BAROMETRIC EVAPORATOR PROTOTYPE TEST

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ABSTRACT

The purpose of this project is to 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 an impaired 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 disaster or drought has compromised water supplies.

This project assembled a prototype BE coupled with an existing Vertical Tube Evaporator (VTE) pilot plant providing a controlled source of hot water, condensing capacity, brine management, and instrumentation of flows, temperatures, pressures, and conductivity to record performance data. Testing was carried out over a range of low to moderate feed temperatures and with adjustments to the orifice size of a flash initiator. Mass flows were calculated by enthalpy methods used for flash drums and by direct measurement.

Keywords: Thermal Desalination, Geothermal, Solar, Waste Heat, Barometric Evaporator

I. INTRODUCTION

The technology tested addresses a critical need in many communities for sustainable water resource management; specifically, the ability to increase water supply at a lower cost, using existing resources in the community [1]. In many arid regions, brackish groundwater or seawater is available for desalination. Also available in many communities is waste heat, geothermal or solar heat. These resources can offer a potentially lower cost and more sustainable approach for communities and their water needs [2, 3, and 4].

The Barometric Evaporation Process is designed to efficiently convert hot saline water to steam and recover it as distilled water without additional thermal 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.

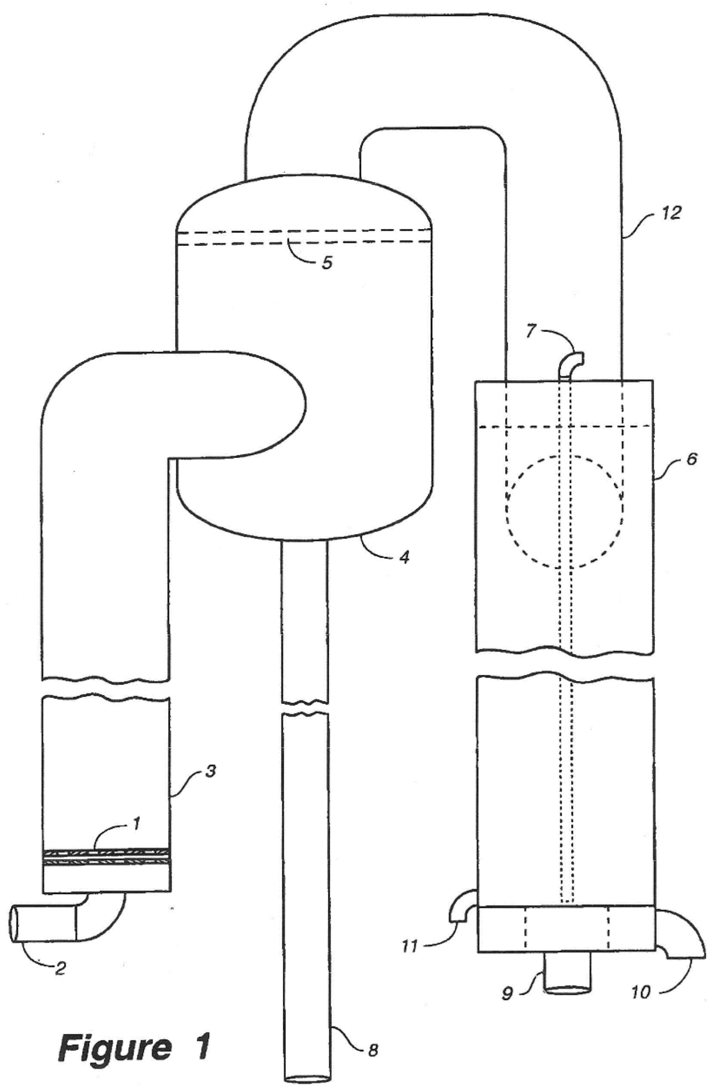

Figure 1. Implementation of a Barometric Evaporator, from U.S. patent #6,254,734 B1

A Barometric Evaporator (BE) operates by drawing hot (50°C or higher) saline feed up one or more vertical flash channels into a vacuum. A Barometric Evaporator paired with a Vertical Tube Evaporator (VTE) is illustrated in Figure 1. The prototype tested is similar to this design, except that the brine outlet was off center while a single flash channel entered the bottom center of the Separation Vessel and the upward spray was dispersed by a baffle. Typically, the flash channel(s) would be about 10 meters 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. Vapor separates from the brine in an evacuated brine/vapor separation chamber at the top of the flash channel and passes through a demister into an evacuated condenser. Concentrated brine flows down a tube by gravity to ground level; likewise for distillate. The only pumps required are a vacuum pump to establish a vacuum at startup and remove any non-condensable gasses and a coolant circulation pump for water or fan for air cooling. The Barometric Evaporator is described in U.S. patent number 6,254,734 B1 issued to Dr. Hugo H. Sephton in July 2001. This test offers the first data on this technology.

Table 1. List of Labelled Components of Barometric Evaporator Shown in Figure 1.

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 up to 10 m
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

This Project assembled a prototype BE coupled with an existing Vertical Tube Evaporator (VTE) pilot plant 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.

II. RELATED TECHNOLOGY BACKGROUND

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 [5]. 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 [6]. 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 [7, 8, and 9]. 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 [10]. 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 an evaporation process theorized by Gude and Nirmalakhandan in 2008 for use with low grade heat sources [11] and tested as a prototype in 2009 [12]. That process was further modeled and prototyped with heating energy input from a photovoltaic panel in 2010 [13]. The shared features include the use of rising and falling barometric legs, vapor separation in an evacuated chamber at the top of the unit, a condenser at the top of the unit, and the use of low grade waste heat, solar, or geothermal heat. The key differences include first, the introduction of heat in the vapor separation chamber in the Gude and Nirmalakhandan process while the BE introduces heat into the saline feed. Second, the BE 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 process is intended to operate at low temperatures only. The BE is intended to operate efficiently over a range of low to moderate temperatures (50°C to 100°C).

III. BE PROTOTYPE EQUIPMENT

Without prior data or experience to work from, the optimal cross section and area of a flash channel was unknown. To gain empirical data, an arbitrary choice was made to start with a circular cross section in the form of ½", ¾", and 1" standard pipe or stainless steel tubing as vertical flash channel.

Initially, a small lab scale prototype was assembled with 10 m of ½" stainless steel tubing terminating at the top inside a 3" diameter sight glass used as a brine/vapor separation chamber with a descending ½" brine return pipe and with vapor drawn out the top through a demisting mesh into an evacuated laboratory condenser. The small lab scale prototype had minimal instrumentation, only thermometers and a vacuum gauge. It was used only to test optional configurations of flash initiator and to validate the principle of operation, continuous flash of hot brine while rising and cooling in a vertical channel into vacuum, return of un-flashed brine by gravity into atmospheric pressure, and collection of distillate by condensation.

The flash initiator design chosen after testing was a stainless steel conical insert that could be raised to seat snugly on an O-ring around the bottom entry point of the flash channel to close it, or could be lowered by turns of four parallel stainless steel threaded rods to vary the annular opening allowing hot brine into the bottom of the flash channel. Multiple tests run with the lab scale prototype were useful to work out a start-up protocol, experiment with the length of the flash channel, visually observe the flashing behavior over a range of temperatures, and validate production of distillate from natural brine by a BE..

