowledge	Less understanding, no working model
Microwave: Experimentation	More work, better knowledge for presentation	Dangerous, high cost
Belt: Theory	Free, less work, proven equations	Less understanding, no fabricated belt for presentation
Pre-made Belt: Experimentation	Easy, verifiable performance, possible manipulation	High cost, may not fit prototype, limit control over design
Home-made Belt: Experimentation	Understanding of working model, control over all construction aspects	Large amount of work, moderate cost
Water Collector: Theory	Free, less work, proven equations	Less understanding, no fabricated collector for presentation
Water Collector: Experimentation	Understanding of working model, control over all construction aspects	Large amount of work, moderate cost

Based on this matrix, the microwave will be inspected by theory, due to extreme health hazards associated with working with microwave radiation. Theory will be integrated into the belt construction in order to develop an operational subsystem, while the water collector design will be expanded from the theoretical equations. Varying each one of the belt variables while leaving the others constant will be conducive to determining the most efficient belt design.

4. CONVEYOR BELT

Though an overall basic component, the conveyor belt subsystem has many details that must be considered when looked at more closely. In order to most efficiently expose the soil to the microwaves, and thus extract the water contained, a conveyor belt was the best option. The belt, originally designed to be entirely gravity driven, has now been equipped with a small internal motor, allowing the speed of the belt to be automated and regulated. This modification also allows the amount of time the soil is exposed to the microwaves to be precisely set. The belt is still placed at an angle in order to provide gravitational assistance.

When initially designing the belt several variables were discovered, each needing to be optimized in order to maximize both belt and overall system efficiency. Variables include belt length, belt width, soil support, and the angle the belt will be held at. After examining each separately, it became apparent that all variables seemed interdependent. Separating one variable from the rest required looking outside the scope of the belt subsystem. The solution came from microwave experimentation, which determined that maximum heating efficiency would occur with a minimum soil thickness. Relating this information back to the belt subsystem, the soil support was selected. Rather than the original plan calling for ledges, a roughly textured belt now suits the operation better. Knowing soil thickness, along with total necessary soil throughput, the width and total length of the belt could be calculated. A width of .229m and a total length of .457m were chosen to keep the system compact while at the same time allowing the subsystem to be integrated easily with the casing. Soil thickness also determined belt angle based upon the angle of repose, which is the angle at which the sand would begin sliding down the belt. Therefore, a downward angle of 30° was chosen because anything beyond that would prove to be too steep.

In order to process 10.0kg of soil per hour, the belt needs to run at a speed of 13.8m/min. Using equations obtained from the literature, a portion of the power necessary to drive the belt will be provided by the gravity, even though the gravity on Mars is $3.69 m/s^2$, only about 1/3 that of gravity on Earth (Mulhern Belting). A 9-volt motor equipped with a small gear has been included in order to better regulate the belt speed. The gear on the motor will be linked with a chain to a larger gear on the belt bearing. The difference in gear sizes provides a favorable gear ratio for high torque, limiting strain on the motor.

Another feature of the belt is that it must be able to withstand both extremely high and low temperatures that will be present during operation. While the belt will be exposed to extremely high temperatures inside the system through heat conduction from the soil, it will also be exposed to the volatile conditions of the Martian environment. Working with this constraint, the belt chosen must be microwave save, that is, the microwaves must not heat it. That would most likely alter the belt's chemical properties.

The conveyor belt will be attached to the frame of the furnace by two metal rods running through each of the rollers, and two support rods extending from one roller to the other. That is the only way that the belt is connected, but it is an integral part of the system. It runs the soil through the system and provides a fresh flow of dirt, which allows the operation to take place. In essence, the belt controls the flow and amount of soil that runs through the microwaves, so it actually determines that the specifications for the system are met.

5. MICROWAVE

The JFEET team decided to use microwave energy to extract the water in the Martian soil and the water that is chemically bound to the soil. Advantages over other methods include the specific items listed below.

- Greater efficiency than a thermal energy source
- Directly heat the bound and unbound water while not wasting energy by heating the soil
- Moving parts are minimal in number
- High reliability
- No warm-up period, instant on—instant off
- Energy is not attenuated by atmosphere

5.1 Calculations

The following are assumptions made when performing calculations for the magnetron section of the water extraction unit.

