the Energy to Lead

REPORT FOR:

Nicor Gas, SoCalGas® and Peoples Gas and North Shore Gas

Venturi Steam Trap – Functional Laboratory Study

Report Issued:
March 26, 2019

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Abbreviation	
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BET	Blue Energy Technologies
BTU	British Thermal Unit
DOE	Department Of Energy
°F	Degrees Fahrenheit
F&T	Float and Thermostatic
FFTF	Flexible Fuel Laboratory
GAL	Gallon
GPM	Gallons Per Minute
GTI	Gas Technology Institute
IB	Inverted Bucket
in	Inch
IR	Infrared Imaging
ISO	International Organization for Standardization
LB	Pound
LBM	Pound-Mass
LBM/HR	Pounds-Mass Per Hour
LBS/HR	Pounds Per Hour
LBW	Pound-Weight
NPT	National Pipe Thread
Ω	Ohm
PSIA	Pounds Per Square Inch Absolutes
PSIG	Pounds Per Square Inch Gauge
PTC	Performance Test Code
RPM	Rotations Per Minute
RTD	Resistance Temperature Detector
SEC	Seconds
SCG	Southern California Gas Company
TD	ThermoDisc
TEI	Thermal Energy International, Inc.
VFD	Variable Frequency Drive

Background

Steam traps are used extensively in building steam heating and industrial process applications to separate condensate from steam. Venturi steam trap technology seeks to address some of the disadvantages of other stream trap types: mechanical, thermostatic, thermodynamic, and fixed orifice. Overtime, mechanical, thermostatic, and thermodynamic types of steam traps can fail in either the open or closed position, whereas fixed orifice type of steam traps can only fail closed. Although there are no rigorous studies supporting the assessment of the useful life of these four types of steam traps, the widely accepted lifespan, based on anecdotal experience, is 6 years. However, the useful life under the surface varies widely,[1] and the annual failure rate of traditional four types of steam traps ranges from 8% to 17%.

Venturi steam traps do not contain any moving parts, and their manufacturers cite this feature for reduced failure rates leading to longer operational life than mechanical steam traps. Venturi steam trap vendors have indicated that there are venturi steam traps in operation for over 20 years, and some vendors warrant their products for 10 years, provided they are maintained according to prescribed maintenance requirements. Other manufacturer-claimed benefits include permanent energy savings (because less steam is lost through increased efficiency and elimination of failed open traps), and lower maintenance and operating costs.

Venturi technology has been available in the United States since 1984, however, the U.S. market has not seen significant adoption to date, despite the technology's promise to combine maintenance benefits with operational capability. The potential for eliminating the steam loss due to failed open traps, as seen in the traditional four types mentioned above, is significant and worth further appraisal of venturi technology.

With this aim in mind, GTI independently and objectively conducted laboratory testing to compare the efficacy of venturi steam traps by three manufacturers against comparably-sized mechanical steam traps at different pipe sizes, pressures, and condensate loads. Venturi steam traps provided by Thermal Energy International Inc. (TEI), Steamgard LLC, and Blue Energy Technologies (BET) were assessed. The testing was conducted based on the American Society of Mechanical Engineers Performance Test Code (ASME PTC) 39 – 2005 standard for measurement of steam losses in a purpose-built, instrumented steam loss piping circuit with the adjustable process operating conditions. Market prevalence information available in a SoCalGas workpaper led GTI to select steam operating differential pressures of 125, 65, and 25 pounds per square inch gauge (psig) and pipe sizes of 1", 3/4", and 1/2".

The objective of the functional testing was to:

1) Validate venturi steam traps' performance at different pressures
2) Validate venturi steam traps' performance at different condensate loads

Results

The laboratory study captured ambient temperature and pressure, steam supply temperature and pressure, and calorimeter initial temperature, final temperature, initial weight, and final weight data. These parameters were collected for 134 test trials.

[1] "Steam Traps." Review and Acceptance. Workpaper. T. DeCarlo and E. Kirchhoff. Energy and Environmental Analysis, Inc.; Southern California Gas. December 2006.

Experimental data have demonstrated the ability of venturi orifice steam traps to discharge varying condensate loads safely across a range of steam pressures, in line with industry requirements. Even when testing outside the specified operational range of the venturi orifice traps (which some data points represent), these traps were found to operate effectively, discharging condensate with measured steam loss values comparable to mechanical steam traps, within experimental error.

Next Steps/Recommendations

The potential for venturi technology to reduce steam waste by reducing the failure rates seen in other steam trap types could produce benefits that include energy savings and lower operational and maintenance costs. GTI's laboratory test results provide confidence to conduct objective field testing of venturi steam traps at diverse sites to further evaluate performance under real-world, higher-risk steam process conditions. Further study would serve to document the path to venturi steam trap selection for energy efficiency programs. The useful life of venturi steam traps is anecdotal and comes primarily from venturi steam trap manufacturers. The conceptual validation of safe and sound operation of traps from the tested three venturi manufacturers should be part of the further research.

The American National Standards Institute (ANSI) defines a steam trap as a “self-contained valve which automatically drains the condensate from steam containing enclosure while remaining tight to live steam, or if necessary, allowing steam to flow at a controlled or adjusted rate. Most steam traps will also pass non-condensable gases while remaining tight to live steam.” Effective removal of condensate by a trap from a steam system is important for maintaining the performance of process equipment, as well as ensuring safe operation of the system.

There are four main types of steam traps: mechanical, thermostatic, thermodynamic, and fixed orifice. Each type has unique advantages and disadvantages. Mechanical traps can accommodate large discharge capacities but aren’t as compact as thermostatic traps. Although thermostatic traps are smaller and less expensive, they can be slow to respond, which spurred the development of thermodynamic traps. Thermodynamic traps provide faster response to changing steam loads and have been used in the largest numbers over the history of steam traps. Fixed orifice traps operate best in conditions with steady steam loads, which have traditionally limited their application.