A larger Barometric Evaporator prototype was constructed from available PVC pipe and fittings and mounted on the top of the 30 foot tower of a Vertical Tube Evaporator (VTE) Pilot Plant already installed at a geothermal power plant in Southern California. Using geothermal steam as a heat source, the VTE Pilot Plant was used to supply heated saltwater or freshwater as feed to the larger BE prototype. A second

VTE unit in the Pilot Plant was used as a condenser with measurement of distilled water condensed from the larger BE prototype by a Coriolis meter.

The larger BE prototype was constructed with a brine/vapor separation chamber made from an 8” PVC tee with a window in the middle of the tee to observe the flow from the top of the flash channel fitted to the center of an 8” flange at the bottom of the 8” tee. The descending brine return leg exited the bottom flange in a 1” pipe to ground level in parallel with the rising flash channel. The top of the 8” tee terminated in an 8” flange that connected to a 4” PVC pipe that would draw vapor to the VTE unit used as a condenser by venting from the VTE vapor side to a vacuum pump used to evacuate any non-condensable gasses in the feed water. The BE prototype was installed with instrumentation including platinum RTD’s to measure the temperature of feed, vapor at the top of the brine/vapor separation chamber, unevaporated water at the bottom, and water in the descending brine return piping. A 1” magmeter measured return flow in the descending brine pipe. A pressure/vacuum gauge and transmitter measured vacuum in the brine/vapor separation chamber. The vapor/brine separation chamber and vapor pipe were wrapped in 1.5 inch pipe insulation.

The same ½” flash channel used for the lab scale BE prototype was fitted to the larger BE prototype for the first round of testing. Larger flash channels made from ¾” CPVC and 1” CPVC were fitted for subsequent testing. All were wrapped in pipe insulation.

IV. BE PROTOTYPE TEST CALCULATIONS

A Barometric Evaporator serves a similar vapor-liquid separation function as a flash drum (or knock out drum) except that evaporation happens along the length of a flash channel without a nozzle at the entry of the flash channel to the vapor-liquid separation chamber. The calculations chosen to evaluate the BE performance are therefore similar to those used for a flash drum.

$$X = \frac{H_U^L - H_d^L}{H_d^V - H_d^L}$$

Where:
X = the mass ratio of liquid vaporized over the remaining liquid.
H_U^L = the upstream feed liquid enthalpy at the upstream temperature measured in Btu/lb. or J/kg.
H_d^V = the vapor enthalpy at the downstream saturation temperature measured in Btu/lb. or J/kg.
H_d^L = the remaining liquid enthalpy at the downstream temperature measured in Btu/lb. or J/kg.

Direct measurement of distillate flow after condensing enabled an alternate direct calculation of the percentage of feed vaporized by the BE. This calculation from measured flow is impacted by vent loss in VTE 2 and by any mass flow measurement inaccuracies in the Coriolis flowmeter used for distillate and by volumetric flow measurement inaccuracies in the magmeter used for the brine return flow. The alternate calculation is a simple ratio of mass flows assuming that feed flow = vapor + return liquid flow:

$$Y = \frac{\dot{m}_d^V}{\dot{m}_u^L} = \frac{\dot{m}_d^V}{\dot{m}_d^L + \dot{m}_d^V}$$

Where:
Y = the mass ratio of liquid vaporized over feed liquid.
$\dot{m}_d^V$ = the mass flow of vapor as measured by the distillate flow from VTE 2 in kg/min or lb/min.
$\dot{m}_u^L$ = the mass flow of feed as measured by the sum of distillate flow and return flow in lb/min.

$\dot{m}_d^L$ = the mass flow of liquid return flow in lb/min

The percentage of heat energy in the feed converted to evaporation is estimated by:

$$E_{conv.} = \frac{\dot{m}_d^V H_d^V}{\dot{m}_u^L H_u^L}$$

Where:
$E_{conv.}$ = the energy flow in the down-stream vapor over the energy flow in the upstream feed liquid.
H_d^V = the downstream vapor enthalpy in Btu/lb. same as above.
H_u^L = the upstream feed liquid enthalpy in Btu/lb. same as above.

The energy loss ratio (E_{loss}) is estimated as the percentage of heat energy flow in the feed not accounted for by heat energy flow in the vapor and in the liquid return flow using the calculation:

$$E_{loss} = \frac{\dot{m}_u^L H_u^L - \dot{m}_d^V H_d^V - \dot{m}_d^L H_d^L}{\dot{m}_u^L H_u^L}$$

V. BE PROTOTYPE TESTING AND RESULTS

Testing of the larger BE prototype began with a ½" flash channel made from 316 stainless steel tubing. Flashing was observed from the top of the flash channel with feed temperatures above 120°F appearing as spurting out the top of the flash channel at lower temperatures and a powerful spray at higher temperatures compared to a weak flow from the top of the flash channel when the feed temperature is reduced below roughly 120°F where no flashing was observed. Although flashing was observed with the ½" flash channel, any vapor condensed in the VTE unit was too little to measure. This may be due to vent loss in a VTE unit designed for higher mass flows than the BE could produce from a single ½" flash channel or to other system losses. Distillate was collected from the small lab scale BE prototype with a laboratory condenser and the same flash channel.

5.1 Tests with ½" Flash Channel and Freshwater Feed

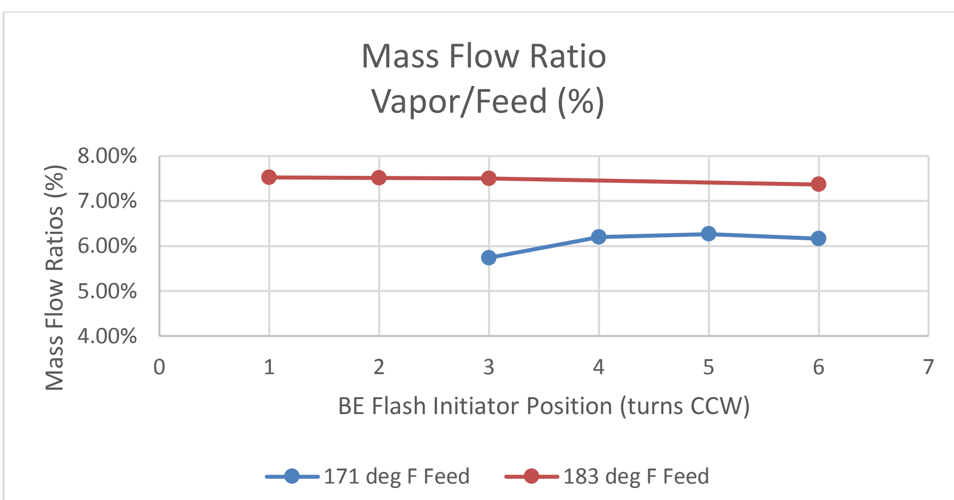

Figure 2. Mass Flow Ratios from Flash Initiator Position Test with ½" Flash Channel (Dec 2017).

While distillate production in the larger BE prototype system with the ½” flash channel could not be directly measured, a mass flow could be calculated by using the calculation based on upstream feed and downstream vapor and brine enthalpy. Figure 2 shows the mass flow ratio of vapor over feed calculated by enthalpy at two feed temperatures and across several flash initiator opening settings. Increasing turns counterclockwise (CCW) of the threaded rods, corresponded to a lower conical insert position with a wider opening into the bottom of the flash channel. The mass flow ratio (X above) varies with temperature, but showed very little variation with the opening of the flash initiator at the base of the ½” flash channel.