Table 5: Design Assumptions

Duty Cycle	12hrs on/12hrs off
Mass flow rate:	0.400 kg/hr 20.0 kg/hr
Specific Heat (Cp):	4.20 kJ/kg∙C
Temperature Change	500°C
Mass of Magnetron	5 kg to 8 kg

*For the purpose of calculations, mass values for "sand" were used (Cengel).

Using the above assumption and the First Law of Thermodynamics, the power requirement from the magnetron section was calculated to be 2.4kWfrom Equation 3 below.

Equation 1 (Eq. 1), The First Law of Thermodynamics:

$$\sum \dot{m}_i (h_i + \frac{1}{2} v_i^2 + gz_i) - \sum \dot{m}_e (h_e + \frac{1}{2} v_e^2 + gz_e) + Q + W = \frac{dU}{dt}$$

By assuming steady state and negligible elevation change, the Equation 2 (Eq. 2) is derived from Eq. 1:

$$Q = \dot{m}(h_e - h_i)$$

To determine the amount of energy required to fulfill the parameter constraints, Equation 3 (Eq. 3) was used:

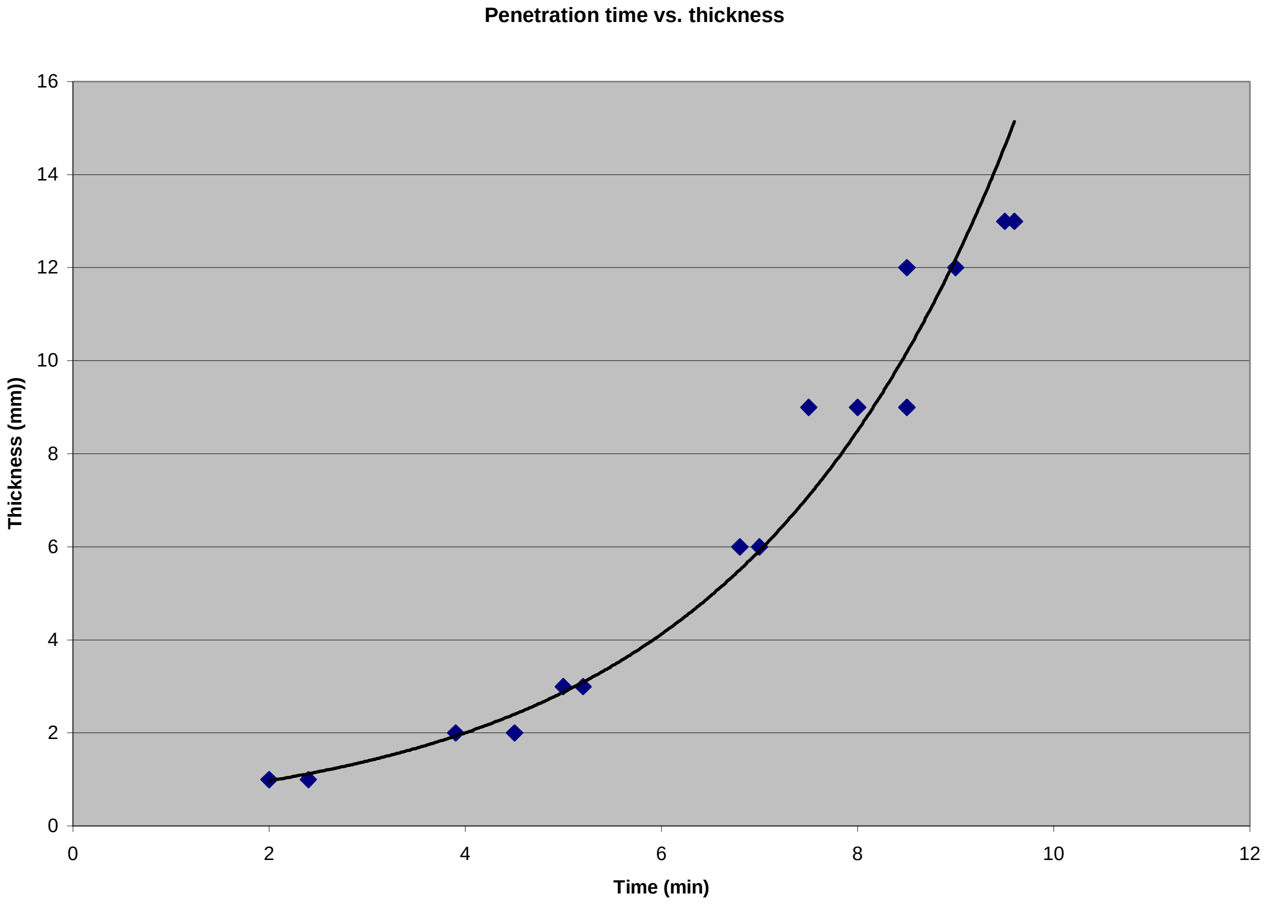
$$Q = \dot{m} C_p (T_e - T_i)$$

If the initial soil temperature was greater than 0°C, less power would be required (See Reference Table 2). With a lower power requirement, either less electrical power would be required, or more mass could be processed. Thus heating the water in the soil requires approximately one half the amount of energy necessary than if using electrical thermal heating. The use of electrical thermal heating would require the heating of the soil, which would then heat the water, while microwaves are capable of heating the water directly. Some energy will be lost to the soil due to conduction; however even with the energy loss the energy requirement is still less then that from the electrical heating method.

Due to the low atmospheric pressure on Mars (0.7 kiloPascals on average) and the low temperatures at night, the possibility of the system being at the triple point during operation had to be considered. By setting the time of operation during the daylight hours, this possibility had an extremely low probability of occurrence due to the high temperature during the daylight hours (averaging 40°C). In addition to working in the daylight, the system will be in a pressurized casing and that will reduce the chances of triple point occurring even further.

5.2 Experimentation