1. Mechanical Trap Types
   - Inverted (or “closed”) bucket (IB) trap
   - Ball float trap
2. Thermostatic Trap Types
   - Bimetal temperature control trap
   - Liquid-filled bellows trap
   - Float and thermostatic (F&T) trap
3. Thermodynamic Trap Types – ThermoDisc (TD) trap
4. Fixed Orifice Trap Types

However, the useful life under the surface varies widely,[2] and the annual failure rate of traditional four types of steam traps ranges from 8% to 17%. Overtime, mechanical, thermostatic, and thermodynamic types of steam traps can fail in either the open or closed position, whereas fixed orifice type of steam traps can only fail closed. One study of for industrial applications found that 16.3% of steam traps were leaking or failed open (blow-through), with an additional 7.7% blocked. Two different studies concluded that leaks in steam traps for commercial dry cleaning and laundry facilities were around 27%.[2]

Although there are no rigorous studies supporting the assessment of the useful life of these four types of steam traps, the widely accepted lifespan, based on anecdotal experience, is 6 years. This is the number most widely used in most States’ energy efficiency Technical Resource Manuals in the United States.

Venturi steam trap technology is a new development in the steam trap technologies to address some of the shortfalls of the four types of steam traps. Venturi traps do not contain or rely on moving parts; their manufacturers often cite this feature for reduced failure rates leading to longer operational life than mechanical steam traps. This technology has been available in U.S. market since 1984, though the specific market penetration of venturi steam traps is presently unknown. The U.S. market has not seen significant adoption to date, despite the technology’s promise to

[2] “Steam Traps.” Review and Acceptance. Workpaper. T. DeCarlo and E. Kirchhoff. Energy and Environmental Analysis, Inc.; Southern California Gas. December 2006.

combine the maintenance benefits of fixed-orifice steam traps with operational capability over an increased range of conditions. During this study, GTI had numerous engagements with venturi steam trap vendors. The venturi steam trap vendors indicated to GTI that there are venturi steam traps in operation for over 20 years. Some of the vendors warranty their products for 10 years granted that they are maintained according to prescribed maintenance requirements. The potential for eliminating the steam loss through failed open traps, in traditional four types described above, is significant and worth further appraisal of venturi technology.

Venturi traps are comprised of a fixed port venturi nozzle and an orifice, as illustrated in Figure 1. A venturi is a piece of narrow tube between wider sections, so named because it creates the venturi effect where the velocity of a fluid passing through it increases as the cross-sectional area decreases with the static pressure correspondingly decreasing. Fluid condensate accelerates to pass through the orifice and drops in pressure, partially filling the orifice with condensate. Flash steam, which is produced from the saturated water under decreasing pressure in the venturi, expands in volume to limit the amount of fluid that may subsequently discharge through the orifice. Steam flash is the thermodynamic phenomenon that prevents large amounts of steam from leaking out of the trap when the orifice is not full of condensate. In the event an orifice is occupied by less than 68% condensate,[3] a small amount of steam will pass through and flash (e.g., raise the temperature of) the saturated condensate, creating the backpressure that chokes further steam loss. Most manufacturers recommend or include the strainer and blowdown valve, or recommend a drip-leg, upstream of the small venturi nozzle, to remove the dirt and scale buildup over time. Manufacturers recommend cleaning the strainer at least once a year or on a regular maintenance schedule based upon amount of particulates in the steam supply.

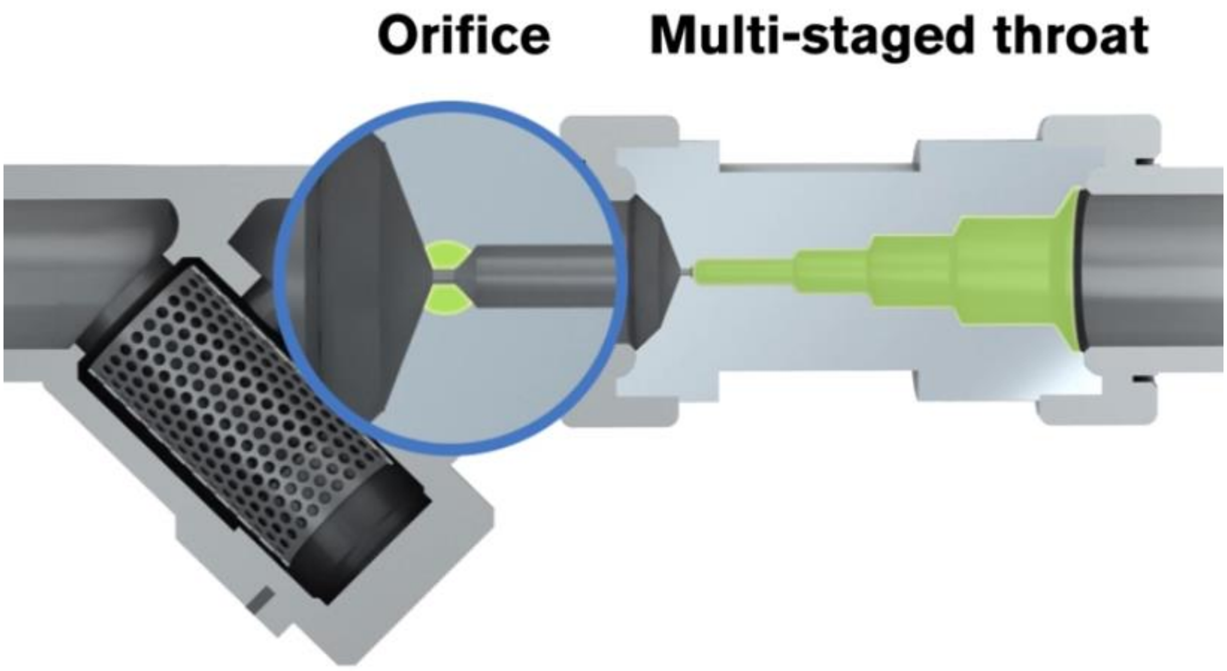

Figure 1: Venturi Steam Trap

[3] MEI Resources. http://meiresources.com/expertise/our-technology/. Last accessed November 2018.

In the United States, venturi traps have relatively little substantiation in the public record. The U.S. Department of Veterans Affairs issued a Design Alert by on May 23, 2003, on fixed-orifice and venturi steam trap types due to the limited nature of public and third-party test data of the technology. The alert noted that fixed-orifice and venturi traps have no mechanisms to modulate and control the capacity of the trap, and as such, they require very precise sizing, likely with proprietary selection procedures. The alert also noted that smaller size units could fail closed due to plugging from debris, which can develop into a serious safety hazard because of “water-hammer” on main steam drips, preheat coils, or anywhere else a fail closed feature cannot be tolerated.

