Barometric Evaporator Desalination Project

An Application to the United States Bureau of Reclamation
for Project Funding under the 2013 Desalination and Water Purification Research and Development Program

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Tasks I,II,III

Technical Proposal

Executive Summary

This proposed Project will test a prototype Barometric Evaporator (BE). The Barometric Evaporator is a novel thermal desalination technology invented to use moderate temperature waste heat, solar, or geothermal heat to directly desalinate brackish water or seawater. The Barometric Evaporation Process and Barometric Evaporator are described in U.S. patent number 6,254,734 B1 issued in July 2001. The Barometric Evaporation Process makes direct use of thermal energy in a warm or hot water source to drive evaporation into a vacuum through vertical continuous flash channels. A Barometric Evaporator can be constructed with minimal motive parts, typically one vacuum pump, a fan for air-cooling and/or a circulation pump for water or geo-cooling. Other flows are driven by air pressure, vapor pressure, and gravity. In principal, this makes for an easy to operate, easy to maintain system with very low electrical power requirements. This is advantageous in industrial desalination applications that reclaim waste heat or utilize moderate temperature solar thermal or geothermal heat that would not be economic if a high electrical demand were required. This process would also be useful in small communities with underdeveloped infrastructure and a limited pool of skilled labor. Ease of installation and low power demand also gives it application in areas where natural disaster or drought has compromised water supplies.

Coupled with waste heat or low-grade heat from renewable energy processes, the system would be economically competitive with membrane technologies in appropriate locations. The electrical requirements will be much lower. Thermal energy derived from waste heat, such as power system cooling water, or low-grade renewable heat such as geothermal sources under 200°F, provide very low cost energy to drive the process. Energy recovery by multiple effect distillation integrated with a Barometric Evaporator as the effect one steam generator can greatly increase production capacity per unit energy when the temperature difference between the heat source and final cooling source is sufficient to support multiple effects.

The Barometric Evaporation Process will be able to desalinate a wide range of source waters to high purity because the process is only marginally sensitive to total dissolved solids, particulates, or other contaminants in the source water. High quality water can be separated from a wide range of dissolved impurities by thermal distillation. When multi-effect distillation is used in series with a Barometric Evaporator, the system can also provide a high recovery rate, which minimizes the volume of brine discharge thus reducing environmental impacts. When coupled salinity gradient solar ponds as a heat source, a Barometric Evaporator can deliver brine concentrate back to the solar ponds creating a net zero brine discharge process.

This Project will execute several prototype scale tests of the Barometric Evaporation Process needed to test the concepts and prepare for the design, fabrication, and testing of a pilot scale Barometric Evaporator. A pilot test will determine whether the economics of the process can be competitive. If successful, the pilot tests would lead to a demonstration Barometric Evaporator with multi-effect energy recovery for testing in several locations around the country. A demonstration would be built for easy transport by truck or barge to any community with a need for potable water, a source of saline water, and a source of low cost heat.

Funding support is requested here to test an existing low temperature prototype Barometric Evaporator built from PVC plastic in the 120°F to 140°F range. Several sizes and shapes of vertical flash channel will be fitted to the prototype unit and tested at a range of pressures, temperatures, and water chemistry to find optimum configurations for the range of conditions that might be encountered in real world operation. The prototype will include a mechanism to regulate flow and pressure drop into a flash channel, connections to change out flash channels, and a separation vessel. The prototype will take advantage of support components already installed in an existing Reclamation supported thermal desalination pilot test facility in Imperial County, California. These include a 30 foot vertical tower, a controlled temperature hot saline water source, a condenser with controlled cooling and vacuum venting, and a brine handling system. Temperature, pressure, and flow instrumentation will be installed on the prototype Barometric Evaporator, enabling thermal efficiency data to be recorded over a range of operating conditions. After one or more optimum flash channel configurations have been selected and tested it will be possible to evaluate how a Barometric Evaporator compares to other thermal and membrane desalination technologies.

The goal of this Project will be to test and validate the Barometric Evaporator prototype, then, if successful, apply the technology within one year on a pilot scale to provide steam generation for an existing Vertical Tube Evaporator (VTE) that is planned for installation at a salinity gradient solar pond demonstration project at the Salton Sea in Imperial County California.

Background and Introduction

Introduction

The proposed project addresses a critical need in a wide variety of U.S. communities with regard to sustainable water resource management; namely, the ability to increase water supply at a lower cost, using existing resources in the community. In many arid and coastally- accessible regions, brackish groundwater or seawater is available for desalination. Also available in many western communities is geothermal heating that can be accessed for the desalination process. When considered as part of a comprehensive and integrated water resource management program, these resources combine for a potentially lower cost and more sustainable approach for communities and their water needs [1, 2, 3].

Multiple forces are creating a higher demand for alternative and sustainable water management strategies, among them: 1. Higher urbanization rates in areas that do not have sufficient water supply, either in arid regions or internationally in developing areas; 2. Water resources depletion, either because of higher rates of development, unrestricted groundwater access, or from climate-based factors (drought); and 3. Effects of long term climate change that may lead to reduced rainfall, desertification, and/or prolonged drought. In all three instances, the need for sustainable methods of water supply and management become more and more critical. Thomas and Durham (2003) refer to the UN Environmental Program analysis that states “severe water shortage affects 400 million people today and will affect 4 billion people by 2050” (p.21). Further, they note that desalination, treated wastewater, aquifer recharge or some hybrid combination will be crucial in an integrated and sustainable community water system.

While a variety of desalination techniques have been developed and implemented with success in various parts of the world [4, 5, 6], the key factors that still need to be addressed are cost effectiveness and sustainability of the life cycle of the desalination process. The ability to create smaller scale solutions, rather than the more traditional “big-pipes-in/big-pipes-out” approaches [2], will be key for facilitating a greener and more sustainable (environmentally and economically) long term water management system. This is particularly an issue with smaller communities, as well as any community that has fewer or insufficient resources.

Technology Background

The Barometric Evaporation Process is designed to efficiently convert hot saline water to steam and recover it as distilled water without additional energy input and a minimum of pumping, offering low cost, low electricity, and low maintenance requirements. The process can be readily adapted for use with a range of low grade heat sources including waste heat from cooling engines, power plants, or industrial processes, or low to moderate temperature solar or geothermal heat sources.

A Barometric Evaporator operates by drawing hot (120°F or higher) saline feed up one or more vertical flash channels into a vacuum. If the unit is designed for the maximum pressure difference from atmospheric pressure to full vacuum, the flash channel would be about 33 feet in length. Vapor flashes continuously from the brine as it rises in the flash channel, cooling as it gives up heat of evaporation to the vapor, but continuing to flash because the pressure is reduced higher up the flash channel. This is quite different from the discontinuous, non-reversible flash at each gate of an MSF unit. Vapor separates from the brine in an evacuated chamber at the top of the flash channel and passes through a demister into an evacuated condenser or into the first effect of a multi-effect VTE or other MED configuration. Concentrated brine flows down a tube by gravity to ground level; likewise for distillate. Because the height of the evacuated separation chamber is near equal to the head of a column of water between vacuum and atmospheric pressure, no pumps are required for feed, or to pump brine concentrate or distillate from vacuum to atmosphere. The only pump required is a vacuum pump to establish a vacuum at startup and remove any non-condensable gasses released from the feed water.

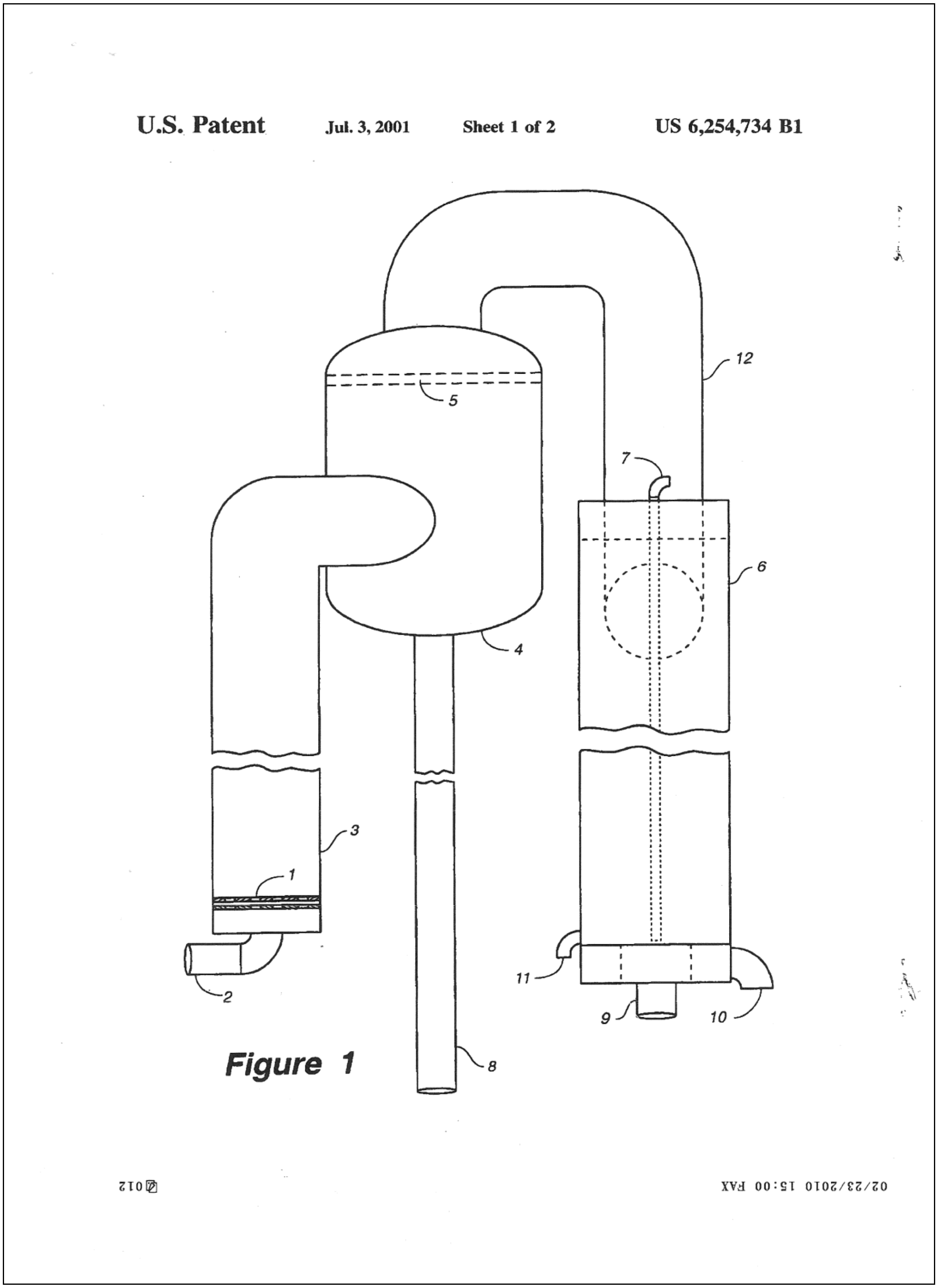


Figure 1. Barometric Evaporator with flash channel, brine/vapor separation vessel, & condenser