To research the potential of release bound water using microwaves, experiments were conducted with nickel sulfate (VI), a compound containing six bonded water molecules. Nickel sulfate is bright green in color and when the water is released, the substance turns pale green. For the first experiments, nickel sulfate (VI) was tested to determine if microwaves released the energy level required to free both the bonded and unbound water. In the subsequent experiments, tests were performed using varying depths to determine the required time for full penetration (explain). All of the experiments were conducted in a household microwave, and the results of all tests can be found on Graph: Nickel Sulfate (VI). Time Experiments were grossly over simplified in that focused magnetrons were not used. Use of scattered microwaves as opposed to focused microwaves means the graph would not be valid under actual model conditions. The main goal of the experiments is to show that microwaves will release bound water.



Graph: Nickel Sulfate (VI) time Experiments

From the graph it is possible to see the relationship between the full penetration time and the thickness of the nickel sulfate (VI).

5.3 Results

Experiments prove that water can be released from a bound state by using microwave energy. This fact is important because with no water release this design is not feasible. As stated before, there are huge differences in conditions of the experiment and conditions that the model would see. Use of actual focused magnetrons on samples is too dangerous at this point but in later research the actual magnetrons will be necessary. In the future Team JFEET would like to begin working with the magnetrons and finding the differences in absorption with respect to different materials. Finding the amount of efficiency gain versus conventional heating would also prove to be an interesting idea to explore. Not only would the results of those future experiments prove useful in this application but aid many other industrial applications outside of the space program. The microwaves are what make this design efficient and it is very important to quantify that efficiency in the future.

5.4 Interface

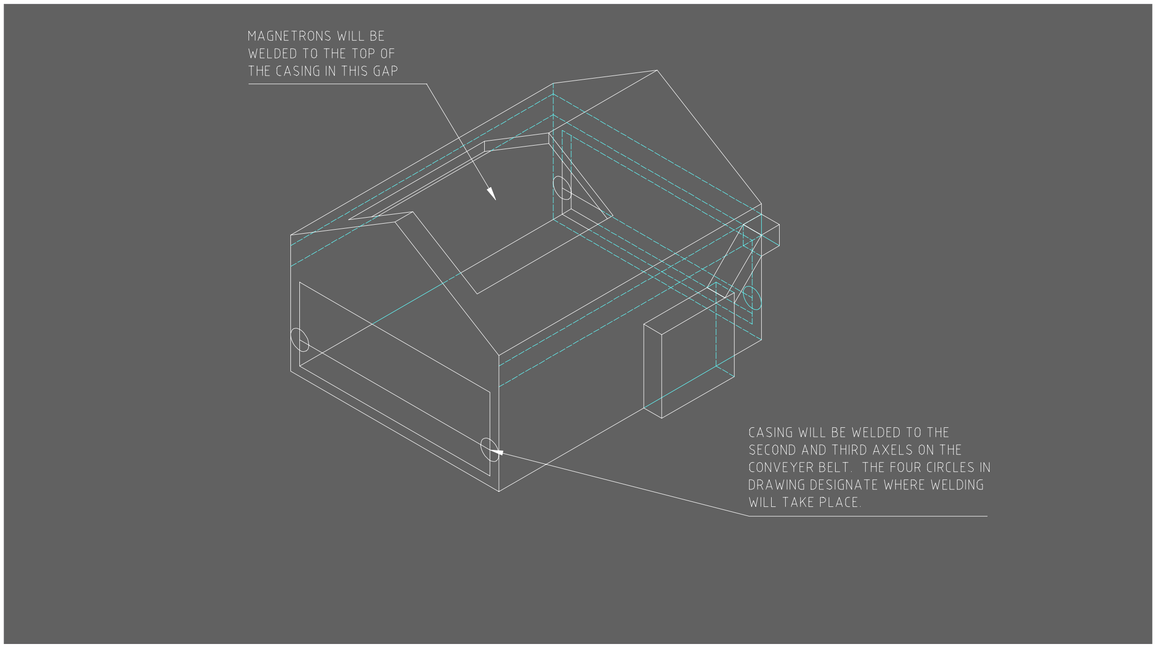
The microwave subsystem will provide the energy source necessary to increase the temperature of the water to at least 500°C, and thus release it from the soil. The two magnetrons will be mounted in series above the conveyor belt near the end of the heating compartment closest to the entrance, which will allow for a condensation section in the compartment opposite to the magnetron section.