Venturi steam trap vendors have claimed many advancements in recent years. The three venturi vendors who participated in this study provide sizing support to their customers on a case-by-case basis, much like the services offered by mechanical steam trap vendors such as Spirax and Armstrong. The three venturi manufacturers claim that their properly sized steam traps can handle steam load variations with no known drawbacks. A critical parameter in sizing venturi steam traps is the operating differential pressure of the trap. Comparable mechanical-type steam traps also require this sizing consideration during selection, however, they are far easier to size given their wider operational range. Most mechanical steam trap manufacturers provide pressure temperature curves for sizing selection, which can be used to select appropriate mechanical steam traps. Therefore, for this study GTI only engaged with venturi steam trap manufacturers to obtain venturi steam traps sized for specific pressures and maximum allowable condensate load.

Much like mechanical-type trap vendors, venturi-type steam trap vendors consider the variability of the steam load by application, ranging from high variability in space heating steam processes to low variability (e.g., consistent steam loads) in some industrial applications such as paper drying. The purpose of the laboratory tests by GTI is to validate the efficacy of venturi steam traps among manufacturers and against mechanical steam traps at different pipe sizes, pressures, and condensate loads. GTI engaged Thermal Energy International Inc. (TEI), Steamgard LLC, and Blue Energy Technologies (BET) for this study because they self-identified as leaders in the venturi steam trap field. GTI independently and objectively administered the functional testing of venturi steam traps against comparably-sized mechanical-type traps.

Test Objective and Known Approaches

The objective of the functional testing was to validate the efficacy of steam traps under varying condensate loads and pressures. The testing was conducted based on the American Society of Mechanical Engineers Performance Test Code (ASME PTC) 39 – 2005 standard for measurement of steam losses in a purpose-built, instrumented steam loss piping circuit. Development of this test code focused on testing mechanical steam traps at near zero condensate load and under a condensate load of 1% of maximum capacity. While GTI's testing was based on the testing method and calculation of steam loss described in the code, it targeted evaluation of steam losses at more typical field-type operating conditions, utilizing adjustable process operating conditions and higher test condensate loads. The laboratory is an ideal setting to initially test functional performance at different pressures, condensate loads, and pipe sizes because improper steam trap sizing is known to cause detrimental damage to significant commercial or industrial steam processes.

GTI performed functional steam loss testing of varying sizes of commercially available venturi steam traps from three manufacturers for comparison with representative mechanical steam traps at varying operating differential pressures and condensate load conditions. Table 1 shows the design specifications available in some of the tested 1" pipe size steam traps. As shown, the mechanical traps were all rated to accommodate larger discharge capacities (e.g., approximately 1000 lbs/hr maximum to 30 lbs/hr) and have design pressures that are a maximum operating differential pressure, rather than a target pressure. Therefore, no additional steps were necessary to size the mechanical traps for different operating differential pressures, whereas venturi traps were switched appropriately for each pressure condition. Venturi steam traps are specified for operating differential pressure and target condensate rate with narrower range.

Test criteria were developed based on the limited previous studies and steam trap populations survey studies, as discussed below.

Table 1: 1" Steam Traps with Corresponding Design Pressures and Condensate Capacities Available for Testing

Steam Trap Type	Manufacturer	Pipe Size (in.)	Specified Pressure (psig)	Condensate Capacity (lbs/hr)
Float & Thermostatic	Nicholson	1	125	1190
Inverted Bucket	Armstrong	1	125	950
Thermal Disk	MEPCO	1	150	1320
Venturi	Steamgard, TEI, and BET	1	125	300
Venturi	Steamgard, TEI, and BET	1	65	300
Venturi	Steamgard, TEI, and BET	1	25	300

A 1999 Department of Energy (DOE) study carried out by Proficient Technologies tested condensate load management efficacy between venturi and thermodynamic disk steam traps. It concluded that venturi steam traps performed better than the representative thermodynamic disk traps in reducing steam loss to half or less of the loss rate seen in thermodynamic traps. These results, however, did not specify or analyze the effects of steam trap size and operating pressure on performance.[4] This study contained a limited data set of only 4 data points and referenced ASME PTC 39.1 for 10-minute samples with a heat exchanger-controlled condensate load.

A 2004 study at Queens University Belfast tested venturi-type traps' steam loss prevention efficacy against mechanical (bucket, thermostatic, thermodynamic disk, and float and thermostatic) steam traps via heat exchanger-varied condensate loads, according to ASME PTC 39. This study confirmed that venturi traps can effectively modulate the condensate throughput in the case of slight condensate backup (e.g., condensate consistently present in the stream entering the steam trap), though the design did not test against conditions where mechanical traps fail. The general conclusion was that venturi-type steam traps were overall more efficient at steam loss prevention than mechanical-type traps at low condensate loads.[5] This study used one venturi-type steam trap and one of each type of the mechanical steam traps.

A 2006 SoCalGas workpaper included a survey on steam traps (with no discernable distinction between mechanical or non-mechanical categories) found in real-world processes, (see Table 6 in Appendix A. Attachments and Commentary). The workpaper found that most steam trap applications in the industrial and commercial sectors operate at low and medium pressures, 11 psig and mid-80 psig, respectively. The survey also found that the most common pipes size is 1" and smaller.[6] The GTI laboratory study used the data of SoCalGas workpaper to define the pressure operating and pipe size characteristics. The steam loss efficacy results from tested pressure and pipe sizes can be extrapolated at different pressures.

[4] Curves for "'EBB2' Nozzle Capacity" and "Two-Phase Flow: Steam vs. Condensate." Condensate removal device efficacy study: Venturi versus thermodynamic type steam traps. U.S. Department of Energy, Proficient Technologies, & PrimeSouth SCE&G. Savannah River Site, SC; Hilton Head, SC. 1999.

[5] "Summary of the performance analysis of venturi orifice steam traps." S. Abu-Halimeh and G. Walker. Post-Graduate Thesis. Queen's University Belfast. February 2004.