A basic implementation of a Barometric Evaporator is illustrated in Figure 1. The labeled components are as follows:

1	Variable orifice plate	Flash initiation and flow regulation
2	Feed inlet	Hot water inflow
3	Flash channel	Up-flow flash equilibrated as brine rises into vacuum 33ft
4	Separation vessel	Vapor/ brine separation on exit from flash channel
5	Demister screen	Separates brine droplets entrained in rising vapor
6	Condenser	Condenses vapor to distillate
7	Vent to vacuum	Keeps system under vacuum, draws out any gasses
8	Brine outlet conduit	Discharges brine after evaporation, descending 33ft
9	Coolant inlet	Supplies the condenser with coolant
10	Coolant outlet	Returns coolant to cooling tower or other heat sink
11	Distillate outlet	Distilled water product outlet from condenser
12	Vapor conduit	Passes vapor from the separation vessel to the condenser

The Barometric Evaporation Process is a novel concept well suited to using waste heat or low-grade heat from renewable geothermal or solar sources. The Barometric Evaporator is described in U.S. patent number 6,254,734 B1. The patent was issued to Hugo H. Sephton in July 2001. Dr. Sephton passed away in 2002. Sephton Water Technology controls the patent rights and has worked in cooperation with Reclamation to develop some of Dr. Sephton's other desalination technologies starting in late 2002. This project will provide the most extensive test and first published data on this technology.

Prior to this Project, the Barometric Evaporation Process had only been prototyped using a simple assembly with a glass separation vessel, lab tubing for the single flash channel and descending legs, an automotive radiator and fan for condensation, a lab vacuum pump to establish a vacuum and remove non-condensable gasses, and a small pool of water heated in the sun as feed. There was no instrumentation, so no data was obtained other than visual observation of distillate production. This Project has assembled a more robust prototype to be coupled with an existing VTE pilot plant infrastructure providing a controlled source of fresh or saline hot water, condensing capacity, brine management, and instrumentation of flows, temperatures, pressures, and conductivity to record performance data for comparison with existing technologies.

Figure 2 shows a more sophisticated implementation of a Barometric Evaporator. Multiple parallel flash channels increase the capacity of the evaporator. An up-flow VTE is used to make efficient use of heat in the vapor from the Barometric Evaporator by condensing the vapor on the outside of a tube bundle with saline water inside the tubes that is evaporated by the heat of condensation and then condensed in the condenser. This second vapor production is near equal in mass to the vapor condensed from the Barometric Evaporator thus nearly doubling the distillate capacity with the same thermal energy input. Additional effects can further increase the capacity within the practical limits of the temperature difference between each evaporator and the final condenser.

U.S. Patent   Jul. 3, 2001   Sheet 2 of 2   US 6,254,734 B1

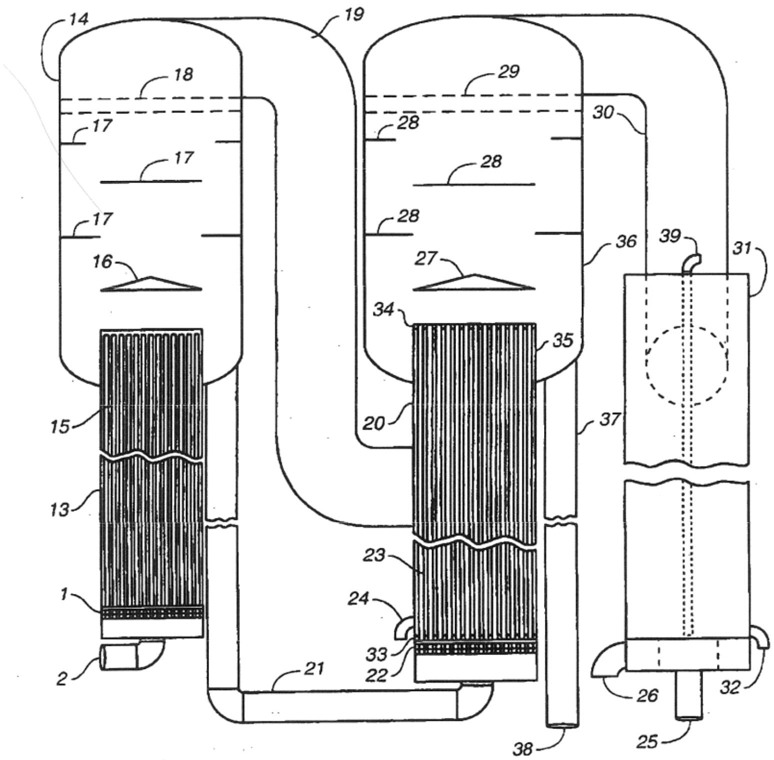


Figure 2

Figure 2. Barometric Evaporator with multiple flash channels, one VTE effect, and a condenser

Known Related Technology

The Barometric Evaporation Process shares some principles of operation with a Vertical Tube Evaporator (VTE) in the up-flow or rising film mode of operation [7]. In both systems saline water is evaporated within an air free tube while flowing upward from a higher to lower pressure. Both the pressure difference and the expanding volume of vapor released by the saline water serve to drive saline water at increasing concentration up a tube against gravity. A foaming agent can be used to enhance this process by forming vapor filled bubbles that fill the tube and help carry liquid upward. When the saline water inside the tube is heated by steam condensing on the outside, up to 200% improvement in heat transfer performance has been shown, probably caused by reducing the water in contact with the tube surface to a thin film [9, 10, 11]. Up-flow VTE uses a flow restriction device, typically an orifice plate, at the bottom of the tube to initiate the flash of heated saline water under pressure to vapor as it enters the evaporator tube at lower pressure. Some prior theoretical work has been done on predicting the two-phase flow characteristics, pressure, and heat transfer in a VTE with reasonable correlation to experimental data [12]. This theoretical model does not incorporate foamy flow.

The Barometric Evaporation Process differs from an up-flow VTE in that the heat energy for evaporation is present or introduced into the saline water before it is fed to a flash channel rather than being introduced through the wall of an evaporator tube by heat of condensation from steam on the outside. A similar two-phase flow occurs, but the saline water in the flash channel is allowed to cool as it rises in the flash channel releasing heat energy to evaporation. No experimental data exists on the Barometric Evaporation Process to compare with existing or new theoretical models.

The Barometric Evaporator and Process has several key features in common with a recently described low-temperature / low-pressure evaporation process theorized by Gude and Nirmalakhandan in 2008 for use with low grade heat sources [13] and tested as a prototype in 2009 [14]. The newer process was further modeled and prototyped with heating energy input from a photovoltaic panel in 2010 [15]. The shared features include the use of rising and falling barometric legs for feed from and product/concentrate reject to atmospheric pressure respectively, vapor separation in an evacuated chamber at the top of the unit, a condenser at the top of the unit to recover distillate, and the use of low grade waste heat, solar, or geothermal heat to drive the evaporation process.

The key differences include first the introduction of heat to drive the process in the vapor separation chamber at the top of the unit in the Gude and Nirmalakhandan process while the Barometric Evaporation Process introduces heat into the saline feed at the bottom of the unit. Second, the Barometric Evaporation Process uses a flash inducing orifice and vertical flash channel to facilitate evaporation in the rising saline water feed column and help draw feed upward against gravity. Third, the Gude and Nirmalakhandan describes thermal energy recovery from the descending brine reject column by heat exchange with the rising saline water column, but does not describe using a multi-effect evaporator or any other method to recover heat from the vapor produced because the unit is intended to operate at low temperatures only. The Barometric Evaporation Process is intended to operate efficiently over a range of low to moderate temperatures (120°F to 210°F).

Potential of Proposed Technology

The Barometric Evaporation Process is a novel, but untested, thermal desalination process with very low electrical requirements, that maybe competitive with existing desalination technologies when coupled with low cost waste or renewable heat sources and optimized effectively. There is no directly applicable data to optimize the design of the flash channels, nor to evaluate the overall performance of a BE. This Project will provide that data from prototypes.

Barometric Evaporation technology has wide applicability to economic conversion of saline water to potable water wherever low-grade, low cost, or waste heat is available. A low to moderate temperature distillation process like this is inherently capable of producing potable water from a wide range of saline water sources including brackish ground water, agricultural drain water, gray water, partially treated municipal or industrial waste water, tidal flood water, seawater, and brine rejected from RO or other desalination processes.

This Project will test several configurations and materials in a single flash channel and record system thermal efficiency data from the prototype Barometric Evaporator at a range of operating conditions. These data can be compared to existing or modified theoretical models to predict the performance of pilot and commercial scale Barometric Evaporators.

If the thermal performance and capacity of the prototype looks promising, this Project will lead in about one year to the design, fabrication, and testing of a pilot scale Barometric Evaporator from CPVC with multiple flash channels and energy recovery through an existing pilot scale two-effect VTE. The pilot Barometric Evaporator will draw hot brine from a demonstration salinity gradient solar pond planned for the southeast shore of the Salton Sea. Concentrated brine will cycle back to the bottom solar pond for a zero net discharge operation. Vapor will be condensed in the VTE and cycle back to the surface of the salinity gradient solar pond to maintain the gradient in a ‘falling pond’ configuration. Thermal energy from steam generated in the Barometric Evaporator will be recovered by the VTE to distill Salton Sea water for use as surface evaporation makeup for both the salinity gradient solar pond and for an adjacent saline habit.

Data and experience from a pilot test will determine whether the economics of the Barometric Evaporation Process coupled with multi-effect distillation are competitive. If the capital, operation, and maintenance costs per unit of distilled water delivered are favorable, the Barometric Evaporator could be useful in any region that has a shortage of potable water, a source of saline waste water, ground water, or seawater and access to a low cost heat source such as waste heat from a power generating or industrial process, geothermal heat above 150°F, or sunshine to heat saline water in ponds or thermal solar collectors. The market potential in the many regions of the Western United States that fit that description will depend on the economics of the Barometric Evaporation Process compared to other processes. It has the potential to be very competitive when energy costs are high because it can use low grade or waste heat and requires minimal electricity.