The microwave unit will operate at kilowatts at 2.45 GHz. This frequency was chosen because it does not interfere with the electromagnetic spectrum and also contains convenience in implementation. The condensation section will provide and area for the water vapor to cool and condense for collection. To prevent water vapor from entering the magnetron assembly, the magnetron output will be covered with a protective panel transparent to Rf energy in the range of 2.45GH, which will prevent the possibility of corrosion or shorting of the magnetrons caused by the water or water vapor. The magnetron will receive electrical power via an electrical distribution system from the solar panel subsystem. Use of microwaves within the metal casing should not present a problem. The metal casing would simply reflect the microwave energy before it is absorbed by the water within the soil.

6. CASING

Water collection is one of the most important parts of the entire system. The basic functions of this subsystem is to trap and condense free water vapor, and then collect the water in liquid state and carry it off to storage. The first step in this process involves heating of the water stored inside the soil, causing evaporation. The evaporated water will condense on the ceiling while the soil is moved through the casing and dumped off the system by the conveyer belt. The casing will allow evaporated water to condense on the ceiling and run down the sides. The walls of the system will be strategically positioned such that the water will pool and be collected on the sides by a gutter system and run to the back right side of the casing. Once collected, the water will run through a measuring device and into the storage tanks. Though the theory of this water collection process is sound, experiments need to be done in order to fully understand the process.

The casing is to be constructed with lightweight sheet metal coated with white enamel. The sheet metal will best withstand large temperature fluctuations and supply a durable covering for our water extraction system. Likewise, the white enamel is applied to the metal in order to best work with the metal to reflect the microwaves inside, therefore increasing the intensity of waves on the soil. Initially, the casing will be seven flat pieces of sheet metal. The enamel coating will also help prevent corrosion of the casing due to the presence of water vapor. Each piece is to be welded together for strength. The assembled casing will then be welded to the second and fourth axles of the conveyer belt. This assembly will allow approximately 15cm of overhang between the conveyer belt and casing, which is ample room for the input and output of soil. The magnetrons will also be welded in the slots on top of the casing. Finally, metal gutters will be welded inside the casing. The gutters will collect the condensed water and carry it to one corner of the case. For this to happen, one gutter must be sloped 6°, and the short gutter above the belt exit is sloped 8° so gravity will move the water to the water metering sub-system. The external dimensions of the entire water extraction system are 23cm wide, 30cm long, and 25cm high. The dimensions exclude a layer of insulation around the casing system. Further research is recommended for insulation appropriate for the surface conditions of Mars.



6.1 Experimentation

Experiments were performed to test whether or not the water would actually collect on the ceiling and run down the sides.

- Using plexi-glass, a simple case design was constructed that resembled the actual project casing.
- Construction of the casing was such that the angles at which the roof panels were aligned could be adjusted
- Water was boiled under the plexi-glass to simulated the evaporated water which would be released from the soil
- Roof angles were maximized so that water could run down the sides of the casing without "raining" on the cooking dirt below

6.2 Results

After multiple trials using multiple angles, the ideal angle for the plexi-glass to have is a 90-degree angle between the separate pieces, which yields a 45° angle for each piece in relation to the vertical.