5.2 Tests with ¾” Flash Channel and Freshwater Feed

The ½” flash channel pairing with the larger BE prototype having distillate production below a directly measurable flow rate, the system was fitted with a ¾” flash channel made from CPVC pipe and a conical insert flash initiator reworked to the ¾” pipe diameter. Tests were run starting in January 2018.

To test the BE flash initiator opening size with a ¾” flash channel, a test was run with the ¾” conical insert flash initiator set to 1, 1.5, 2, 2.5, 3, and 3.5, turns CCW from a closed position at 138°F freshwater feeding the ¾” CPVC flash channel. Similar test conditions were run a second day with the ¾” flash initiator set to 3.5 turns and 4 turns CCW from closed position at 137°F feed temperature and later set to 4, 5, 6, 7, and 8 turns CCW from the closed position at the 137°F feed temperature set point. Distillate production was measurable with the ¾” flash channel sizing.

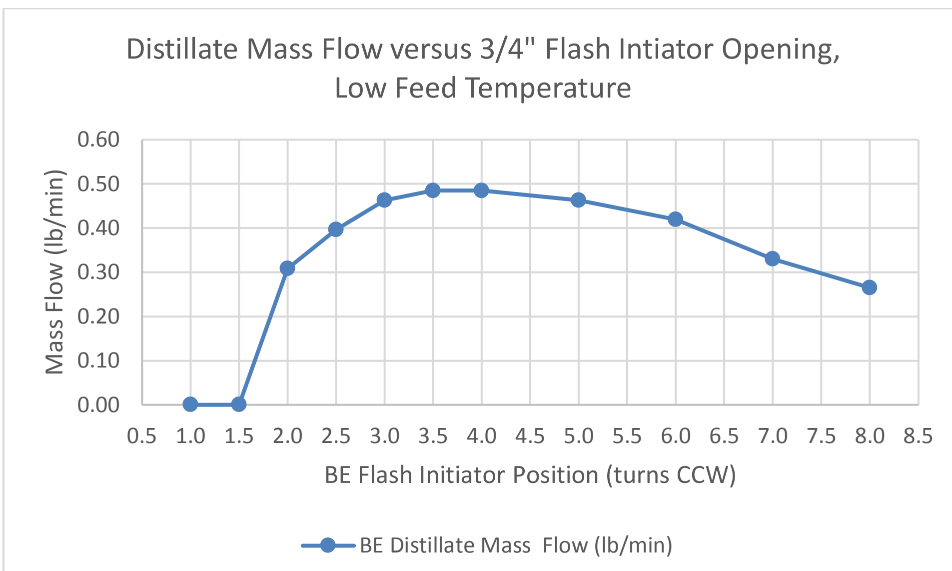

Figure 3. Distillate Mass Flow from Flash Initiator Test with ¾” Flash Channel at 137°F Feed.

As shown in Figure 3, distillate production rose with increasing flash initiator opening, from functionally closed below 1 turn of the threaded rod conical insert positioners, to a peak of 0.5 lb/min between 3.5 and four turns of the positioners, then gradually declining as the flash initiator was opened further. The rate of return flow through the 1” descending leg follows a similar pattern shown in Figure 4, except that the higher rate of return flow is measurable at 1 turn of the threaded rod conical insert positioners and reduction in return flow at flash initiator openings greater than 4 turns is minimal.

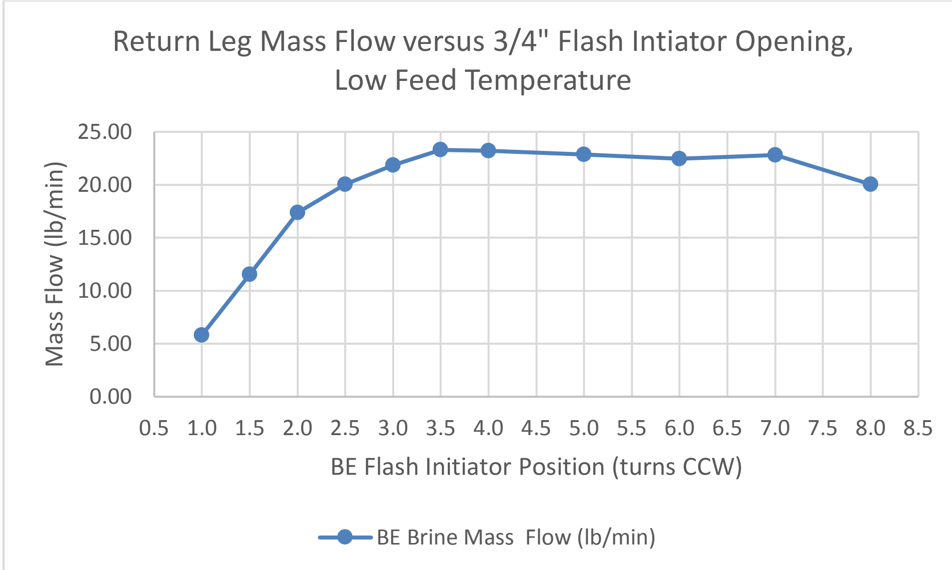

Figure 4. Return Mass Flow from Flash Initiator Test with ¾" Flash Channel at 137°F Feed.

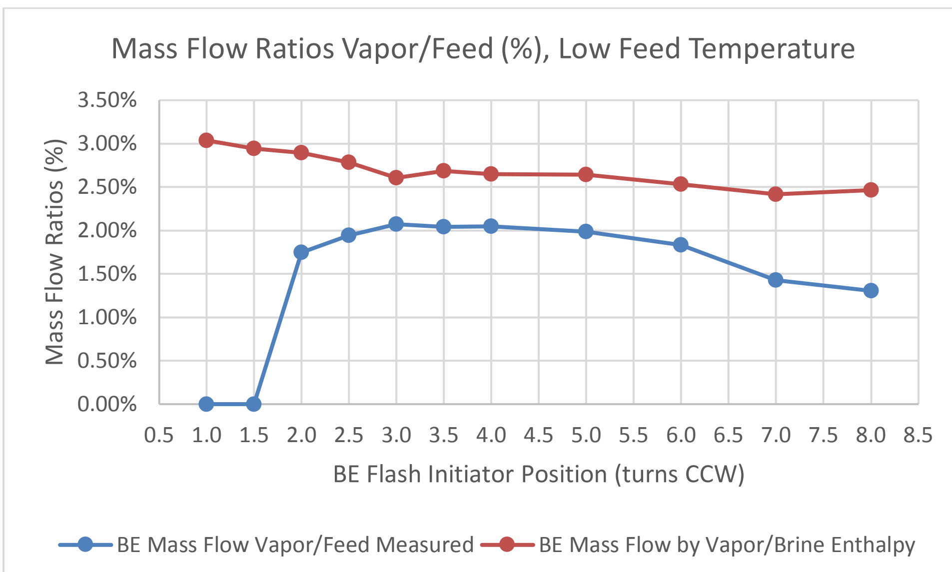

Figure 5. Mass Flow Ratios from Flash Initiator Test with ¾" Flash Channel at 137°F Feed.