[6] "Steam Traps." Review and Acceptance. Workpaper. T. DeCarlo and E. Kirchhoff. Energy and Environmental Analysis, Inc.; Southern California Gas. December 2006.

GTI designed and constructed a multiple manifold functional steam trap test skid and installed the skid in the GTI Flex Fuel laboratory. This test skid is based upon the testing apparatus schematic shown in ASME PTC 39-2005 but with a few modifications to accommodate a thorough test plan. One modification is the addition of a positive displacement pump (tagged P-1 in the figure below), which was used instead of the heat exchanger to supply and modulate condensate load. This is a more effective means of controlling condensate than generating condensate in a heat exchanger. The condensate load was pumped from a pressure vessel port of the steam boiler. A second modification consisted of configuring the piping arrangement to allow up to five steam traps in a horizontal configuration. This enables multiple trap tests during one operational run of the testing apparatus. Figure 2 is a schematic of the test skid. Appendix D. Test Skid on 11x17 page shows a larger print of the test skid schematic. Table 2 lists the instruments used to measure various input parameters.

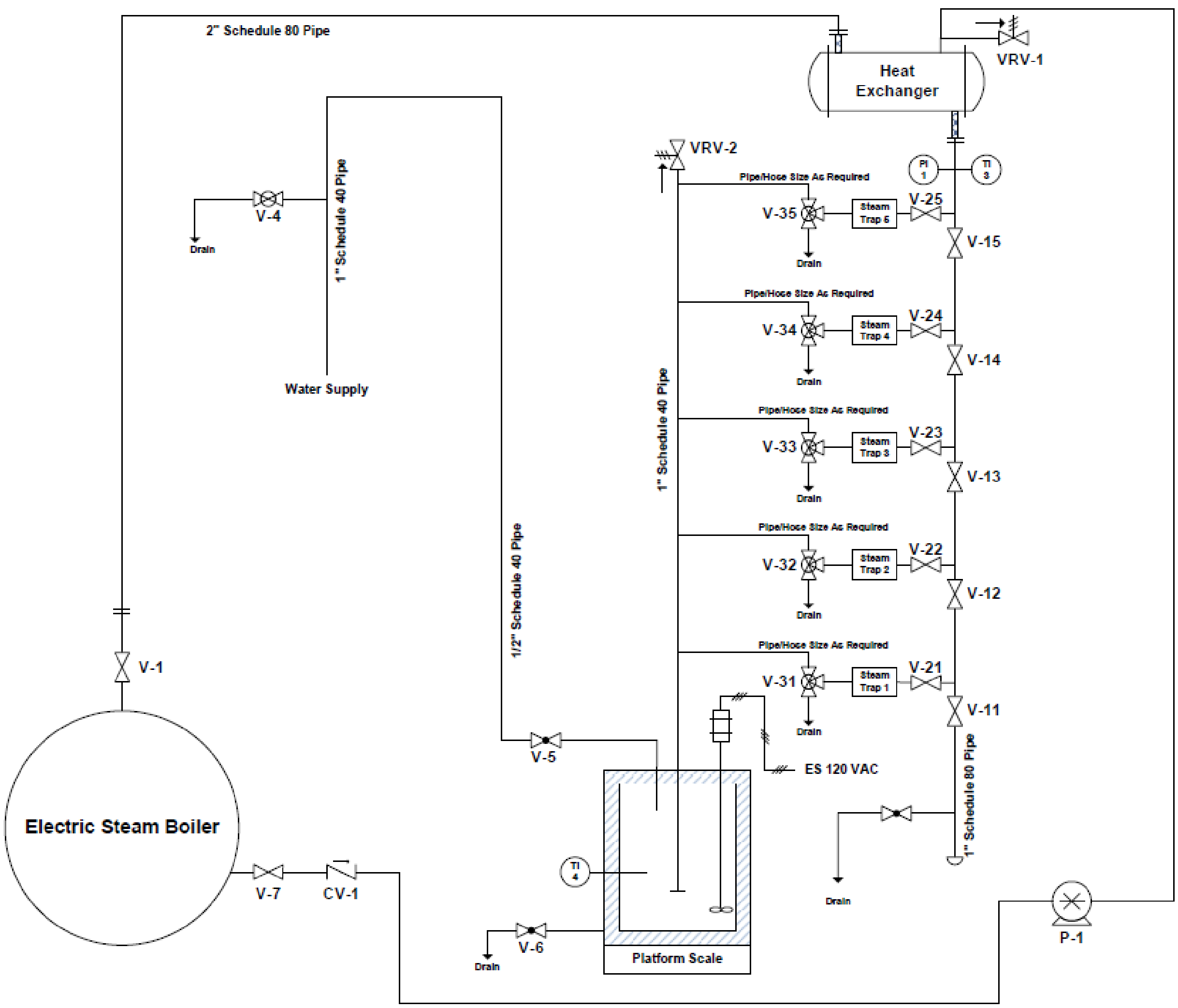

Figure 2: Horizontal Test Skid Schematic Drawing

A 500 pounds per hour (lbs/hr) steam boiler produced saturated steam for the testing. The saturated steam was piped to the main header of the testing skid. The steam boiler has the capability to produce saturated steam at designated testing pressures in the increment of 1 psig. The steam supply line and test skid piping were insulated to reduce energy losses. Figure 3 shows a picture of the test skid.

Figure 3: Photo of Test Skid in GTI Laboratories

Table 2: Equipment and Sensor Specifications

Equipment Description	Equipment Location	Manufacturer & Model
Water Temperature Sensor, of 2-wire Pt 100Ω RTD-type	Calorimeter	TEL-TRU Digi-Tel ND5AC57111-P22154
Steam Temperature Sensor, of 2-wire Pt 100Ω RTD-type	Inlet Stream	TEL-TRU Digi-Tel ND5AC57111-P22094
Mass Change Scale, with 18 in. x 23 in. Stainless Steel Platform with 600 Lb. Capacity	Calorimeter	ULINE Deluxe Platform Scale H-474
Digital Pressure Gauge Sensor, with High Accuracy with Temperature Correction	Inlet Stream	OMEGA DPG409-150G
Steam-to-Liquid Passive Heat Exchanger, as Steam-Condensate Mixing Chamber	Inlet Stream	Taco
Variable Frequency Drive (VFD) Pump, with Digital Display	Condensate Controls	Micropump GC-M23.PUS.E
Insulation Sheet, of Fiberglass for 1-1/2 in. Application with Very-High-Temperature Rating	Calorimeter	McMaster-Carr 9356K12
Insulation Sleeves, of Mineral Wool for 1-1/2 in. to 2 in. Pipe installed by Skilled Union Contractor	Skid Piping	