Technical Risks

The principal technical risk of this investigation is the possibility that the thermal efficiency of an optimized Barometric Evaporation Process may not prove to be competitive with other thermal desalination processes. A second technical risk is that, even with high thermal efficiency, the production rate of distillate from equipment of a particular scale may not be high enough to justify the capital costs. A third technical risk is that scaling in the flash channels and separation vessel may be higher than with other thermal desalination technologies, but this is less likely for a low to moderate temperature process. If the thermal efficiency, production rate, or scale control were not satisfactory from the prototype Barometric Evaporator tests, then the planned salinity gradient solar pond demonstration would have to fabricate an alternate steam generator. A vacuum flash chamber was successfully used for steam generation and gradient management at the California State Department of Water Resources salinity gradient solar pond test at Los Banos, California [17], so that would provide a reasonable, but less energy efficient, fallback option for the planned salinity gradient solar pond test at the Salton Sea.

There is minimal risk from assembling a prototype and carrying out the tests as this work fits into the operations of an existing desalination pilot test plant. A protocol is in place for collection of saline feed water and for blending distillate with brine discharge close to the original composition for return to the saline water source. This protocol has been approved by the appropriate regulatory authorities for Salton Sea water and can be extended to other saline water sources in the area if needed in the future.

Technical Approach

Project Purpose and Goals

This purpose of this Project is to test the Barometric Evaporation Process at a prototype scale so the potential of the technology can be understood and compared to other desalination technologies. Prototype testing will permit optimization of the design for high thermal efficiency. If the Barometric Evaporation Process can be optimized to be competitive with other low to moderate temperature thermal desalination processes, then it would be worthwhile to design and build a pilot Barometric Evaporator to fully test the capacity and economics of the process. This Project will determine whether proceeding to a pilot scale is warranted. The specific goals of this Project are:

1. To test the fundamental operation of a Barometric Evaporator. This includes rising flow driven by the pressure difference between atmosphere and vacuum, accelerated by expanding vapor in a flash channel. It also includes descending flow of brine by gravity out of a vacuum and flow of vapor to a condenser or secondary evaporator. These flows can be roughly estimated from pressure differences and pipe sizing, but the rising leg is a complex two phase flow that needs empirical testing.

2. To optimize the design of critical novel components of the process including flash channels, flash initiators, foamy flow, and brine/vapor separation.

3. To test and optimize the design and operation of the Barometric Evaporator across the range of potentially useful hot source water temperatures 120°F to 140°F that the existing Barometric Evaporator can handle.

4. To quantify the thermal efficiency of the Barometric Evaporation Process by measuring the distillate produced per unit of thermal energy consumed.

5. To evaluate and measure scale formation on key Barometric Evaporator surfaces when operating with high salinity source water.

6. To estimate the size and cost of the equipment necessary to scale up the process to a pilot or demonstration scale and develop an optimal design for such a scale up.

7. To determine whether a Barometric Evaporator would be more advantageous than a standard vacuum flash chamber for use as a steam generator with salinity gradient solar ponds at the Salton Sea or elsewhere.

Test Procedures Proposed

1. Mount the existing low temperature PVC prototype Barometric Evaporator on the existing 30 foot tower of VTE Pilot Plant. Integrate the PVC prototype Barometric Evaporator with the VTE Pilot Plant to control source water temperature and salinity, cooling rate, and vacuum. Use the PVC prototype Barometric Evaporator to test and optimize basic flow parameters such as cross section and height of the rising flash channel leg, cross section and height of the descending brine leg, and cross section, vapor pressure, and flow into a condenser under low temperature, high vacuum operation. The configuration of splash baffles and demister screening also needs to be optimized for high distillate quality with minimum brine droplet entrainment versus pressure drop across the demister screen or screens. Test various internal brine/vapor separation configurations by direct observation of splash baffles in operation and monitoring of vapor pressure, temperature, distillate conductivity, and distillate flow. This work will be done pre-award at the Applicant's expense and is underway now.

2. Search the literature for any relevant theoretical models and data from processes that operate on similar principles. This will provide a basis of comparison with existing technology. It may offer a theoretical model that can be used to optimize the Barometric Evaporation Process more effectively than empirical testing over a wide range of parameters. If a theoretical model compares well with test data already collected from the low temperature PVC prototype Barometric Evaporator, it can guide the later design of higher capacity pilot and demonstration Barometric Evaporators using higher temperature materials.

3. Design and test at prototype scale several types of variable flash initiators. The Barometric Evaporation Process relies on an initial flash-down of hot feed to vapor as the feed enters the flash channel, but only just enough to start the process. Liquid and vapor should ideally be in thermal equilibrium throughout rest of the rise through the flash channel to lower pressure and temperature. To operate over a range of feed

temperatures, the initial flash-down needs to be adjustable. Adjustable orifice plates are described in the Barometric Evaporation Process and Evaporator patent for controlling feed flow and initiating flash-down and in more detail in US Patent #5,156,706 for controlling flow inside a down-flow VTE. A test of the down-flow control mode at a Huntington Beach, California VTE Pilot Plant in the late 1990's had problems with fouling and sticking between the sliding plates according to test participant Dieter Emmermann. An adjustable flow restrictor that is robust and can be scaled up to control feed into multiple flash channels is needed. Alternate designs such as an orifice and tapered plug will be tested against a fixed and sliding orifice plate in an apparatus allowing direct observation of the flash-down and recording of flow rates, pressure differential and temperatures. From these tests, a best design will be installed in the prototype Barometric Evaporator.

4. Install a selected variable flash initiator at the base of a ½" CPVC pipe installed as the rising leg, or flash channel, in the existing PVC prototype barometric evaporator. Test this configuration over the potentially useful low temperature source water range of 120°F to about 140°F with freshwater feed. Using freshwater as feed for the early flash channel optimization tests is a practical choice. The boiling point elevation of saline water has only a modest affect on the evaporation rate so freshwater thermal performance data is not very different from saline water. Install and test larger ¾" CPVC pipe as a flash channel and install and test stainless steel tubing at ¾", ½", and ¼" to observe the effect of different flash channel diameters and rigidity on performance.

5. With each flash channel choice installed use geothermal steam in the VTE to preheat freshwater feed over a range of temperatures. The VTE Pilot Plant can be operated to supply an ample amount of water of any salinity on demand at a steady temperature maintained within a few tenths of a degree from ambient up to 212°F. This provides a convenient means to simulate feed water heated by a variety of waste heat or renewable heat sources. Different temperature and pressure conditions as well as the presence and concentration of surfactant should influence which size of flash channel gives the best performance. For a given flash channel size, system performance data over a range of feed temperatures and surfactant additive concentrations should identify whether that flash channel size is useful at a particular source water temperature.

6. There is data on optimal sizing of vertical tubes with and without foamy flow [10], but the existing theory and test data on evaporation in vertical tubes or channels relate to introduction of heat across the tube wall, a non-equilibrium process. There is no known data to suggest an optimal configuration for flash-down of water to vapor at thermal equilibrium in a vertical flash channel such as that in a Barometric Evaporator. The rate of draw of hot saline feed should be inversely related to the resistance to flow at the flash initiator, wall friction in the flash channel, and the length of the flash channel. For non-foamy flow in a VTE this has been modeled assuming annular liquid flow with vapor in the center [12]. That model does not apply to foamy flow with a surfactant additive. In that case liquid will be carried up

the tube more rapidly by the vapor with a break point between full foamy flow and slug flow. Absent an established theoretical model, empirical data can be collected over a range of temperatures with varying amounts of surfactant, or none using a range of flash channel cross sectional areas and lengths to find an optimal configuration for likely operating conditions. These data may provide a means to derive a mathematical relationship between flash channel sizing and certain operating parameters that will be predictive in the future.

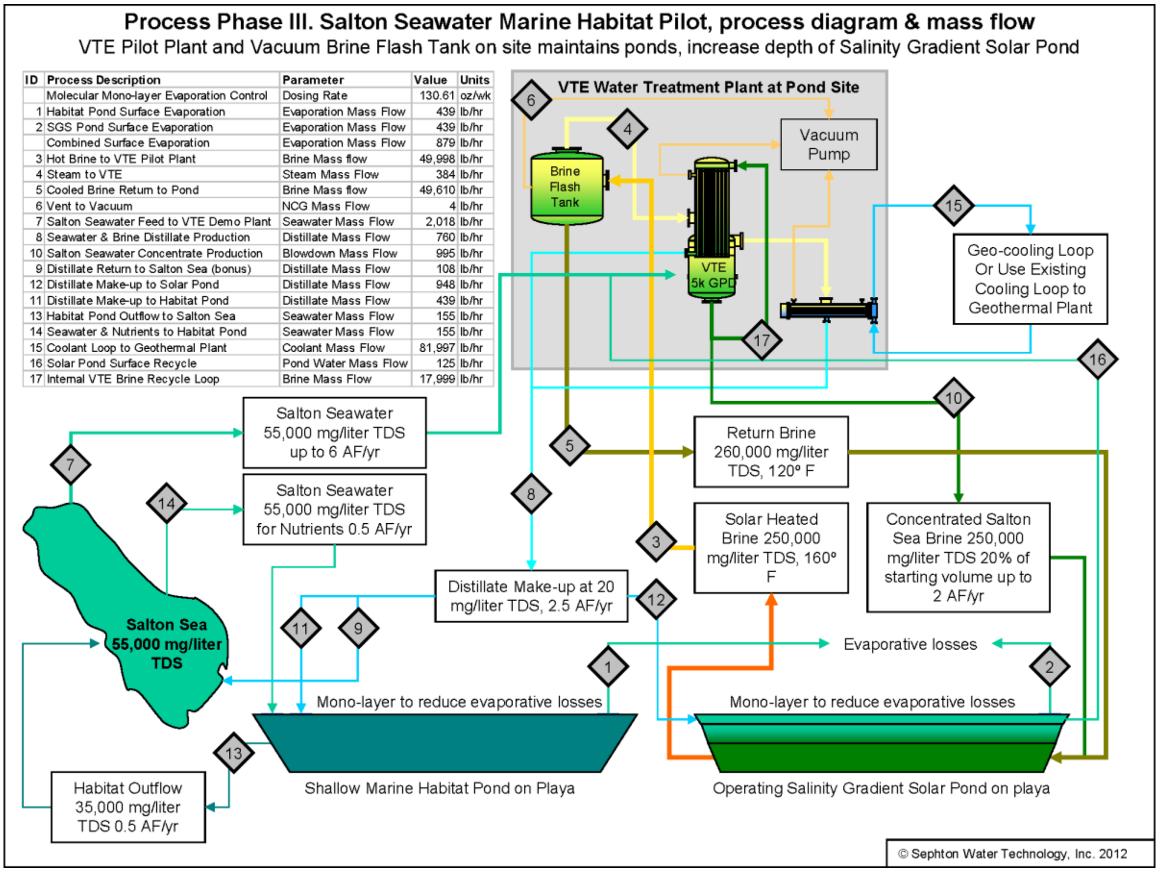
7. Because a Barometric Evaporator has no requirement for steam distribution to the outside of evaporator tubes, a square or hexagonal cross section might be optimal for a tightly packed column of multiple channels. Offset corrugated sheets arranged ridge to ridge might be cost effective. Tubes are easily obtained in various diameters and materials, so they're an easy cross section to start with to find an optimal cross sectional area and length for a single flash channel at a particular range of operating temperatures. With that established, alternate cross sectional shapes with a similar area can be tested before building a multiple channel pilot Barometric Evaporator.