The mass conversion ratio from freshwater feed to vapor calculated from upstream and downstream enthalpy values decline gradually with wider opening of the flash initiator as shown in Figure 5. Mass conversion calculated from direct measurement of flows reads zero until the flash initiator is opened 2 turns CCW because any mass flow of distillate was too little to be measured at 1 turn or 1.5 turns CCW. As seen in Figure 5, the direct measured vapor to feed mass flow ratio rises to a maximum between 3 and 4 turns CCW, then declines gradually with wider flash initiator openings.

The percentage of heat energy in the feed converted to evaporation in the same experiment is plotted in Figure 6. It follows the nearly same pattern as distillate mass flow peaking at 21% between 3 and 4 turns of the threaded rod flash initiator positioners. The BE prototype system heat energy loss follows an inverse pattern with the lowest losses of 5% at the maximum distillate flow rate.

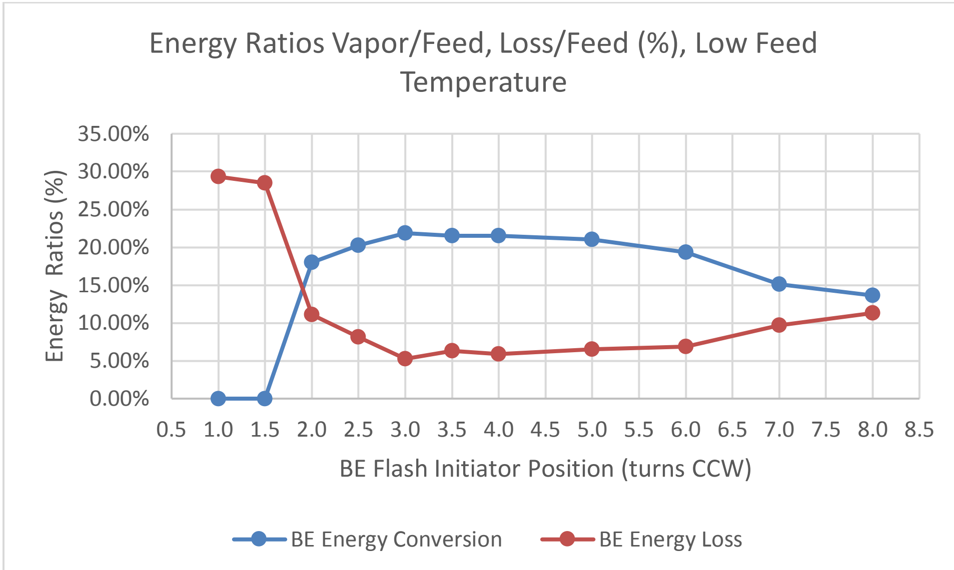

Figure 6. Energy Conversion Ratios from Flash Initiator Test with ¾" Flash Channel at 137°F Feed.

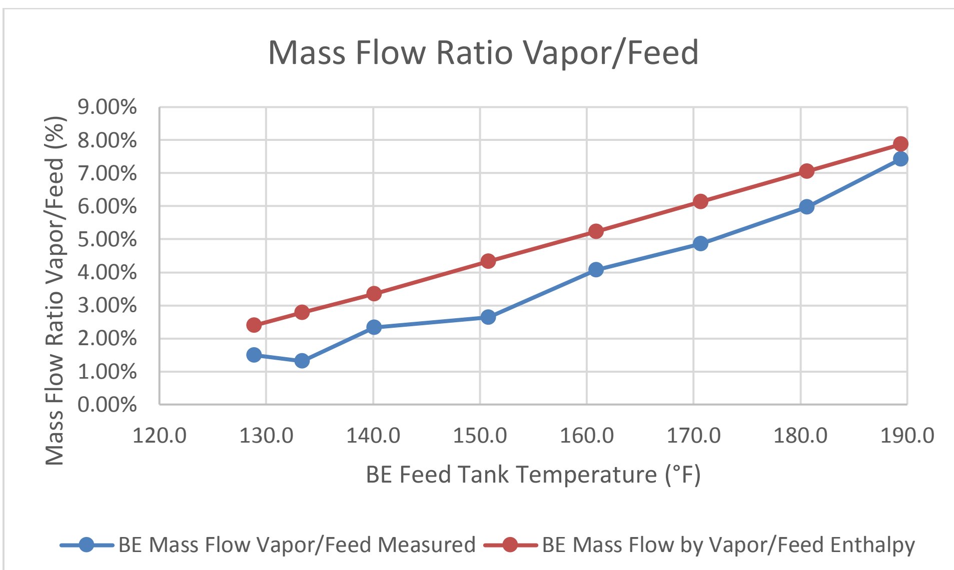

Figure 7. Mass Flow Ratios from Feed Temperature Variation Test with ¾" Flash Channel.

The BE Prototype was tested on January23, 2018 over a range of freshwater feed temperatures with 10 meters of ¾" CPVC pipe as a flash channel and with a ¾" conical insert flash initiator set to 2 turns CCW from the closed position. Data points were taken at eight feed temperatures. Mass conversion from freshwater feed to vapor calculated from upstream and downstream enthalpy values were quite linear with feed temperature as seen in Figure 7. Mass conversion calculated from direct measurement of flows shows inaccuracies of the measurement in Figure 7, being roughly linear at the same slope but at a lower value, likely due to vent losses of vapor before being measured as distillate.

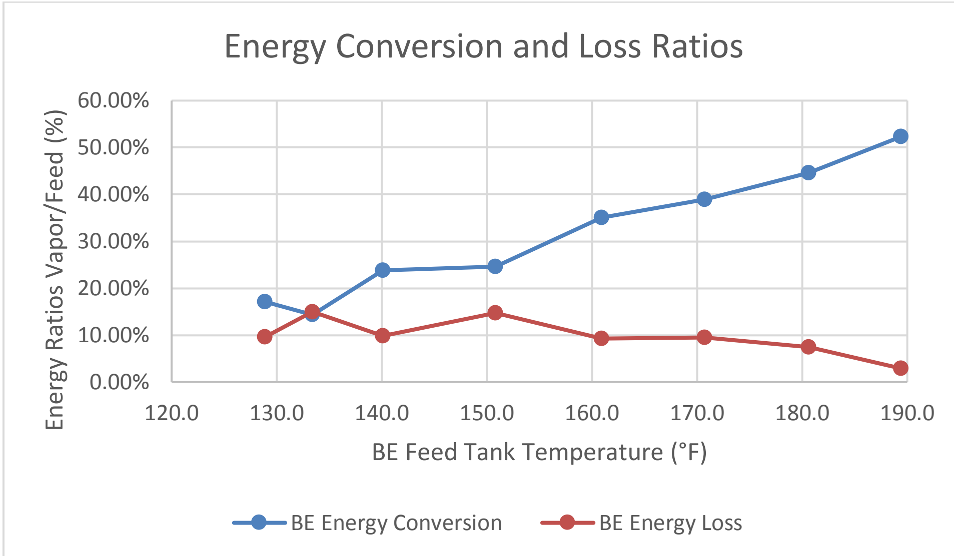

Figure 8. Energy Conversion Ratios from Feed Temperature Variation Test with ¾" Flash Channel.