These laboratory trials quantified the steam loss prevention and condensate removal capability of each steam trap. The steam loss and condensate load were plotted on a scattered plot to compare the traps across different operating conditions and traditional versus venturi steam traps. The steam loss is the result of a weight balance across the trap under steady-state process conditions, which are defined as:

- Steam pressure measured at the skid inlet stream adheres to the intended test pressure
- Condensate flow rate set at the VFD pump adheres to the intended test condensate load
- Steam temperature measured at the skid inlet stream is steady
- Steam traps are heated in a bypass mode before testing and holding steady surface temperatures, verified via infrared imaging (IR) camera

Achieving the respective steady states prior to each test required a reasonable amount of time between trials to dissipate the enthalpy collected in the calorimeter tank from prior tests. Time was also a consideration for the labor-intensive set-up of each pressure and condensate flow condition. In some cases, an hour between each test was necessary to isolate the set of desired operating conditions. To modulate tests at different operating differential pressures, the pressure controller on the boiler was adjusted accordingly. To modulate tests at different condensate loads, a positive displacement pump with high-accuracy variable frequency drive motor settings was used instead of the heat exchanger element prescribed in ASME PTC 39 – 2005. With known maximum condensate loads per the trap specifications, GTI determined the corresponding pump motor setting. There was another source of condensate generation in the testing apparatus. This source is the result of natural phase change in the steam distribution line.

The two sources contributing to the condensate load utilized in tests are: the natural phase change within the skid column and the positive displacement pump-injected condensate analogous to process load at the top of the inlet stream column. This sum equals the condensate load discharged by traps into the collection calorimeter tank, with any additional weight and energy attributable to steam loss.

The ASME standard minimally requires 10 minutes of data collection. However, GTI collected data to a minimum of 30 minutes at steady state per test to ensure aggregate quality data. The aggregate quality data provide longer experimental observation time and additional confidence in data. The experimental data were recorded at every 5-minute intervals for all tests. This frequency of data collection aided in detecting any adverse conditions such as trap flooding. A steam trap floods when it is unable to discharge the condensate load, which then causes condensate to back up in the steam line. A step-by-step experimental procedure is detailed in Appendix C.

Each test was performed after the steady-state conditions were achieved. The experimenter recorded ambient laboratory atmospheric conditions via local weather station data for temperature and pressure compensation. Once the calorimeter has been filled to an adequate cold-water level, the experimenter recorded initial steam temperature, steam pressure, ambient temperature, ambient pressure, and the initial weight and temperature of the calorimeter tank. The correct diversion valves, as illustrated in Figure 2, were turned to begin the test. Temperature, pressure, and calorimeter weight readings were manually recorded every 5 minutes through the end of the test.

These data feed into the calculation of overall Condensate Flow and Steam Loss. Appendix B. Field Data Calculation Spreadsheet Methodology contains the built spreadsheet tool and formulae used to calculate the desired outputs per test.

The matrix of operating conditions across all tested steam traps is available in Table 7 and Table 8 in Appendix A. Attachments and Commentary. In total, this study covered 134 tests, which is the most extensive sample size compared to historical studies. Of 134 tests, 128 tests were in horizontal orientations and the remaining 6 tests were in vertical orientation. Each venturi trap was tested at the specified operating differential pressure and different condensate operating range. Venturi steam traps were exchanged at each different operating pressure and pipe sizes, whereas the mechanical steam traps were exchanged at different pipe sizes. Mechanical steam traps are able to discharge condensate at wider pressure range.

Based on market prevalence information available in the previously cited SoCalGas workpaper, GTI selected steam operating differential pressures at 125, 65, and 25 psig and pipe sizes of 1/2", 3/4", and 1". An overwhelming majority of representative steam traps operate at pressures of 125 psig and lower, as shown in Table 6 in Appendix A.

The laboratory study captured ambient temperature and pressure, steam supply temperature and pressure, and calorimeter initial temperature, final temperature, initial weight, and final weight data. These parameters were collected for all 134 test trials. The data were then entered into a custom-built Microsoft Excel-based calculator to compute steam loss and condensate load in pounds per hour [lb/hr]. Table 5 in Appendix A shows a sample of this calculator. It was developed based on ASME formulae, detailed in Appendix B. Scattered plots are generated to illustrate the steam loss as a function of condensate load.

Figure 4 shows the steam loss in pounds per hour as a function of condensate load for 1" mechanical and venturi steam traps at all three pressure conditions. The pressure conditions are 125, 65, and 25 psig. Data from the experiments support the safe removal of condensate load by the venturi steam traps across different operating pressures and condensate loads. Although a steam trap's function is to trap live steam and discharge condensate, in real work conditions, even properly functioning steam traps allow some steam through. All tested steam traps were brand new. The measured steam loss between the venturi and mechanical steam traps is comparable within experimental error; however, there are no standards governing performances of steam traps that can provide a benchmark.