8. Test the system performance with seawater feed. Seawater is the most prevalent saline water source and is accessible to many areas in the southern and western United States that suffer from potable water shortages now or in the recent past. Salton Sea water is accessible at the VTE Pilot Plant site. It has higher salinity and higher concentrations of scale forming ions than ocean water. That makes it a good worst case test water source.

9. Test the system performance with seawater feed and several concentrations of a surfactant foaming agent. Addition of a foaming agent has two benefits for a Barometric Evaporation Process. First, a foamy two phase flow of vapor filled bubbles will stabilize the entrainment of saline liquid in the rising vapor inside a flash channel. These bubbles break much more easily than air filled bubbles when they exit the flash chamber into the vapor separation chamber allowing separation of vapor. This will allow liquid to rise in the flash channel more quickly and efficiently. This can increase the capacity of a Barometric Evaporator of a given size because more feed will flow through each flash channel. The magnitude of this effect in a Barometric Evaporator is unknown, but has been observed in VTE equipment [10]. Second, foam will greatly increase the surface area of the vapor/liquid interface allowing thermal equilibrium to be more quickly reached. This is expected to have a benefit for both the thermal efficiency of the process and for the capacity, but the magnitude is unknown. Addition of a surfactant foaming agent in the 1-20 ppm concentration range is known to enhance evaporation rates of seawater in a VTE [16]. Thermal performance testing with surfactant should provide data to evaluate the magnitude of these affects. At higher surfactant concentrations and excessive vapor flow rates in the separation chamber, the foaming agent can cause unacceptable carryover of brine into the distillate condenser. This has to be monitored carefully by observation and adjustments to flow rates in the system until good operating conditions are established.

Applicability to Reduced Environmental Impacts and Renewables

The first example for application of the Barometric Evaporator and Desalination Process described in U.S. patent number 6,254,734 B1, columns 12 and 13, is for use with a salinity gradient solar pond. Solar heated brine from the bottom layer of the pond is drawn into the Barometric Evaporator and partially flashed to vapor with the remaining slightly concentrated brine being returned to the bottom of the pond for solar reheating and gradient maintenance. The hot vapor from the Barometric Evaporator can be used to supply heat to a second evaporator (such as a VTE) where it is condensed to distillate.



ID	Process Description	Parameter	Value	Units
	Molecular Mono-layer Evaporation Control	Dosing Rate	130.61	oz/wk
1	Habitat Pond Surface Evaporation	Evaporation Mass Flow	439	lb/hr
2	SGS Pond Surface Evaporation	Evaporation Mass Flow	439	lb/hr
	Combined Surface Evaporation	Evaporation Mass Flow	879	lb/hr
3	Hot Brine to VTE Pilot Plant	Brine Mass flow	49,998	lb/hr
4	Steam to VTE	Steam Mass Flow	384	lb/hr
5	Cooled Brine Return to Pond	Brine Mass flow	49,610	lb/hr
6	Vent to Vacuum	NCG Mass Flow	4	lb/hr
7	Salton Seawater Feed to VTE Demo Plant	Seawater Mass Flow	2,018	lb/hr
8	Seawater & Brine Distillate Production	Distillate Mass Flow	760	lb/hr
10	Salton Seawater Concentrate Production	Blowdown Mass Flow	995	lb/hr
9	Distillate Return to Salton Sea (bonus)	Distillate Mass Flow	108	lb/hr
12	Distillate Make-up to Solar Pond	Distillate Mass Flow	948	lb/hr
11	Distillate Make-up to Habitat Pond	Distillate Mass Flow	439	lb/hr
13	Habitat Pond Outflow to Salton Sea	Seawater Mass Flow	155	lb/hr
14	Seawater & Nutrients to Habitat Pond	Seawater Mass Flow	155	lb/hr
15	Coolant Loop to Geothermal Plant	Coolant Mass Flow	81,997	lb/hr
16	Solar Pond Surface Recycle	Pond Water Mass Flow	125	lb/hr
17	Internal VTE Brine Recycle Loop	Brine Mass Flow	17,999	lb/hr

Figure 3. Process and mass flow diagram for planned Salton Sea salinity gradient solar pond test

The use of thermal energy captured and stored in salinity gradient solar ponds to drive a distillation process has been tested in the field and described in the literature [17,18,19]. The Applicant has been working with the Imperial Irrigation District to demonstrate the process shown in Figure 3 that would use salinity gradient solar ponds on the shore of the now receding Salton Sea to avoid a public health problem from salt dust blowing off the exposed lakebed and to create two other environmental benefits. One is to provide a salt sink for rising salinity that threatens to destroy to the Salton Sea ecosystem within several years and the second is to supply a clean selenium free water supply to habitat ponds planned as a refuge for the threatened wildlife by using distilled Salton Sea water in place of local brackish water flows, many of which carry problematic levels of selenium. The State of California recently announced a provisional grant award [20] sufficient to fund the first year of this effort based on a proposal with the following stated objective:

Develop a cost effective method to supply contaminant free water to shallow marine habitat ponds at any location on the Salton Sea playa by distillation of Salton Seawater using solar thermal or geothermal energy to remove all contaminants of concern. The Project will work out cost, energy, and water treatment requirements for employing Salinity Gradient Solar Ponds to provide the energy and salt sink needed to reclaim Salton Seawater and maintain habitat ponds without harming the ecosystem.

The salinity gradient solar pond demonstration proposed a water treatment process previously demonstrated at a test in Los Banos, California [17]. That test used an evacuated Brine Flash Tank similar to the one shown in the top center of Figure 3 as a steam generator for the VTE and a brine concentrator for the solar pond. A Barometric Evaporator can replace traditional low to moderate temperature steam generators supplying steam to a thermal desalination process from a hot water source. The Barometric Evaporation Process operates more closely to a reversible thermodynamic process that the highly non-reversible Brine Flash Tank steam generator used in the Los Banos process, therefore a Barometric Evaporator may provide better thermal efficiency.

If the prototype testing in this Project is successful and shows superior thermal efficiency, a pilot scale Barometric Evaporator will be fabricated in place of the Brine Flash Tank shown in Figure 3. This will enable more efficient heat recovery from the solar pond improving the overall clean water output of the system to supply the habitat ponds proposed. Brine concentrate from both the Barometric Evaporator and the VTE go to increasing the bottom layer thermal storage capacity of the salinity gradient solar pond with zero discharge to the environment. If the project were continued for multiple years to the point that the salinity gradient solar pond was filled to maximum operating depth, then brine concentrate would be used to charge a second salinity gradient solar pond, expanding the solar collection, energy storage, and water treatment capacity of the system

The proposed demonstration is small, but the process can be replicated over thousands of acres if the economics prove feasible and the Salton Sea problems increase as predicted.

Applicability to Sustainable Regional Water Supply

In the 2009 Integrated Water Resources Management Plan, the Imperial Irrigation District (IID) predicts a future imbalance between water supply and demand on the order of 100,000 acre-feet annually as demand from municipal and renewable energy customers grows [21].

The Imperial Valley region of Southern California where prototype testing will be done has a wide range of unused saline water sources including over one million acre feet of brackish groundwater in the East Mesa area ranging from 500 to 10,000 parts per million (ppm) TDS, one million acre-feet annually of irrigation drain water from 1,000 ppm to 4,000 ppm, and over six million acre-feet of saline lake water currently in the Salton Sea at about 50,000 ppm. The area also has geo-thermally heated water from existing wells ranging in temperature from 200°F to 500°F and in salinity from about 5,000 to 300,000 ppm TDS.

Some of the moderate depth groundwater from the East Mesa area is geo-thermally heated to around 180°F. Indeed the area has surface hot springs fed by geothermal brackish water. Wells up to a few thousand feet deep and above 250°F are already exploited for geothermal power production. The lower temperature brackish groundwater available in the East Mesa area is not economic for power production, but is an ideal candidate for reclamation by direct use of the Barometric Evaporator Process. An integrated East Mesa brackish groundwater reclamation process is shown in Figure 4.

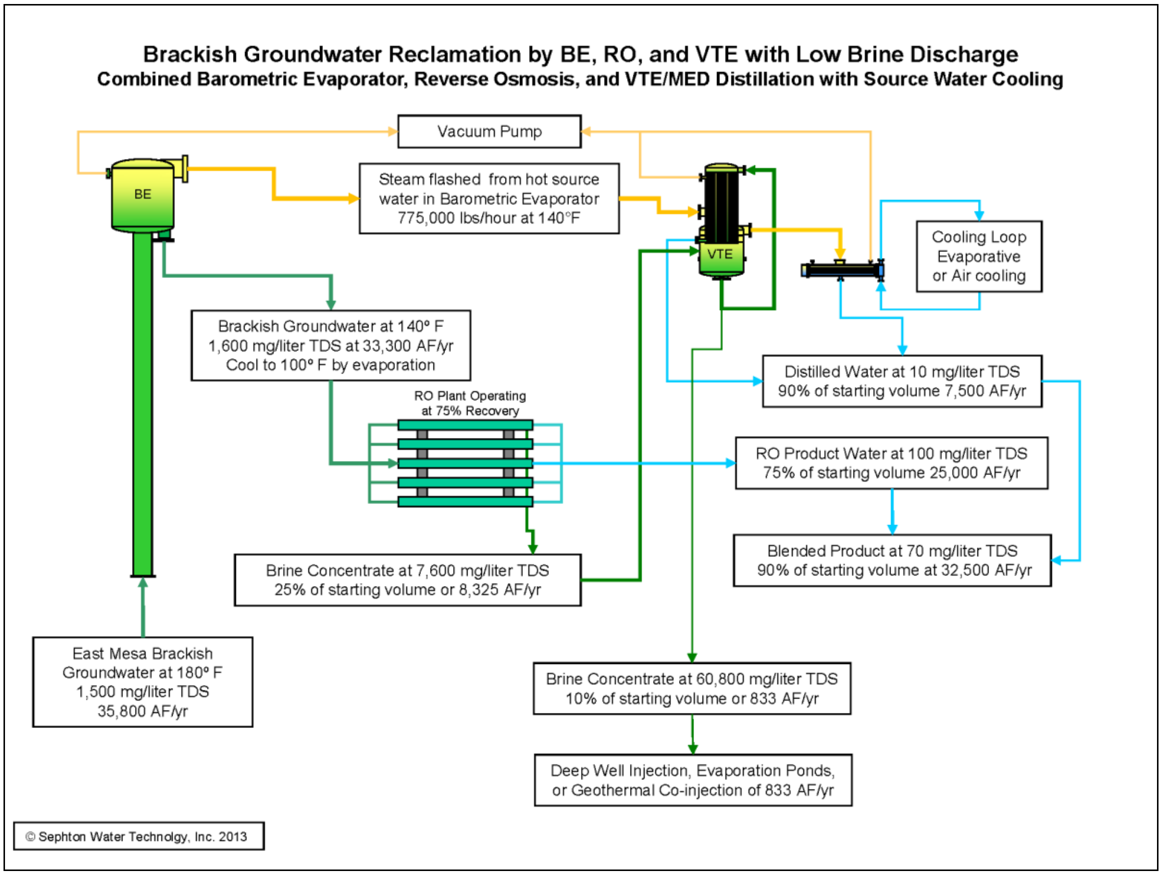


Figure 4. Scheme for hot East Mesa groundwater reclamation integrating BE, RO, and VTE