The percentage of heat energy in the freshwater feed converted to evaporation in the same feed temperature variation test, Figure 8, showed increased with rising temperature from less than 20% at 129°F to greater than 50% at 189°F, close to the maximum temperature safe to operate the CPVC flash channel and PVC brine/vapor separation chamber materials of the larger BE prototype. Energy losses declined with increasing feed temperature to 3% at 189°F.

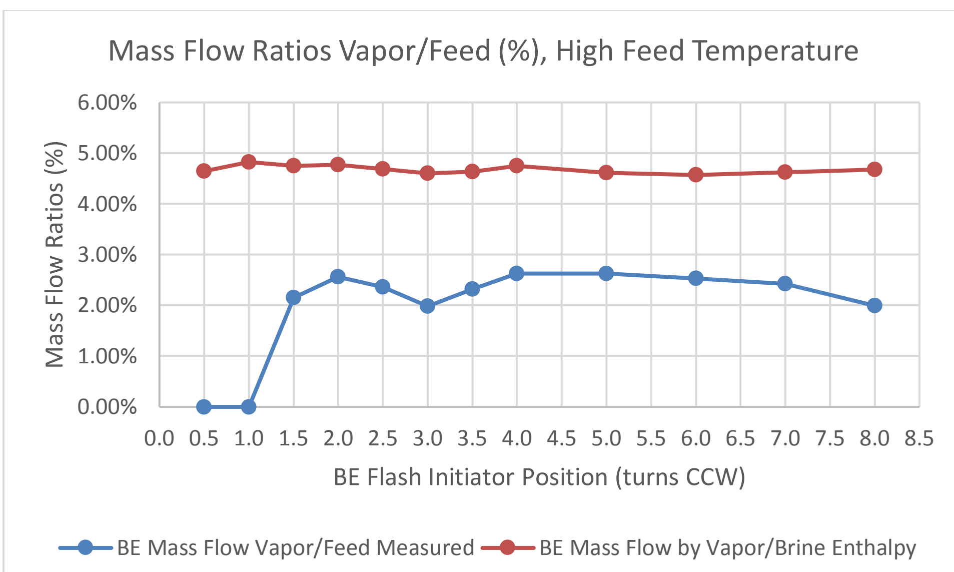

Figure 9. Mass Flow Ratios from Flash Initiator Test with ¾" Flash Channel at 175°F Feed.

The flash initiator opening size had a measurable impact on the distillate flow and on the mass flow ratios and energy conversion and loss at the relatively low 137°F feed temperature tested in January 2018. A similar test series was run in January 2019 at the higher freshwater feed temperature of 175°F with the ¾" flash channel after replacement of much of the VTE Pilot Plant's vacuum system. At the higher feed temperature, there was inconsistent mass flow at the 3 turns CCW flash initiator position. At larger openings above 4 turns CCW there was minimal drop off in the measured mass flow ratio and in the mass flow ratio calculated from enthalpy as shown in Figure 9.

The percentage of heat energy in the freshwater feed converted to evaporation at the 175°F freshwater feed temperature through the ¾" flash channel run in January 2019 was less than 20% and the system thermal losses were on the order of 15% as shown in Figure 10. The reduced energy efficiency in the tests run in 2019 may be related to the change in the VTE Pilot Plant vacuum system providing less depth of vacuum in the BE prototype rather than the higher operating temperature.

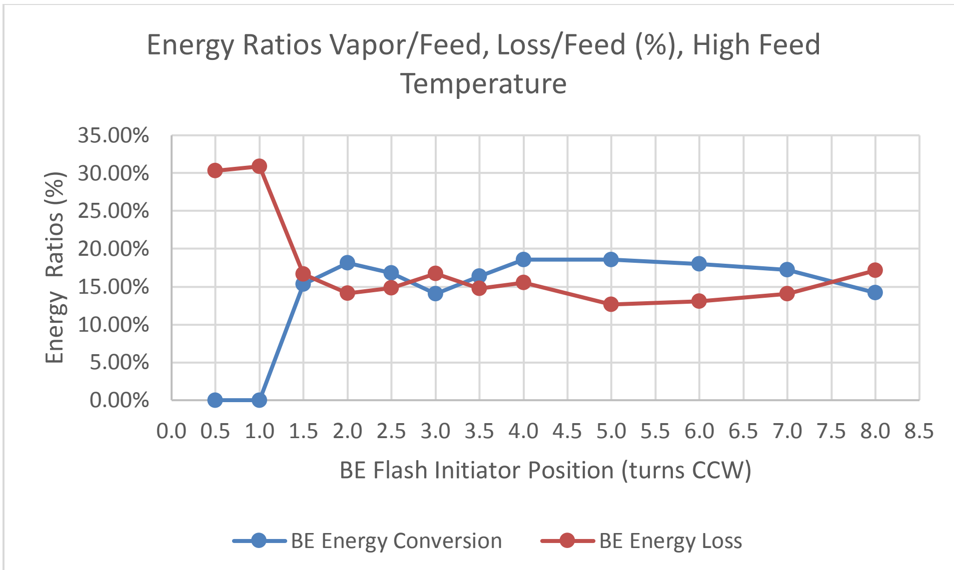

Figure 10. Energy Conversion Ratios from Flash Initiator Test with ¾" Flash Channel at 175°F Feed.

5.3 Tests with 1" Flash Channel and Freshwater Feed

To investigate whether a larger flash channel diameter could improve the rate or thermal efficiency of evaporation, the system was fitted with a 1" flash channel made from CPVC pipe and a conical insert flash initiator reworked to the 1" pipe diameter. Tests were run starting in February 2019.

The first test tried flash initiator openings at a fixed freshwater feed temperature of 141°F. At that temperature, there was no draw of feed up the 1" flash channel at any flash initiator setting. A second test used higher temperature freshwater feed at 177°F. At the higher feed temperature the 1" flash channel drew hot feed up 10 m to the brine/vapor separation chamber and flashed vapor with measurable distillate production. The absolute mass flow of distillate in the 1" flash channel was similar to the ¾" flash channel at a peak of about ½ lb/min.

At about 2.5%, the mass flow ratio of condensed vapor over feed shown in Figure 11 was only slightly higher than in the ¾" flash channel. Once open, there was very little influence of the flash initiator position on the rate of distillate production or on the flow of feed through the BE prototype system at the 177°F feed temperature. The percentage of heat energy in the freshwater feed converted to evaporation at the 177°F freshwater feed temperature through the 1" flash channel was also similar to the ¾" flash channel at 15% to 20% as shown in Figure 12.