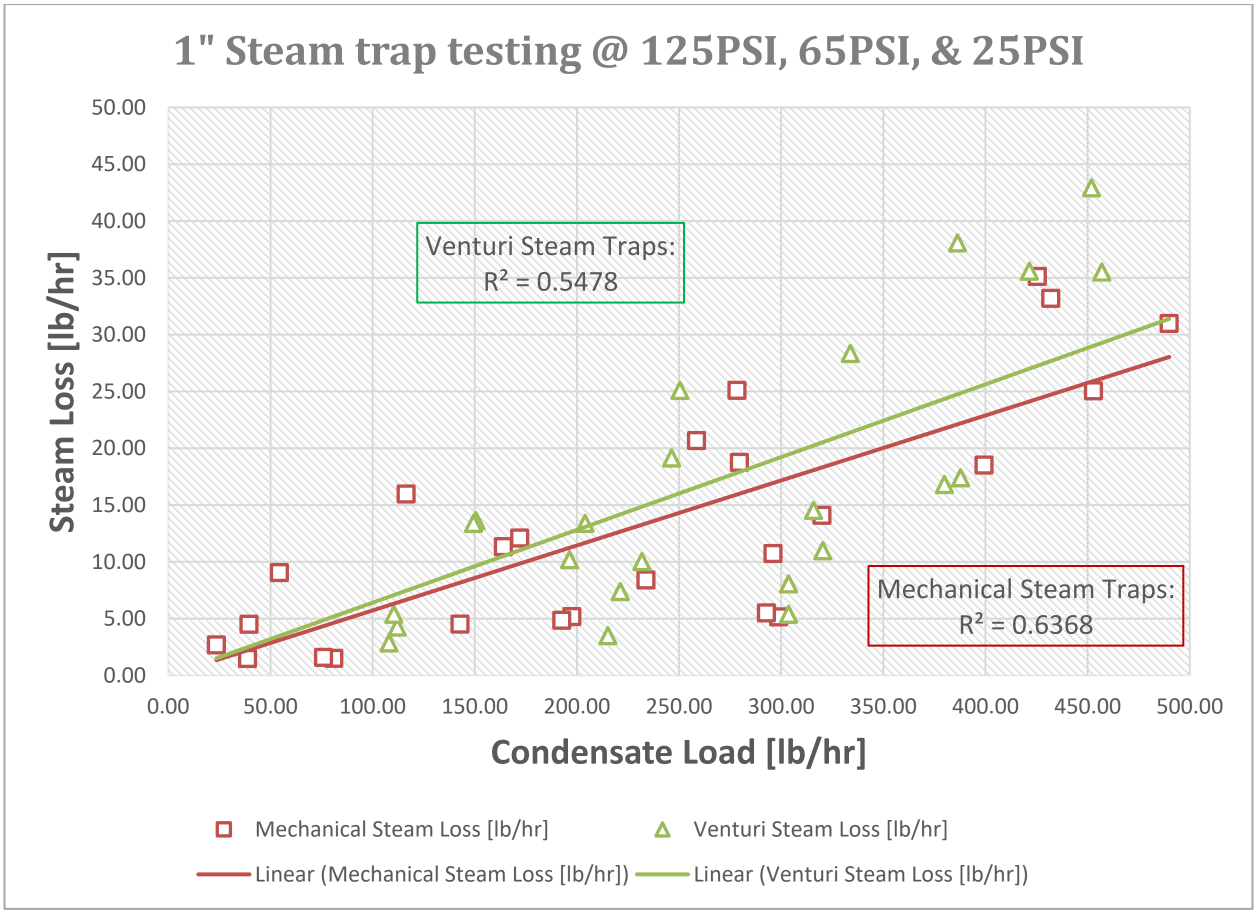

Figure 4: Steam Loss as a function of Condensate Load for 1" steam traps at all three target pressures – 125 psig, 65 psig, 25 psig

Figure 5 and Figure 6 show the steam loss in pounds per hour as a function of condensate load for 3/4" and 1/2" mechanical and venturi steam traps at all three pressure conditions. As was the case for the 1" steam traps, the data from these experiments support the safe removal condensate load for venturi steam traps across different operating pressures and condensate loads per the industry standard for mechanical steam traps. All tested steam traps were brand new, and measured steam loss between venturi and mechanical steam traps is comparable.