A Barometric Evaporator using East Mesa brackish groundwater at 180°F generates steam for a VTE process by flashing about 7% of the hot brackish source water. The brackish water is further cooled to the 100°F range ideal for a Reverse Osmosis (RO) process for recovery of 75% of the brackish source water. The reject brine from the RO process is fed to a four or five effect VTE process where the brine is concentrated to less than 3% of the starting volume using heat recovered from the source water by the Barometric Evaporator. The final brine concentrate is co-injected with geothermal brine into the deep saline aquifer or evaporated in solar ponds. The process is highly scalable. The example in Figure 4 shows a production of 32,500 acre-feet per year. This would supply about one third of IID's projected long term deficit. It is well within IID's 50,000 acre-foot per year upper limit estimate of sustainable groundwater development with recharge by under-runs from Colorado River allocation [21 Executive Summary, page 6].

In the current prototype phase, this Project will directly test selected wastewaters in the immediate vicinity. These will include agricultural drain and other waters collected and concentrated in the Salton Sea and may also include batch testing of local groundwater or surface water from the New and/or Alamo River or nearby irrigation drains. Permits and facilities to test Salton Sea water are already in place. The Salton Seawater data will be applicable to using the Barometric Evaporation Process in coastal communities with seawater and waste heat sources from power plants or industry. For example waste heat from power plant cooling water can be directly used by a Barometric Evaporator to desalinate outflow from once through cooling or hot blow-down from an evaporative cooling tower.

Many arid inland areas in the Western United States have ample supplies of brackish ground water or irrigation drain water. Data from this Project can be used to evaluate the applicability of the Barometric Evaporation Process to reclaim saline water in many other inland localities throughout the Southwest where low grade geothermal, solar, or waste heat is also available.

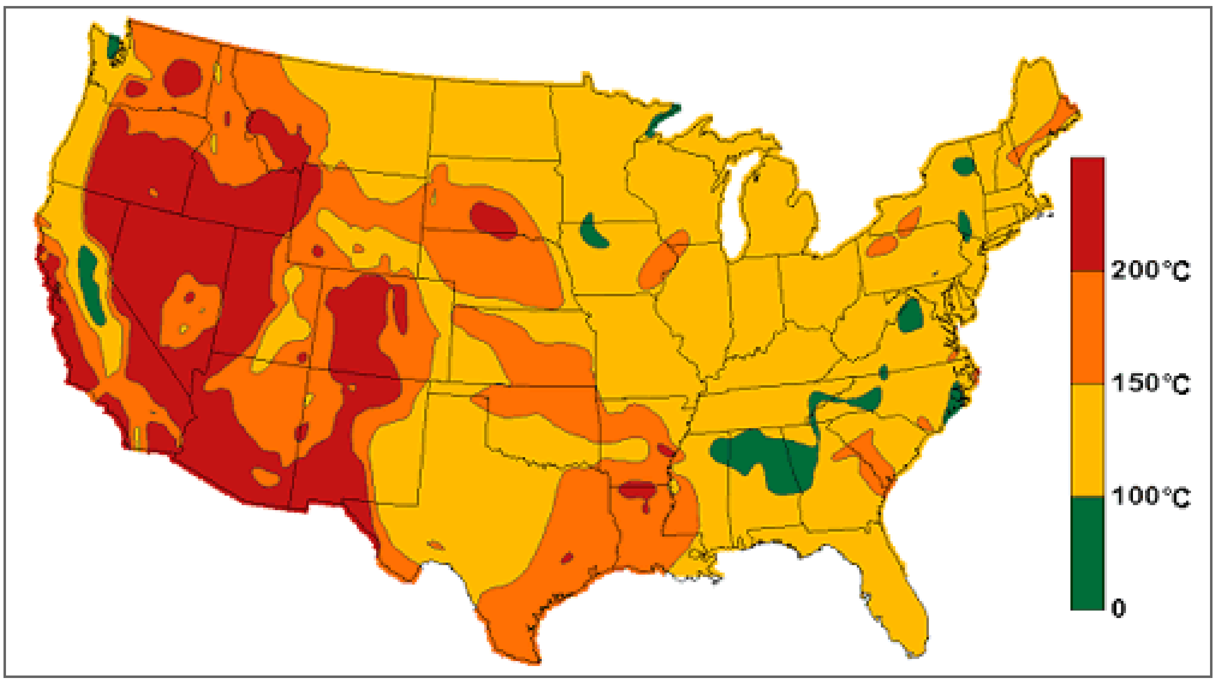


Figure 5. Geothermal Resource Map of the U.S. at 6km depth (U.S. Dept. of Energy)

The Western U.S. has abundant supplies of low to moderate grade geothermal heat (see Figure 5). The process illustrated in Figure 3 is just one way to use a Barometric Evaporator to access low to moderate temperature geothermal resources that may not be economic for electricity production. Remote communities can benefit from employing a Barometric Evaporator alone, or with an up-flow VTE for heat recovery, to distill saline geo-thermally heated groundwater as shown in Figure 6. This process can provide a low maintenance desalination system with electricity required only to power a small vacuum pump, a cooling loop, and to pump hot ground water to the surface and return cooler slightly concentrated water to the aquifer if needed.

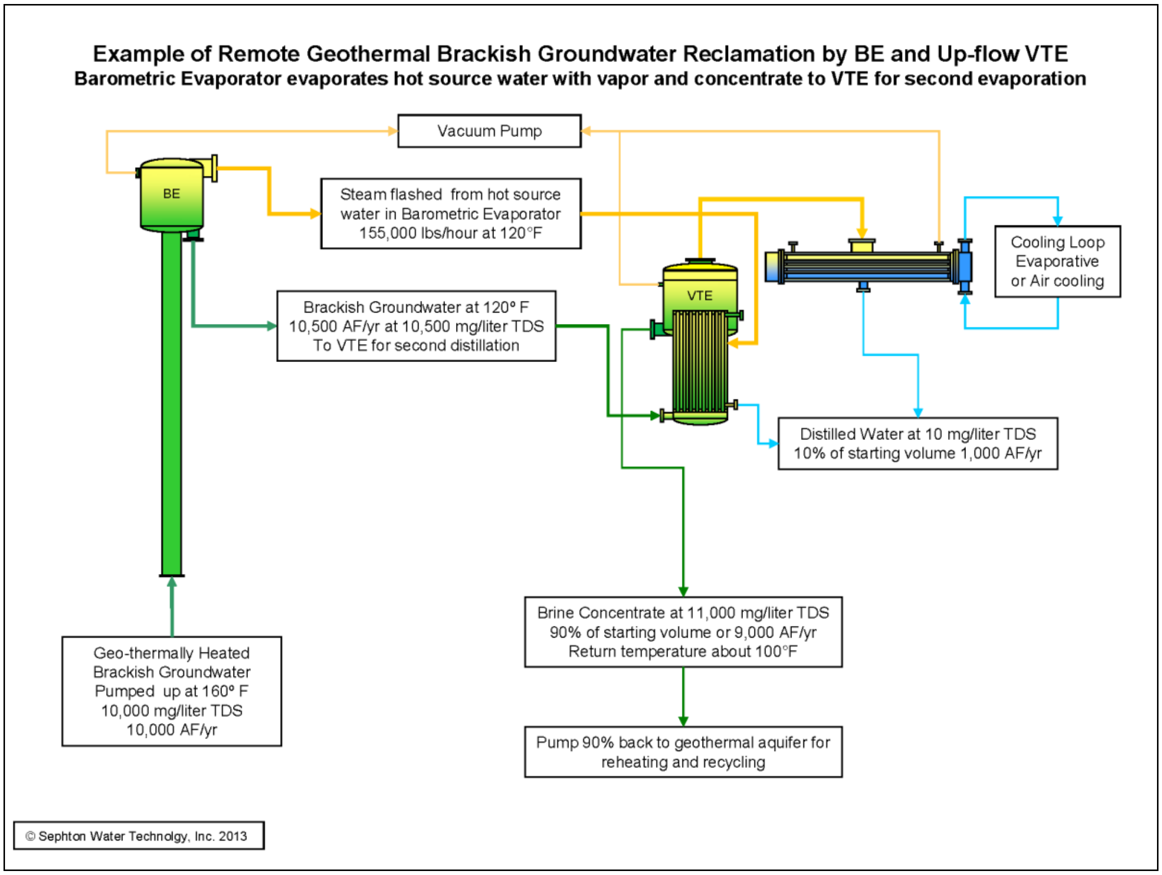


Figure 6. Low maintenance scheme for distillation of low temperature geothermal brackish water

Economics

The Barometric Evaporation Process is only relevant where saline water is available and where low to moderate temperature geothermal, solar, or waste heat can be made available. Fortunately this includes large areas of the southwestern United States.

The Barometric Evaporator is intended to be an efficient, simple, low maintenance device to flash steam from moderately hot water sources 120°F to 212°F. It can be compared with discontinuous steam flash systems akin to the first stage in a multistage flash system. Unlike the discontinuous flash at each stage in a multistage flash, a Barometric Evaporator applies a continuously declining pressure on the source water as it rises in a flash channel. This is likely to offer a benefit in thermal efficiency, but only testing of a well optimized Barometric Evaporator can prove it.

The economics of the Barometric Evaporation Process are as yet unknown. The thermal performance and capacity of a Barometric Evaporator could yield capital cost economics ranging anywhere from poor to highly competitive where a low cost heat source is available. Since heat transfer surfaces are not required, low cost fabrication from plastics is likely to be practical and cost effective for operating temperatures below 180°F. Few pumps are required, and instrumentation and controls are very simple. The capital costs will be driven by the capacity for distillate production per size of equipment and the need to mount the Barometric Evaporator separation chamber at a 30 foot elevation above the source water requiring a tower construction in some locations. It is likely that operation and maintenance costs will be competitive as the process is simple, with few moving parts, very low electrical costs, and no fuel costs.