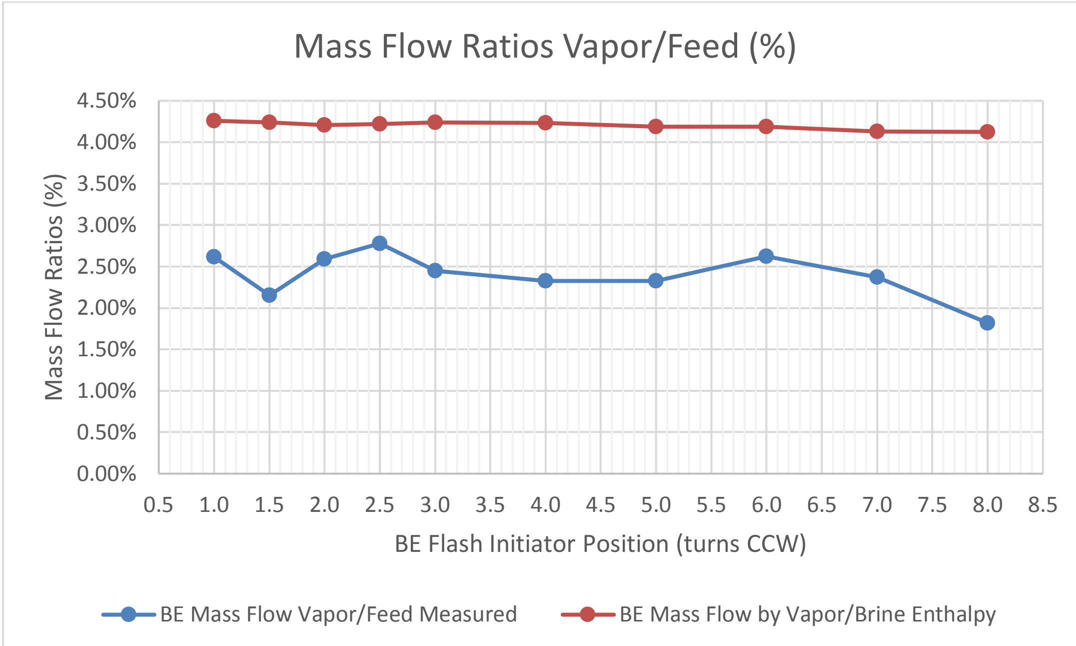

Figure 11. Mass Flow Ratios from Flash Initiator Test with 1” Flash Channel at 177°F Feed.

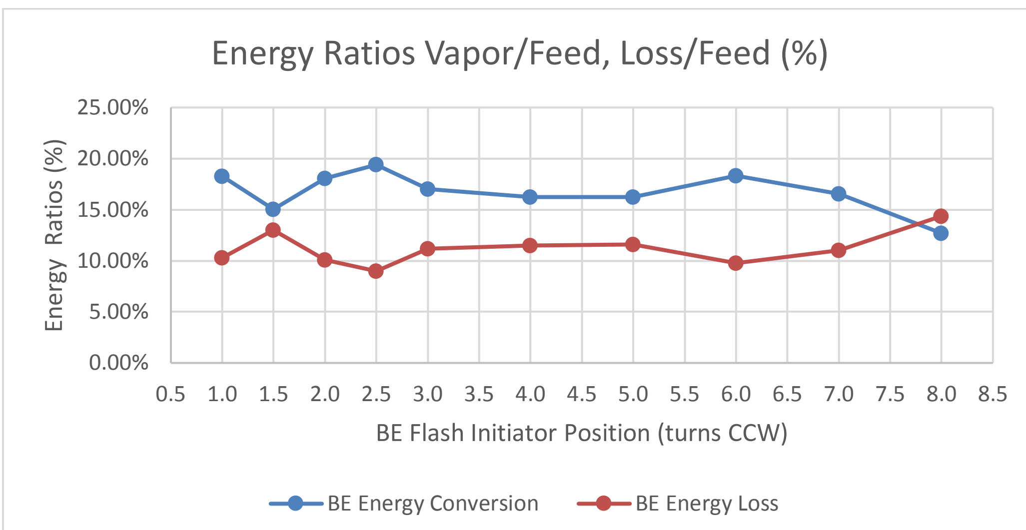

Figure 12. Energy Conversion Ratios from Flash Initiator Test with 1” Flash Channel at 177°F Feed.

The 1” flash channel was tested with a flash initiator setting of 2.5 turns CCW over a range of freshwater feed temperatures from 147°F, where distillate production was not directly measurable, to 191°F near the maximum temperature suitable for the CPVC flash channel and PVC vapor/brine separation chamber materials. Substantial cooling of feed rising in the flash channel as it evaporated kept temperatures at the top of the BE prototype within what a PVC vessel could sustain under vacuum.

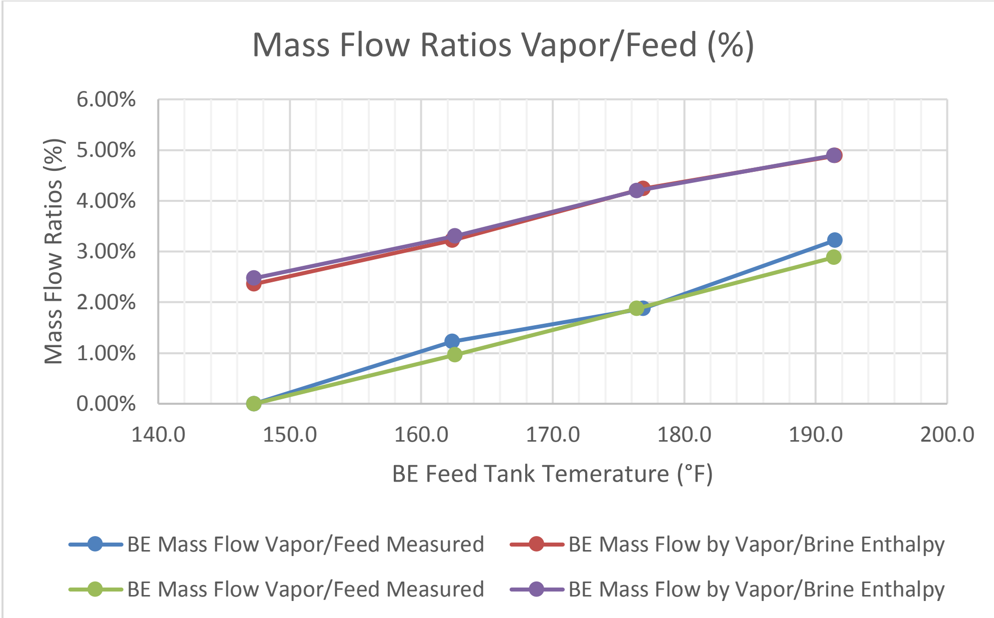

Figure 13. Mass Flow Ratios from Feed Temperature Variation Test with 1" Flash Channel.

Figure 13 shows the measured mass flow ratio of vapor over freshwater feed compared to vapor calculated from upstream and downstream enthalpy values. Both were linear with feed temperature. The mass flow of vapor over feed from direct measurement was at a lower value than vapor mass flow over the return flow calculated by enthalpy, probably due to vent losses of vapor before being measured as distillate.