The ends of the casing need to be securely enclosed as to not let any evaporated air to escape and hinder the entire purpose of the project. The condensing water will not "rain" at the 45°angle. It will take time for the evaporated water to condense enough on the ceiling for it to run down the sides to the storage tanks.

After completion of experimentation, results show that this subsystem will indeed be capable of integration into the final system. The theory is complete, and the experimentation procedures uphold the theory. The extensive experimentation now provides the data necessary needed to properly construct the entire system. Conclusions have also been made stating that the material that the collection system is constructed out of will play a vital role in the actual ability to have the water condense. The whole casing system as well as the rest of the oven will be in a pressurized environment. This allows the water to condense under the set conditions of the regulated environment. The 20g of water per hour will be measured and stored in tanks provided, while the 10kg of soil per hour are cycled through casing by a conveyer belt run off gravity and a small motor powered by solar energy.

6.3 Potential Obstacles

As engineers, JFEET is obligated to explore some of the potential obstacles that might be encountered with the water collection system. The main foreseen obstacle is creating the idealized pressurized environment. The amount of power needed to create such an area could provide problems. So alternatives, such as allowing the water vapor transform to ice, have been considered. This idea would be implemented if pressurization of the entire system proves infeasible.

7. WATER METERING AND TRANSPORTING SYSTEM

Initial specifications require the ability to collect, measure, and provide for storage the water that is extracted from the soil. The collection process will be accomplished with a set of gutter that will mount inside the system case. The collected water in the gutters will be passed via a flexible plastic tube that will run along the outside of the casing to a small compartment that is attached to the outside of the main case. This small-attached case will be of the same material as the main casing. A slightly smaller container is enclosed that will hold the water and then eventually release it for metering. The holding tank will be in the shape of a trapezoidal prism. The trapezoid will have a long height of 7cm, a short height of 5cm, a width of 5cm, and a depth of 2cm. The top edge of this prism is horizontal, therefore perpendicular to the vertical sides. That leaves the bottom of the prism to slope downward for a vertical drop of 2cm. The tank will hold 50g of water before emptying each time. To comply with project specifications, which call for 200g of water per hour, the holding tank will empty approximately four times per hour while the system is operating.

The water will exit the holding tank using the principles of siphoning. "A siphon is an instrument, usually in the form of a tube to form two legs of unequal length, for conveying liquid over the edge of a vessel and delivering it at a lower level. The action depends upon the influence of gravity (not on the difference in atmospheric pressure) and upon the cohesive force that prevent the columns of liquid in the legs of the siphon from breaking under their own weight" (Britanica). A small tube will be attached to the low point of the holding tank and run vertically up the outside of the front surface. At a distance of 1.5cm from the top of the holding tank the tube will pass through a ring protruding from the front surface. After passing through the ring, the tube drops vertically passed the bottom of the holding tank and continues down to the storage tanks.

As the holding tank fills with water, the water level in the tube rises equally. When the water level in the holding tank rises to the apex of the inverted U in the tube, the water will begin to flow down the long end of the tube. This will create a siphon effect and drain the entire tank of water into the storage tanks. To calculate the quantity of water stored, the number of times the tank empties needs to be counted.

A switch device, which consists of a 5mm diameter, hollow, plastic, spherical float, a 3.5cm bent plastic rod, a pivot point, and two gold electrical contacts, will count each time the tank empties. The float is connected to one end of the bent plastic rod and floats along the top of the water level inside the holding tank. The bent rod is positioned over the center point on the top edge of the back surface at the rod's bending point. The rod is attached by, and pivots around, a pin running through the rod's bending. The rod, bent at a point 2.7cm from the end, is attached to the float, extending the rod 0.8cm outside the holding tank. The rod is bent to an angle of 70° from the horizontal at the pivot point. At this time the actual metering portion of the system will be introduced, working with an electrical circuit.

A gold wire, which comes from a circuit board, is coiled around the short end of the plastic rod. A gold contact surface will be attached to the center of the back surface of the holding tank 7mm below the pivot point. Another gold wire is attached to this contact surface runs to the aforementioned circuit board. Gold was chosen because of its high electrical conductivity and resistance to corrosion. Every time the water tank approaches its full point, the float will rise with the water level and, in turn, move the outer arm of the bent plastic rod towards the gold surface on the back surface of the holding tank. When the water level reaches its maximum height, the gold wiring on the plastic rod and the gold surface on the back of the holding tank will be in contact. Each time the two gold materials separate, the electrical circuit is broken and that will break the signal that is being received at the circuit board. The circuit board will be able to count the electrical impulses and multiply it by the capacity of the holding tank, thus finding the amount of water collected.