By using a Barometric Evaporator to supply heating steam to a single or multi-effect VTE, the distillate production per unit heat input can be increased several fold, limited by the temperature difference between the heating steam and the coolant available to a final condenser. This can multiply the distillate production by a factor close to the number of effects added to the Barometric Evaporator. If a hot water source were available at close to the boiling point, then about 12 VTE effects would likely be possible in addition to the Barometric Evaporator giving a gained output ratio of about 12 pounds of distillate for each pound of steam generated in the Barometric Evaporator. This multi-effect configuration increases the distillate capacity per unit of thermal energy used dramatically by recovering heat with each effect, but it also increases the capital cost linearly with each effect added. Adding effects will be economically attractive in applications where the thermal energy resource is limited or comes at a significant cost.

Anticipated Problems

Execution of the site testing within the proposed budget is dependent on equipment, heating, cooling, water handling, and infrastructure resources provided by the VTE Pilot Plant. This plant is currently operated by Sephton Water Technology under a cooperative agreement with the Bureau of Reclamation. The majority of funding to maintain the existing VTE Pilot Plant and expand it to a Demonstration Plant scale is currently provided under a grant from the California State Department of Water Resources awarded to Reclamation with additional funding from Reclamation. If that funding were withdrawn before this proposed project is completed, it could impact the availability of those facilities. Under current agreements, other funds are available to maintain the needed facilities through the rest of 2013. The funds requested here would be sufficient to maintain the VTE Pilot Plant as it is now for the duration of this Project.

Testing of various flash channel configurations with freshwater may not identify any that provide a sufficient thermal performance and distillate production capacity to justify continuing with the testing. If a wide range of configurations has been tested with no promising performance data, then it would be prudent to report that result and not proceed with testing of seawater and brackish water in the prototype evaporators.

Breakdowns or temporary unavailability of equipment or vital infrastructure may delay testing. In that case operating costs can be minimized until the problem is resolved or the equipment is repaired and a no-cost time extension could be requested from Reclamation if necessary. The permitting agencies may be slow to issue permits needed for certain tests or equipment assembly. The same remedy would apply. Fortunately, permits are already in place to cover the great majority of the work proposed because the essential work is consistent with VTE Pilot Plant environmental compliance documents and permits already issued.

Scope of Work

Preliminary Research and Lab Tests

1. Review the literature for any applicable theoretical models not yet found [12] of two- phase flow in a vertical tube or channel that can be adapted and compared to test data.
    a. Personnel: Tom Sephton-10 hours, Huanmin Lu-10 hours
    b. Elapsed Time: 5 days
2. Review the literature for applicable theoretical models and test data on the overall thermal performance of evaporators operating on similar principles in addition to that already identified [9, 10, 11, 12, 13, 14, 15, 22].
    a. Personnel: Tom Sephton-10 hours, Huanmin Lu-10 hours
    b. Elapsed Time: 5 days
3. Assemble a bench test apparatus for testing flash initiation by pressure differential across a fixed or variable opening orifice plate, or by other means into a glass column. Install instrumentation to measure feed flow, condense and measure vapor, and measure temperature and pressure on both sides of the flash initiator.
    a. Personnel: Tom Sephton-20 hours
    b. Elapsed Time: 10 days
4. Test various configurations of orifice plates and any other flash initiators while recording differential pressure, flow, temperatures, and the amount of vapor flashed. Optimize for maximum flash with minimum flow resistance, pressure differential, and temperature reduction across the flash initiator.
    a. Personnel: Tom Sephton-20 hours, Technician-40 hours
    b. Elapsed Time: 10 days

Flash Channel Optimization Testing with Freshwater Feed

5. With the first choice of flash channel installed, use geothermal heat in one VTE evaporator to preheat freshwater and circulate it through the saline water feed tank to maintain a constant 120°F feed temperature, let the Barometric evaporator draw in and flash feed water to vapor. Adjust the variable flash initiator until flashing of vapor can just be observed. Gradually increase coolant flow through the VTE Pilot Plant condenser and open the isolation valve to the vapor separation chamber to increase the rate of distillation until a maximum is reached. Record temperatures, pressures, and flows at frequent intervals. Increase the temperature of the freshwater feed by a few degrees, stabilize the feed temperature then check the flash initiator and gradually change the coolant flow rate to identify a cooling rate where distillate production is at a maximum and where it is negligible. Repeat this procedure, raising the feed temperature a few degrees at each step and making adjustments to the flash initiator until data from a top feed temperature of 210°F has been recorded.
    a. Personnel: Tom Sephton-10 hours, Technician-10 hours
    b. Elapsed Time: 2 days

6. Repeat the preceding test procedure with each flash channel configuration available. Test each flash channel configuration with 5, 10, or 20 ppm of linear alkyl benzene sulfonic acid foaming agent added to the freshwater feed. Adjust the flash initiator and vapor flow rate into the condenser to allow foamy two phase flow in the flash channel under test while preventing carryover of foam into the condenser. If no flashing or evaporation is observed after making adjustments to the system, that flash channel configuration or temperature condition can be eliminated from later testing.
    a. Personnel: Tom Sephton-50 hours, Technician-50 hours
    b. Elapsed Time: 40 days
7. Analyze and compare the data to existing or adapted theoretical models to determine whether there is a good agreement of data to the model.
    a. Personnel: Tom Sephton-5 hours, Dieter Emmermann-5 hours, Huanmin Lu-5 hours
    b. Elapsed Time: 10 days

System Testing with Seawater Feed

8. With a selected flash channel installed, use geothermal heat in one VTE evaporator to preheat Salton Sea water and circulate it through the saline water feed tank to maintain a constant 120°F feed temperature. Let the Barometric evaporator draw in and flash feed water to vapor. Adjust the variable flash initiator. Gradually increase coolant flow through the VTE Pilot Plant condenser to find a maximum distillation rate. Record temperatures, pressures, and flows frequently. Repeat the test procedure, raising the feed temperature a few degrees at each step and making adjustments to the flash initiator until data from a top feed temperature of 200°F has been recorded. Collect samples of feed, distillate, and brine concentrate at selected operating conditions to send to an outside lab for chemical analysis of major ions and TDS.
    a. Personnel: Tom Sephton-10 hours, Technician-20 hours
    b. Elapsed Time: 2 days
9. Repeat the preceding test procedure with 5, 10, or 20 ppm of linear alkyl benzene sulfonic acid foaming agent added to the seawater feed. Adjust the flash initiator to cause foamy two phase flow in the flash channel while controlling the vapor flow rate into the condenser to preventing carryover of foam into the condenser.
    a. Personnel: Tom Sephton-30 hours, Technician-60 hours
    b. Elapsed Time: 6 days

System Testing with Saturated Salton Sea Brine for Solar Pond

10. Develop a protocol for concentrating and clarifying saturated Salton Sea brine. Concentration to saturation has been tested in the past with the VTE Pilot Plant. Saturated brine needs to be tested in the Barometric Evaporator to measure scaling. The brine needs to be clear of particulates or biota that would reduce transmission of sunlight. Settling and filtration will be tested at the existing VTE Pilot Plant. Settling in tanks has been observed to produce clear VTE brine. The rate will be quantified by measurement of brine turbidity with time after agitation using a turbidity meter at the VTE Pilot Plant. Growth rates of airborne algae and

other microorganisms will be quantified by measuring turbidity on open brine tanks over time. Filtration methods up to microfiltration will be pilot tested to remove small particles and microorganisms. The sterility of distillate from the Barometric Evaporator that would be delivered to the solar pond for surface dilution will also be tested.

   a. Personnel: Tom Sephton-120 hours, Dieter Emmermann-24 hours, Technician-120 hours
   b. Elapsed Time: 30 days

11. Develop a protocol for decolorizing saturated Salton Sea brine. A yellow color from organic matter that limits transmission of sunlight needs to be removed. The organic matter could also foul the Barometric Evaporator surfaces. Activated charcoal was shown to remove the color from organic matter in a 1982 NASA-JPA feasibility study of salinity gradient solar ponds using Salton Seawater concentrate. The recommendation will be tested by filtering concentrated clarified brine concentrate having the distinct yellow color with activated charcoal. Short visible wavelength absorption of filtered and unfiltered brine samples will be measured in a colorimeter. The filtration process will be optimized for flow rate and efficiency. Decolorized and non-decolorized saturated brine will be tested in the Barometric Evaporator by operation over time. The flash channels and interior surfaces of the brine/vapor separation chamber will be inspected for any organic fouling that may or may not occur with decolorized and non-decolorized brine.
    a. Personnel: Tom Sephton-120 hours, Technician-120 hours
    b. Elapsed Time: 30 days

Data Analysis, Design, and Reporting

12. Compare the saline water data to theoretical models and determine whether there is a good fit of data to existing or adapted models. If not, try to come up with a model or set of equations based on empirical data that would make it possible to predict the performance of a single or multiple flash channel Barometric Evaporator from feed temperature, cooling flux, feed salinity, foaming agent concentration, atmospheric temperature and pressure, and any other factors that are shown to be relevant.
    a. Personnel: Tom Sephton-5 hours, Dieter Emmermann-5 hours, Huanmin Lu-5 hours
    b. Elapsed Time: 10 days
13. Design the process, equipment layout, foundation slab, piping, electrical, instrumentation, and pond integration to relocate the existing VTE Pilot Plant to the pond site and repurpose it to make-up pond water using thermal energy from flashing solar heated brine. If testing has been successful, a pilot scale Barometric Evaporator will be designed to integrate with the VTE Pilot Plant. Construction of the Barometric Evaporator from CPVC would be a cost effective option. If testing of the Barometric Evaporator has not been successful, the VTE 1 unit can be repurposed as a vacuum chamber flashing hot pond brine to supply steam to VTE 2 in a process similar to the Los Banos solar pond test. Several piping and control systems will change in either event. New piping connections to the ponds need to be designed.

   a. Personnel: Tom Sephton-160 hours, Dieter Emmermann-40 hours, John Matthew (consulting mechanical engineer) 40-hours
   b. Elapsed Time: 25 days
14. Prepare a final report summarizing all test procedures, flash channel choices, performance data and comparisons of data to theoretical models.
    a. Personnel: Tom Sephton-80 hours, Dieter Emmermann-40 hours, Huamin Lu-10 hours
    b. Elapsed Time: 20 days
15. Write a paper reporting any promising results and submit to peer reviewed journals.
    a. Personnel: Tom Sephton-20 hours, Dieter Emmermann-5 hours, Huamin Lu-5 hours
    b. Elapsed Time: 20 days
16. Publish a process description and summary of test results on a website.
    a. Personnel: Tom Sephton-2 hours
    b. Elapsed Time: 10 days