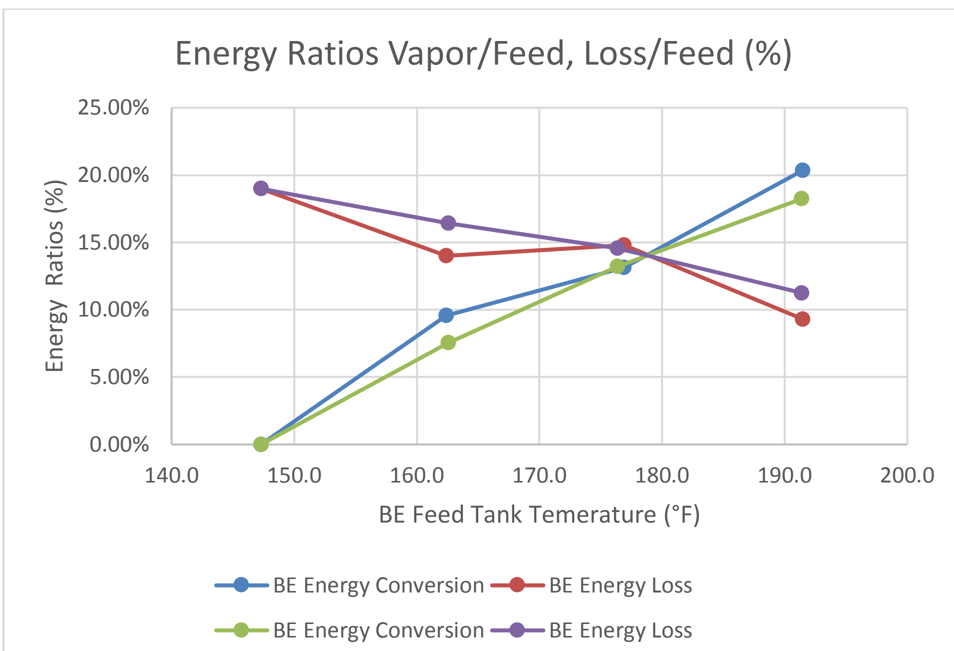

Figure 14. Energy Conversion Ratios from Feed Temperature Variation Test with 1" Flash Channel

The energy conversion from heat in the feed to vapor shown in Figure 14 was close to linear with feed temperature ranging from 0% at 147°F to 20% at 191°F. This is substantially lower than with the ¾" flash channel. The energy losses estimated with the 1" flash channel are also worse at 18% to 10% varying downward with increasing temperature.

5.4 Tests with 1" Flash Channel and Saltwater Feed

Testing of the larger BE prototype was done with natural saltwater from the Salton Sea in Southern California, a mixed salt lake with total dissolved solids at roughly 6.5% by weight at the time the tests were run in 2019. The 1" flash channel was used in these tests with the 1" flash initiator set to 2.5 turns CCW. Steady state operating data was recorded at two temperature points for each test condition. The natural saltwater was feed from a covered and vented holding tank, sand filtered, deaerated, then fed to one VTE unit to be heated by geothermal steam to a preset temperature target, then run to a partly open feed tank to be drawn into the bottom of the flash channel through the flash initiator as with the earlier freshwater feed testing. In a subsequent set of tests, a surfactant with the trade name LAS-99 (Linear Alkylbenzene Sulfonic acid) was dosed at 10 mg/Liter into the saltwater feed to measure whether a moderate foaming effect would change the continuous flash process in the BE flash channel.

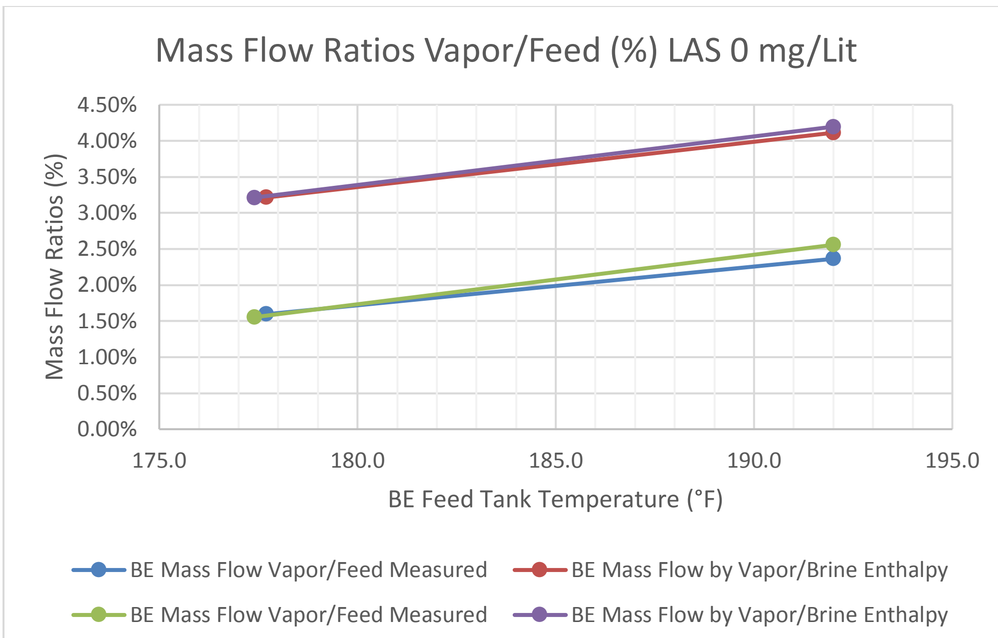

Figure 15. Mass Flow Ratios, Two Saltwater Feed Temperatures, 0 mg/Lit LAS, 1" Flash Channel.

As shown in Figure 15, the mass flow ratio is slightly lower for saltwater feed compared to freshwater feed. This applies to both the higher calculation based on upstream and downstream enthalpy values and to the lower mass flow ratio directly measured from distillate and brine return flows. The addition of LAS-99 at 10 mg/Liter does not improve this ratio as seen in Figure 16. The conversion of thermal energy in the saltwater feed to vapor shown in the energy conversion ratio in Figure 17 is moderately lower than what was measured with freshwater feed, but the BE prototype system energy losses measured are less for saltwater feed than with freshwater feed. The addition of 10 mg/Liter LAS-99 seen in Figure 17 appears to flatten the impact of feed temperature on the energy conversion and energy loss.

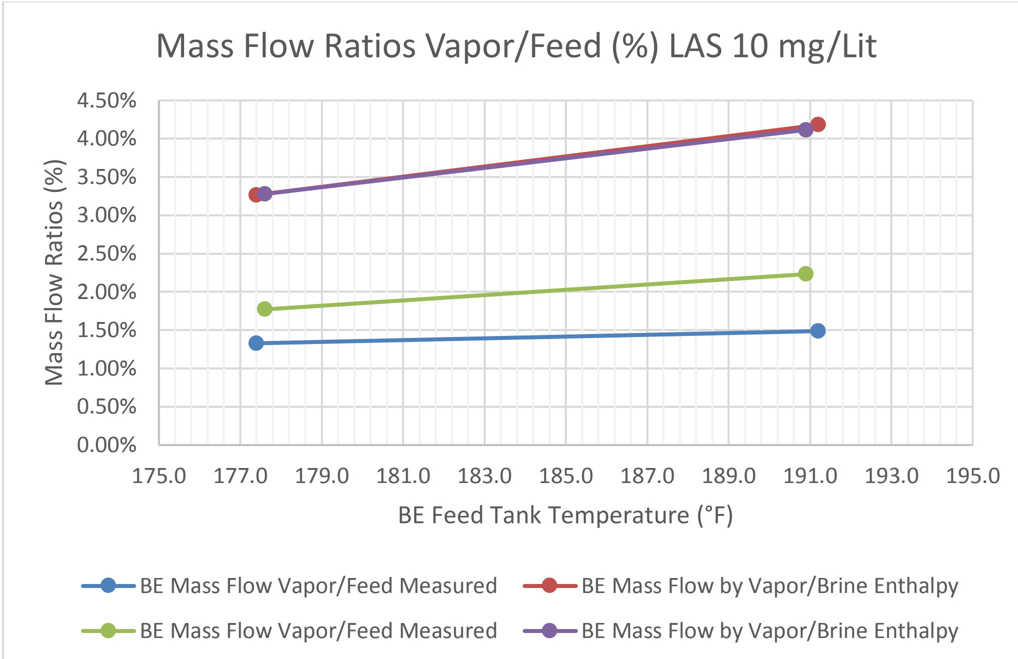

Figure 16. Mass Flow Ratios, Two Saltwater Feed Temperatures, 10 mg/Lit LAS, 1" Flash Channel.