8. OUTREACH

In the spring of 2000, Team JFEET presented the MPO design in a school-wide competition. Among those in attendance were EPICS students as well as other Colorado School of Mines students, CSM faculty and staff, and field specialists. In winning that competition the team was given the opportunity to continue with the development of the water extraction unit. Utilizing information learned from that experience, the team modified the design and increased the understanding behind certain key concepts. The team also met with engineer Darren Clark from Lockheed Martin. This visit gave better ideas of what an engineer in the aerospace industry thought of the feasibility of the project. Team JFEET has been working in conjunction with last year's representatives from the Colorado School of Mines, C.R.A.T.E.R., to integrate the EPICS program at CSM. Just recently a public presentation was held at CSM where Team JFEET, C.R.A.T.E.R., and other similar projects were presented. In attendance were CSM faculty, Mike Duke and his colleague, and the other EPICS groups. It is important to embrace community involvement in and around the Colorado School of Mines area, all of these endeavors have allowed Team JFEET to do that.

9. CONCLUSION

Team JFEET has designed a system, referred to as the MPO, capable of extracting water from the soil of Mars. The MPO meets design constraints for mass, water production, durability, while microwave energy to extract water from the Martian soil in the most efficient manner. The MPO design minimizes the number of moving parts, has high reliability, and most importantly does not waste power by heating the water and soil indiscriminately, as would be the case with electrical thermal heating of the soil.

Heating of the soil with microwaves is accomplished with electrical energy provided by silicon solar cells. The silicon cells greatly increases the quality the overall system by providing a reliable source of high-output energy. High-energy output is important due to the length of daylight at the equator of Mars, where the MPO is expected to operate.

The soil will be processed with the use of a conveyor belt mounted on an angle to take advantage of gravity assistance. The recovered water vapor will be condensed and delivered to the water metering and transport subsystem. The water metering and transport subsystem utilizes the basic principles of siphoning to measure the water collected. There is only one moving point in the subsystem, the float and plastic rod, which helps decrease the chance for error. A siphon depends on the natural force of gravity, and although the gravity on Mars is less than that of Earth's, it does not have a significant enough effect to change the siphon system.

A microwave-based system is capable of heating the water directly, and does not heat the soil. Therefore, the microwave energy is applied to the water, which is then heated to the required temperature. Due to conduction of heat, some of the energy in the water will be lost to the surrounding soil, but this loss is believed to be less with the microwave system than with other forms of conventional heating. Ultimately, the best choice for a water extraction system is one that uses the least amount of moving parts, has a high history of reliability, directly applies energy to the material, and has a high efficiency. Taking these requirements into consideration it becomes apparent that Team JFEET's MPO is the best selection.

Overall, our system will have a mass of less than 20kg and produce 200g of water per hour.

10. FUTURE STUDIES

The experimentation up until now has been limited to crude models at best. Pending results of this competition the next step would be to seek outside funding that would enable project continuation. Ultimately Team JFEET would like to create a prototype and model it in Martian like conditions. This is the only way to prove the true effectiveness of the design. To this point research, theory, and basic experiments have been driving the current design. The contrast of theory and reality is huge and can only be realized by building a prototype. Once a working prototype is completed, advanced experimentation can commence, revealing the strengths and weaknesses of the design.

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APPENDIX

Decision Matrix

	Advantages	Disadvantages	Feasibility	Durability	Restrictions	Total
Inclined Pipe	Few moving parts, continuous operation, easy to collect vapor	mass	8	7	bulky, 7	22
Kettle/Pot	Simple, few moving parts, easy to get rid of, amount vs. time	insulation, high energy	8	8	mass, 6	22
Sifter	No moving parts, simple	soil clog, high temp, work fast	5	8	soil flow, 4	17
Funnel	No moving parts, simple, small amt. of soil to heat	clogging, collecting H20	8	7	rock size, 6	21
Conveyor Belt (pizza oven)	Continuous operation, soil output	energy intensive, moving parts	6	4	energy, 5	15
Focused Light	Solar energy, high temp for small area	night operation, setup & alignment	3	6	sunlight, 6	15
Microwave	Compact	energy needed to operate	8	9	energy/mass, 7	24