Dismantling

17. Disconnect and remove all instrumentation from the Barometric Evaporator
    a. Personnel: Tom Sephton-4 hours, Technician-4 hours
    b. Elapsed Time: 3 days
18. Disassemble the Barometric Evaporator piping from the VTE Pilot Plant
    a. Personnel: Tom Sephton-4 hours, Technician-4 hours
    b. Elapsed Time: 2 days
19. Disassemble the Barometric Evaporator vessels and tanks
    a. Personnel: Tom Sephton-4 hours, Technician-4 hours
    b. Elapsed Time: 2 days

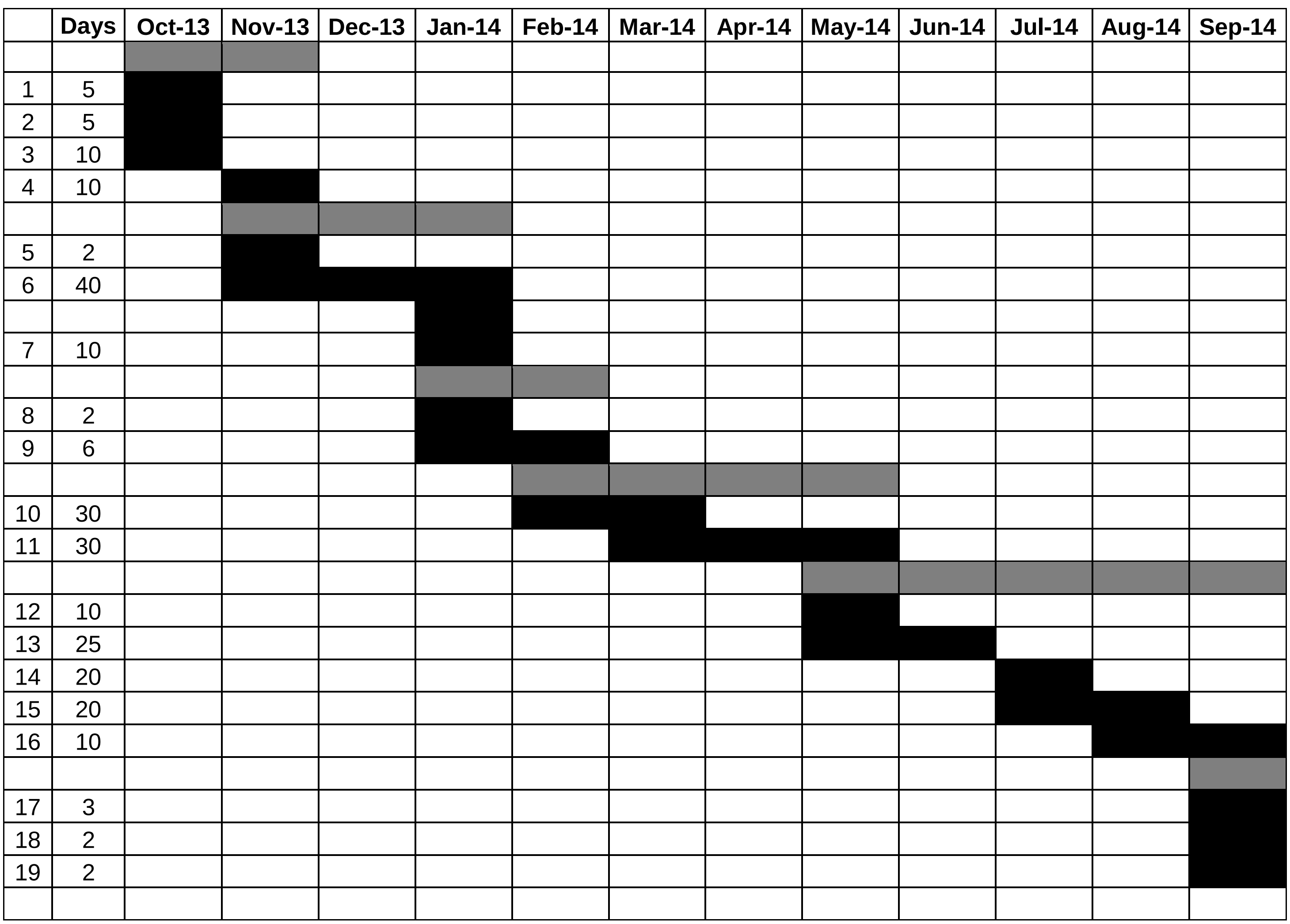
Research Work Plan and Schedule

Task Schedule and Milestones

	TASK	Start	Finish	Milestones
	Preliminary Research and Lab Tests			
1	Review literature for theoretical models of two- phase flow in a vertical tube or channel	1-Oct-13	7-Oct-13	report
2	Review literature for theoretical models and test data on evaporators operating on similar principles	8-Oct-13	14-Oct-13	report
3	Assemble a bench test apparatus for testing flash initiation	15-Oct-13	28-Oct-13	assembled
4	Test various configurations of orifice plates and any other flash initiators while recording data	1-Nov-13	12-Nov-13	report data
	Flash Channel Optimization Testing with Freshwater Feed			
5	With the first choice of flash channel installed, test the Barometric Evaporator on freshwater	13-Nov-13	15-Nov-13	report data
6	Repeat the preceding test procedure with each flash channel configuration available and test LAS	18-Nov-13	10-Jan-14	report data
	Write Quarter 1 Report	13-Jan-14	13-Jan-14	submitted
7	Analyze and compare the data to existing or adapted theoretical models	14-Jan-14	27-Jan-14	report results
	System Testing with Seawater Feed			
8	With a selected flash channel installed, test the Barometric Evaporator on seawater	28-Jan-14	29-Jan-14	report data
9	Repeat the preceding test procedure with 5, 10, or 20 ppm of LAS	30-Jan-14	6-Feb-14	report data

	System Testing with Saturated Salton Sea Brine for Solar Pond			
10	Develop a protocol to concentrate and clarify Salton Sea brine, test in the Barometric Evaporator	7-Feb-14	20-Mar-14	report data
11	Develop a protocol to concentrate and clarify Salton Sea brine, test in the Barometric Evaporator	21-Mar-14	1-May-14	report data
	Write Quarter 2 Report	2-May-14	2-May-14	submitted
	Data Analysis and Reporting			
12	Compare the saline water data to theoretical models and determine whether there is a good fit of data	5-May-14	16-May-14	report results
13	Design a pilot Barometric Evaporator integrated with the VTE Pilot Plant for the solar pond	19-May-14	27-June-14	submit design
	Write Quarter 3 Report	30-Jun-14	30-Jun-14	submitted
14	Prepare a final report summarizing all test procedures, flash channel choices, and performance data	1-Jul-14	28-Jul-14	final report
15	Write a paper reporting any promising results and submit to peer reviewed journals.	29-Jul-14	25-Aug-14	submitted
16	Publish a process description and summary of test results on a website.	26-Aug-14	8-Sep-14	site live
	Dismantling			
17	Disconnect and remove all instrumentation from the Barometric Evaporator	9-Sep-14	12-Sep-14	removed
18	Disassemble the Barometric Evaporator piping from the VTE Pilot Plant	15-Sep-14	16-Sep-14	removed
19	Disassemble the Barometric Evaporator vessels and tanks	17-Sep-14	18-Sep-14	removed

Task Schedule Chart



Project Management

On-site project management will be performed by Tom Sephton and Sephton Water Technology, Inc. (SWT). SWT are leading innovators in this area, holding unique patents and existing plant equipment to facilitate the prototype scale testing and proof of concept. Sephton will consult with Dieter Emmermann and Dr, Huanmin Lu on all key technical decisions and report the results of that consultation quarterly where appropriate.

The Imperial Irrigation District is managing the salinity gradient solar and habitat pond demonstration. The IID Project Manager, Bruce Wilcox will provide management and oversight on the use of State funding to support the aspects of this proposed Project that coincide with the Salton Seawater Marine Habitat Pilot Project. The continuation of that project will directly benefit from a successful conclusion of the proposed Project. Bruce Wilcox will consult with SWT and provide local oversight on the progress of the proposed Project.

CalEnergy Operating Company holds a long term lease on the project site and operates the geothermal power plant that now supplies steam and cooling water to the VTE Pilot Plant and will indirectly supply thermal energy and cooling for the prototype Barometric Evaporator. CalEnergy has cooperated with SWT by supplying modest amounts of steam and cooling water for the VTE Pilot Plant for several years. The proposed Project will continue to comply with strict work safety and environmental health and safety rules applied by CalEnergy on all of their regional plant sites.

As described in the Project deliverables, SWT will be responsible for the site build, testing and dismantling of equipment following project completion. Sephton, and the project team will collaboratively work on data analysis, data interpretation and project findings, as well as final report products and dissemination of results in appropriate journals such as *International Desalination Association (IDA) Proceedings, National Water Research Association (NWRA) Proceedings, Desalination, Journal of Water Resources Management, Journal of Water Resources Planning and Management*, and similar.

Project Deliverables

1. Data from bench tests of flash initiators.
2. Quarter 1 Report
3. Data from flash channel test of prototype Barometric Evaporator
4. Barometric Evaporator thermal efficiency and scaling data with various feed sources.
5. Quarter 2 Report
6. Data Analysis.
7. Final Report.
8. Paper submitted to journal.
9. Website updated with results.

Personnel Qualifications

Sephton Water Technology Researcher – Tom Sephton

Tom Sephton is President of Sephton Water Technology where he is currently conducting the VTE Geothermal Desalination Pilot/Demo Project under contract with Reclamation. Mr. Sephton helped develop the VTE technology for this Project while assisting his father and company founder, Hugo Sephton, with earlier demonstrations. Tom took charge of Sephton Water Technology and the current geothermal VTE initiative in 2002.

Mr. Sephton received a B.A. degree in Biochemistry from the University of California at Berkeley (1981) and an M.A. degree in Multimedia from California State University, Hayward (1999). Mr. Sephton's work experience includes two years in biomedical research with HyTech Scientific, four years in biochemical research at U.C. Berkeley, four years as a software engineer for Extempo Systems, and 15 years operating a business specializing in audio/video/animation production.

Consulting Desalination Engineer – Dieter Emmermann

Dieter Emmermann is an independent engineering consultant specializing in the design and construction of single and dual-purpose seawater desalination plants, both thermal (VTE, MSF, and VC) and membrane (RO) type plants. Mr. Emmermann's expertise is based on more than 30 years working in the Middle East (primarily Saudi Arabia, Oman, and Dubai) and China designing and overseeing the construction of these types of plants, ranging in size from 1.2 to 58 MGD. Most of these installations were built on a turnkey basis, including the intake/outfall systems and all of the civil works. Mr. Emmermann received a Diploma in Mechanical Engineering from Karlsruhe Institute of Technology in Germany.