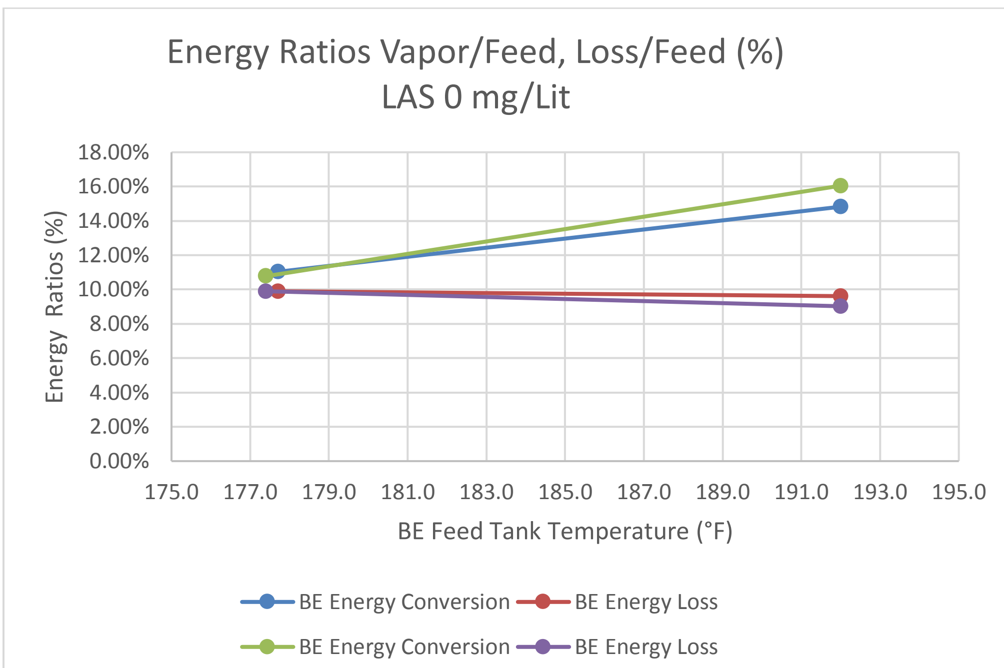

Figure 17. Energy Ratios, Two Saltwater Feed Temperatures, 0 mg/Lit LAS, 1" Flash Channel.

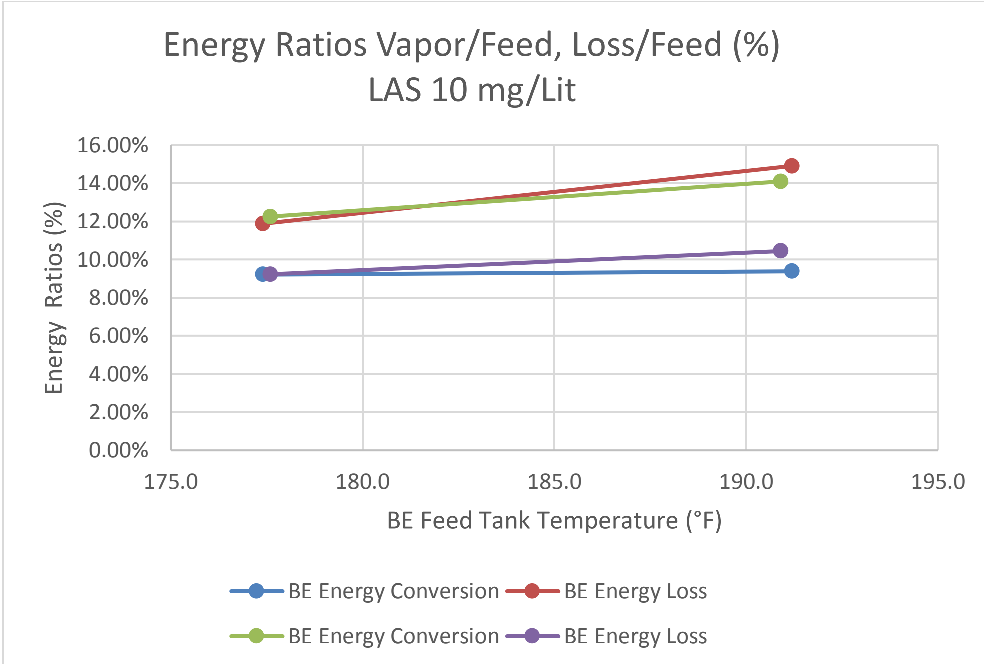

Figure 18. Energy Ratios, Two Saltwater Feed Temperatures, 10 mg/Lit LAS, 1" Flash Channel.

VI. CONCLUSIONS

Experimental results confirmed the fundamental operating principles of a Barometric Evaporator. Flashing of heated feed water with two phase flow up a 10m vertical flash channel from atmospheric pressure into vacuum at the top does convert heat in the feed to vapor that can be separated in the evacuated brine/vapor separation chamber at the top of the flash channel. Unevaporated brine will return by gravity without pumping to atmospheric pressure. Once initiated, flow in the BE system is consistent and stable if the feed temperature is above about 50°C.

Flash channel cross sectional area gave similar mass flow ratios of vapor over feed by enthalpy for ½" and for ¾" pipe sizes although the mass flow of distillate was too small to measure directly with the ½" flash channel and the VTE system used to condense the vapor. The 1" flash channel had mass flow ratios and energy conversion ratios roughly half those of the ¾" flash channel. The 1" flash channel was only useful at higher temperatures, above 70°C. Data indicate the optimal flash channel sizing is in the range of a standard ¾" pipe diameter.

Once open sufficiently, the flash initiator opening has only a moderate impact on evaporation efficiency at lower temperatures and very little impact at higher temperatures.

The measured mass flow ratio of 2.6%, or 4.3% by enthalpy, in the more energy efficient ¾" flash channel at 151°F feed temperature with an optimal flash initiator setting at 3 turns CCW compares favorably with measured values of 0.8%, or 1.7% by enthalpy, for a flash drum operated at the same feed temperature of 151°F in tests at the Los Banos Salinity Gradient Solar Pond test facility in 1986 [14]. The measured energy conversion ratio for the same BE experiment of 24.6% also compares well to the measured energy conversion ratio at the Los Banos flash drum of 7.2%. Other flash drums may be more efficient.

Testing with high salinity heated feed versus freshwater heated feed reduced mass flow and energy conversion of heat in the feed to vapor moderately. Mass flow ratios were reduced from 3% to 2.5% from freshwater to saltwater and energy conversion ratios were reduced from 18% to 16%.

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