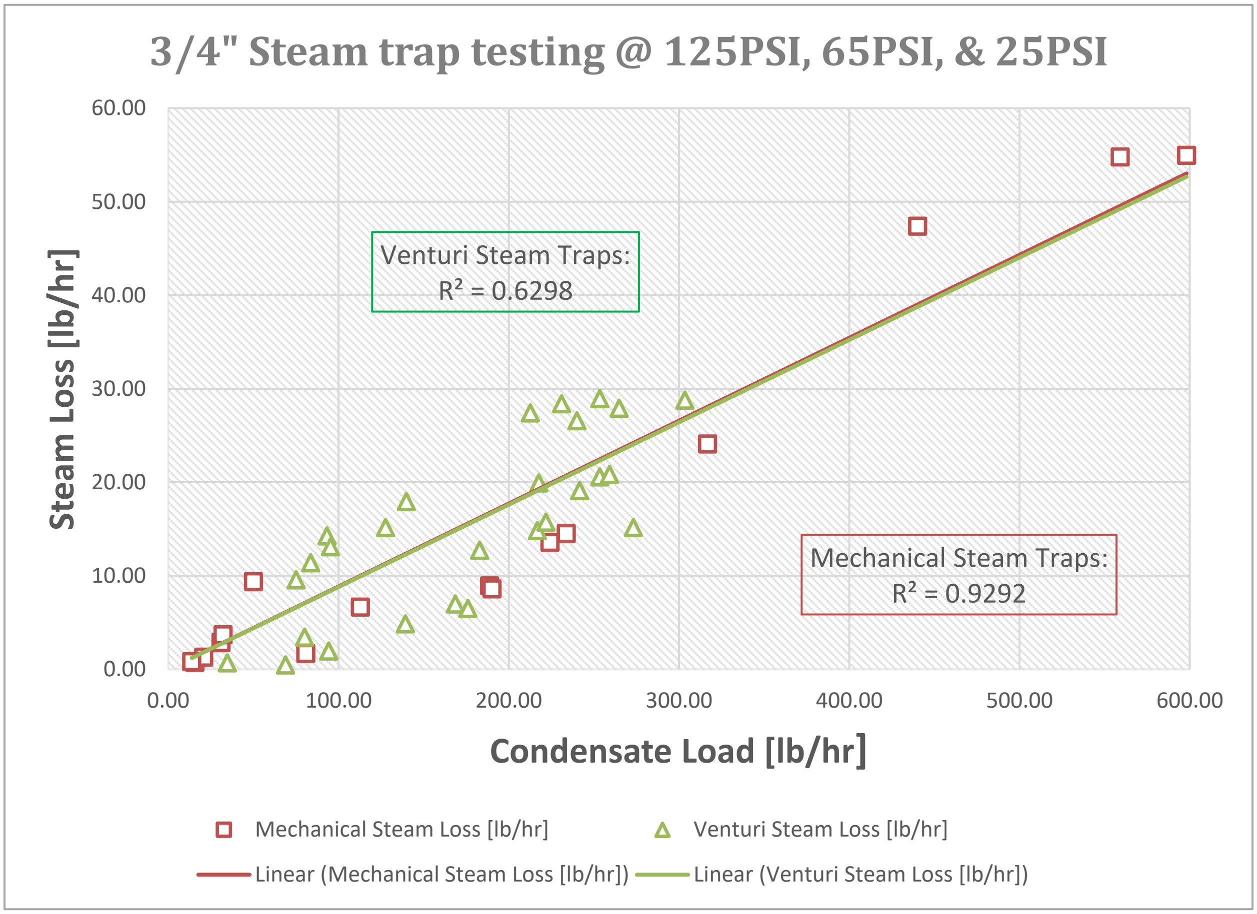

Figure 5: Steam Loss as a function of Condensate Load for 3/4" steam traps at all three target pressures – 125 psig, 65 psig, 25 psig

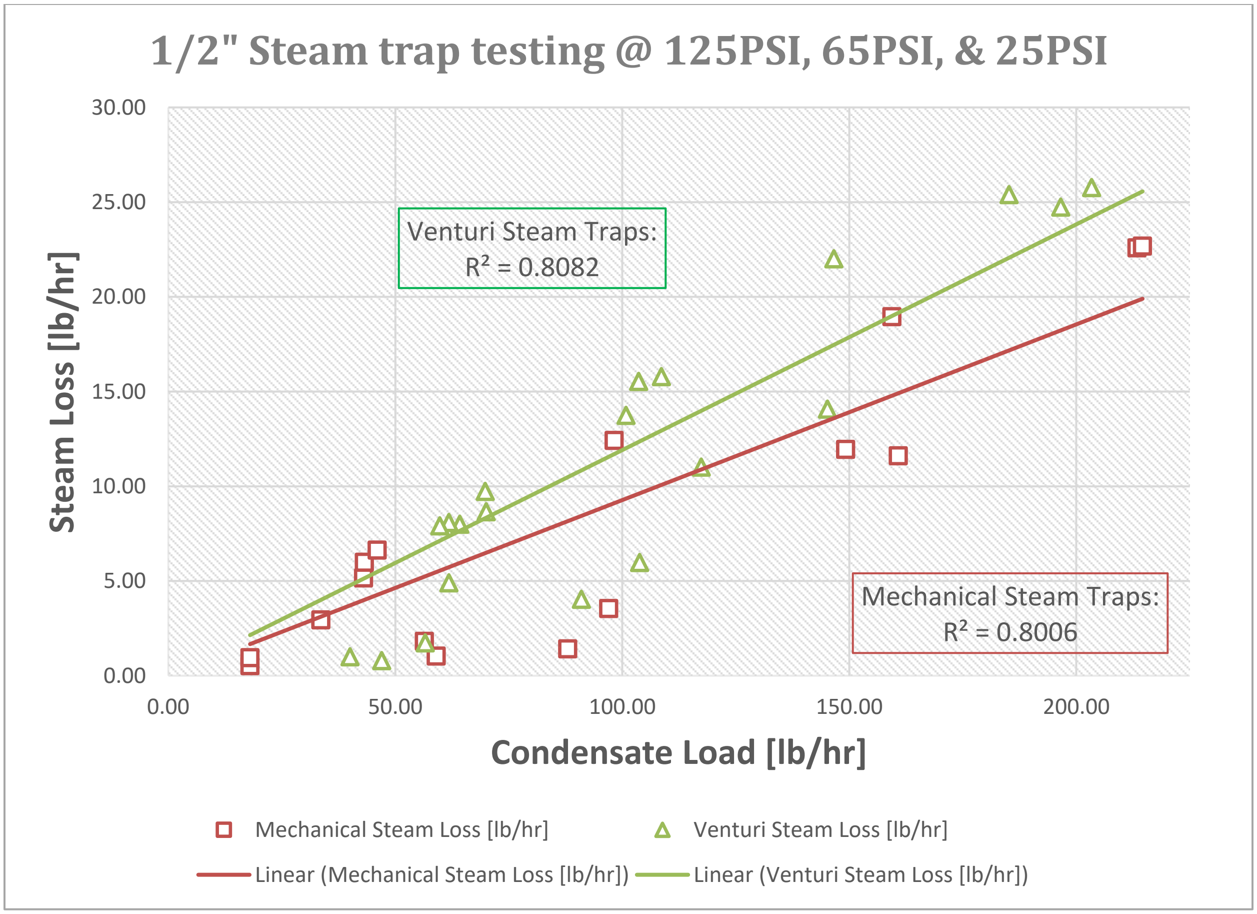

Figure 6: Steam Loss as a function of Condensate Load for 1/2" steam traps at all three target pressures – 125 psig, 65 psig, 25 psig

Measurement error and uncertainty affect the data collected in this custom-built laboratory trial. The weight scale, thermometers, and pressure sensor used for measurement were brand-new, calibrated devices upon delivery. The error bands stated in each equipment specification are recorded below and an uncertainty budget analysis was performed to account for measurement errors. Table 3 shows the calculation of this study's uncertainty budget, ±0.64%. This minor measurement error contributes a small possibility of error to the calculated loss ratio results.

The uncertainity error percentage is within the range of mechanical steam traps versus venturi steam traps performance. For example, the percentage error between mechanical versus venturi steam traps for ¾" steam traps is 0.5 percentages. This is within the realm of experimental error.

Table 3: Uncertainty Budget Analysis

Component of Uncertainty	Uncertainty, U(xi)	Distribution	Divisor	Std Unc	Std Unc, u(xi)	
Calorimeter Temperature Sensor	0.5 °F	Rectangular	1.73	0.29 °F	0.03	%, for values over 100°F
Calorimeter Weight Scale	0.1 lbm	Rectangular	1.73	0.06 lbm	0.10	%, for masses over 60 lbm
Inlet Stream Pressure Sensor	0.08%	Rectangular	1.73	0.046 %	0.05	%, for max. value 130 psig
Inlet Stream Temperature Sensor	0.825 °F	Rectangular	1.73	0.48 °F	0.14	%, for max. value 350°F
combined standard uncertainty, u_c					± 0.32	%
coverage factor, k					2	for 95%
expanded uncertainty, U_c					± 0.64	%

Engineering Versus Product Solution

For this laboratory study, GTI obtain the venturi steam traps for testing directly from venturi manufacturers. GTI provided operating pressure specifications and target condensate discharge range. Based on these parameters, all three venturi manufactures provided steam traps for the study. The mechanical steam traps used in the study were selected from industrial supply houses.