Consulting Scientist – Dr. Huanmin Lu

Dr. Huanmin Lu, recently retired from the University of Texas at El Paso (UTEP), was a Research Specialist and Lecturer in the College of Engineering, where he taught courses in dynamics, thermodynamics, fluid mechanics, and heat transfer. Dr. Lu received an M.S. degree in Physics from Capital Normal University in Beijing, China, and an M.S. in Mechanical Engineering and PhD. in Environmental Engineering and Science from the University of Texas at El Paso. Dr. Lu also has a deep theoretical knowledge and experience with Salinity Gradient Solar Ponds including running the UTEP solar pond project for 16 years.

IID Solar and Habitat Pond Project Manager - Bruce Wilcox

Mr. Wilcox, an ecologist, has over 20 years of experience in the environmental consulting industry. He has worked as a division and program manager as well as section leader for several large environmental and engineering consulting firms. He is currently serving as the IID manager of the environmental compliance program for the Quantification Settlement Agreement water transfer (QSA). As such, Mr. Wilcox is responsible for all aspects of compliance for the various local, state and federal permits and agreements associated with the transfer. He manages a team of consultants and IID employees in the day to day implementation of the transfer mitigation and is also in charge of the team that is finalizing the Habitat Conservation Plan and Natural Community Conservation Plan for the project. He is responsible for developing and managing the annual and five year Joint Powers Authority (JPA) budgets for the QSA and reports directly to the JPA Board. Mr. Wilcox also acts as IID's liaison for mitigation with the other area MSHCP, with the Counties and with the surrounding water agencies. Mr. Wilcox is IID's representative on the State of California Salton Sea Ecosystem Restoration Program and related programs, and is one of the IID liaisons with numerous geothermal and other alternative energy companies.

Facilities and Equipment Information

A VTE Pilot Plant has been assembled and operated over a five-year period by Project partner Sephton Water Technology under grants from Reclamation and the California Department of Water Resources. That Pilot Plant is located in Imperial County, California at a geothermal power plant on the shore of the Salton Sea. The VTE Pilot Plant is on the West side of CalEnergy Operating Company's Salton Sea Unit 1 geothermal power plant, which provides a free source of geothermal heating steam.

Figure 7. VTE Pilot Plant with 30ft tower next to CalEnergy Units 1&2 geothermal plant

The existing PVC prototype Barometric Evaporator will be integrated with the VTE Pilot Plant. The existing Pilot Plant provides a 30ft steel tower to support the vapor separation chamber, vertical flash channel, and descending brine pipe. The VTE Pilot Plant will also provide a controlled temperature hot saline water source, a condenser with controlled cooling and vacuum venting, and a brine handling system. Two VTE units are included so one can be used to provide controlled temperature feed while the second can be used in series with the Barometric Evaporator supplying heating steam. Flash channels in a range of sizes and configurations will be tested and optimal configurations sought for likely operating conditions with various water sources simulating a range of feed temperatures from low cost heat sources. This simulation can be accomplished by heating various saline feed waters in the VTE with precise temperature and flow control. The thermal efficiency will be measured by temperature and pressure at key points in the system and flow rates of feed, distillate, reject brine, and coolant recorded by an automated data acquisition system already installed.

Applicant Experience and Past Performance

Sephton Water Technology carried out the Vertical Tube Evaporator Geothermal Desalination Pilot Test Project from late 2004 through late 2008 under a cooperative agreement with Reclamation. In 2006, Sephton Water Technology collaborated with Reclamation to win a grant award from the California Department of Water Resources to expand the project to a demonstration scale. That project began in early 2008 and has been ongoing under a new cooperative agreement between Reclamation and Sephton Water Technology under the name Vertical Tube Evaporator Geothermal Desalination Pilot/Demonstration Project through December 31, 2012. A new contract is currently being drafted by Reclamation to complete that project.

Work Currently Sponsored by Others

The Vertical Tube Evaporator Geothermal Desalination Pilot/Demonstration Project has been funded primarily by a $1.3 million grant award by the California Department of Water Resources to Reclamation based on a joint Reclamation and SWT proposal in 2006. Resources installed with funds from that project will provide infrastructure, equipment, and operational support for this proposed Project.

The State of California recently announced a provisional $692,000 grant award [20] sufficient to fund the first year of a salinity gradient solar and habitat pond project the applicant has been collaborating on with the Imperial Irrigation District. The intent is to use salinity gradient solar ponds on the shore of the receding Salton Sea to prevent salt dust from blowing off the exposed lakebed, to provide a salt sink for rising salinity, and to supply a clean selenium free water supply to habitat ponds. If the testing of the Barometric Evaporator proposed here is successful, a new pilot scale Barometric Evaporator will be fabricated for use at the solar pond to generate steam for distillation from hot pond brine.

Environmental Impact

This Project will have little or no environmental impact during its execution. The technology developed has the potential to provide environmental benefits in the use of renewable and waste heat energy to desalinate water with low volumes of brine discharge and provide direct environmental benefits to the Salton Sea region by supplying clean selenium free water to habitat ponds with zero brine discharge to the environment.

Most needed permits for this project are already in place and only have to be extended or modified. A CEQA Mitigated Negative Declaration document was created in 2002 then amended in 2004, 2008, and 2010 for the VTE Pilot Plant and a larger VTE Demonstration Plant. This document can be amended again or simply extended in time as the Barometric Evaporator testing fits within the scope of the CEQA document. A NEPA Categorical Exclusion Checklist document was created by Reclamation in 2004 and amended in 2008 and in 2010. This can be amended again or simply extended. An NPDES exemption for a demonstration project was obtained from the Regional Water Quality Control Board in 2004, 2008, 2010, and 2012. This may need to be modified and resubmitted. A minor amendment to Cal Energy's Conditional Use Permit with Imperial County is in place through 2014.

An updated Imperial County building permit will be needed. The seawater intake mitigation to prevent take of desert pupfish may need to be updated with the California Department of Fish & Game and new permission sought for any irrigation drain or river water to be tested.

Dismantling Plans

The prototype Barometric Evaporator equipment will be dismantled and removed from the VTE Pilot Plant structure by a two man crew over about a week and a half at the end of this Project. Separate State and Reclamation funding has been allocated to dismantle the VTE Pilot/Demonstration Plant equipment and return the site to its prior condition when that project is concluded.

References

1. Okun, Daniel A. *Water reclamation and nonpotable reuse: an option for meeting urban water supply needs.*Desalination 106(1996): pp.205-212.

2. Newman, Peter and Mike Mouritz. *Principles and planning opportunities for community scale systems of water and waste management.* Desalination 10 (1996) pp: 339-354.

3. Thomas, Jean-Sebastien and Bruce Durham. *Integrated Water Resource Management: looking at the whole picture.* Desalination 156 (2003): pp. 21-28.

4. Voivontas, D, G. Arampatiz, E. Manoli, C. Karavitis, and D. Assimcopoulus. *Water supply modeling toward sustainable environmental management in small islands: the case of Paros, Greece.* Desalination 156 (2003): pp. 127-135.

5. Bouchekima, Bachir. *Solar desalination plant for small size use in remote arid areas of South Algeria for the production of drinking water.* Desalination 156 (2003): pp. 353-354.

6. Werner, M. and A.I. Schafer. *Social aspects of a solar-powered desalination unit for remote Australian communities.* Desalination 203 (2007): pp.375-393.

7. B. Kunst, *Performance tests on a vertical tube evaporator.* Desalination Volume 38, November 1981.

8. R. Philip Hammond, David M. Eissenberg, Dieter K. Emmermann, John E. Jones, Jr., Hugo H. Sephton, Ferris C. Standiford, Ronald F. Scott, William J. Rider and David W. Dean, *Seawater desalination plant for Southern California*. Desalination Volume 99, Issues 2-3, December 1994, Pages 483-508.

9. Hugo H. Sephton, *Upflow vertical tube evaporation of sea water with interface enhancement: Process development by pilot plant testing.* Desalination, Volume 16, Issue 1, February 1975, Pages 1-13.

10. Howard L. Fong, C. Judson King and Hugo H. Sephton, *Upflow vertical tube evaporation with interface enhancement: pressure drop reduction and heat transfer enhancement by the addition of a surfactant.* Desalination, Volume 16, Issue 1, February 1975, Pages 15-38.

11. Hugo H. Sephton, V*ertical tube foam evaporation for water desalination.* Desalination, Volume 42, Issue 1, July 1982, Pages 27-35.

12. Pinczewski, WV; Gerofi, JP and Fenton, GG. *Heat Transfer in Vertical Tube Evaporation (VTE)*. In: Chemeca 80 (8th : 1980 : Melbourne, Vic.). Chemeca 80: Process Industries in the 80's; 8th Australian Chemical Engineering Conference. Barton, ACT: Institution of Chemical Engineers, Institution of Engineers, Australia and the Royal Australian Chemical Institute, 1980: 272-277.

13. Vera Gnaneswar Gude, Nagamany Nirmalakhandan. *Desalination Using Low Grade Heat Sources.* Journal of Energy Engineering, September 2008 Pages 95-101.

14. Vera Gnaneswar Gude, Nagamany Nirmalakhandan. *Desalination at low temperatures and low pressures.* Desalination Volume 244, Issues 1-3, August 2009 Pages 239-247.

15. Vera Gnaneswar Gude, Nagamany Nirmalakhandan. *Sustainable desalination using solar energy.* Energy Conversion and Management, Volume 51, Issue 11, Anovember 2010 Pages 2245-2251.

16. Hugo H. Sephton, *Vapor compression* v*ertical tube foam evaporation.* Desalination, Volume 23, Issues 1-3, April 1966, Pages 299-310.

17. Kurt Kovac, D.W.J. Hayes, Hugo H. Sephton, *Brine Concentration Utilizing Solar Pond Heat With a Vertical-Tube Foamy Evaporator.* Biennial Conference

Proceedings of the National Water Improvement Supply Association. 1990 Pages 19-48.

18. Huanmin Lu, John C. Walton, Andrew H.P.Swift, *Desalination coupled with salinity gradient solar ponds.* in Desalination 136 (2001) pages 13-23

19. Huanmin Lu, John C. Walton, and Herbert Hein, *Thermal Desalination using MEMS and Salinity Gradient Solar Pond Technology.* University of Texas at El Paso, U.S. Bureau of Reclamation, Desalination Research and Development Program Report No. 80, Cooperative Agreement No. 98-FC-81-0047, August 2002

20. Salton Sea Financial Assistance Program provisional grant award announcement: http://www.water.ca.gov/saltonsea/habitat/draft_list.cfm

21. Imperial Irrigation District, *Integrated Water Resources Management Plan*, 2009 http://www.iid.com/Water/IntegratedPlanning

22. Hugo H. Sephton, *An Investigation of Vertical Tube Evaporation Utilizing the Sephton Flash Tube*, United States Department of the Interior, Research and Development Progress Report No. 361, June 1968