Venturi steam traps must be specified for each application based on the condensate discharge capacities and operating pressures. The venturi manufacturers who participated in this study provide this critical engineering service to their end users. Because of this requirement, venturi steam traps are not available through third-party supply houses. Mechanical steam traps have a wider range of operating conditions for given pipe sizes and can be purchased through various third-party supply houses or directly from manufacturers.

Condensate Discharge in Vertical Orientations

Most mechanical steam traps can only be installed in horizontal positions. The moving mechanism within the traps poses this limitation. Because venturi steam traps have no mechanical mechanism, they can be installed in either horizontal or vertical (downward flow) orientations. Anecdotal evidence suggests that most installed steam traps are in horizontal orientations, however, limited testing of venturi steam traps in vertical orientation will provide benefit when the space constraints prohibit installation in horizontal orientation cost-effectively. GTI performed only 6 out of 134 tests on venturi steam traps in a vertical orientation. Figure 7 shows the safe discharge of condensate load in vertical orientations for venturi steam traps. This additional benefit can be realized by end users who need to install in space constrained applications, though no energy savings implications should be construed. The traps in vertical orientations are shown in Appendix E.

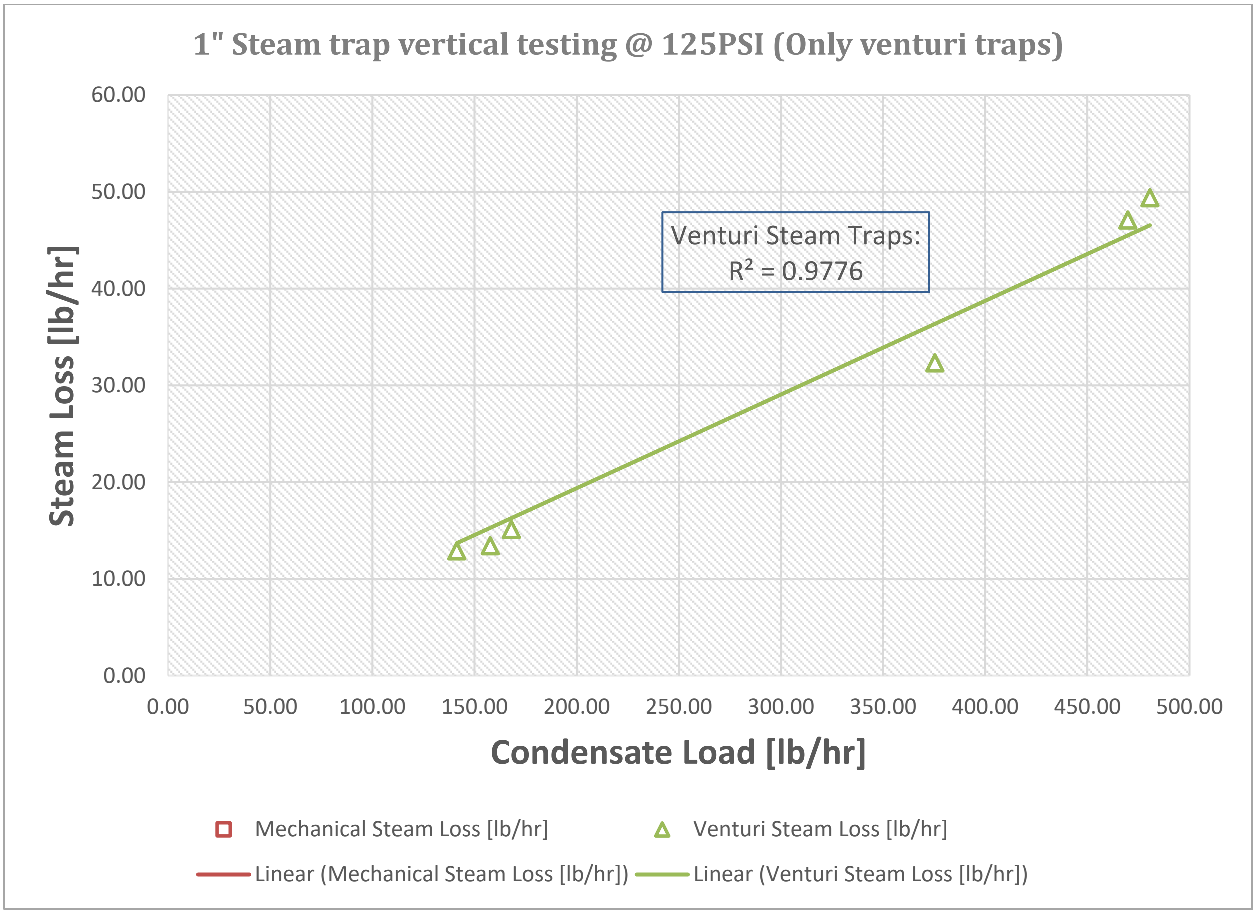

Figure 7: Steam Loss as a function of Condensate Load for 1" steam traps at 125 psig in Vertical Orientations

Useful Life

The widely accepted anecdotal useful life of the four steam trap types is 6 years, which is used in various Energy Efficiency Technical Resource Manuals in the United States.[7,8] However, as reflected below, the useful life under the surface varies widely,[9] and the annual failure rate of traditional four types of steam traps ranges from 8% to 17%.

I. Suggested inverted bucket has a typical life in the range of 5 to 7 years
II. Float and thermostatic has a typical life in the range of 4 to 6 years
III. Thermodynamic disc has a typical life in the range of 1 to 3 years

GTI had numerous engagements with venturi steam trap vendors, who indicated that there are venturi steam traps in operation for over 20 years. Some of the vendors warranty their products

[7] "Steam Traps." Review and Acceptance. Workpaper. T. DeCarlo and E. Kirchhoff. Energy and Environmental Analysis, Inc.; Southern California Gas. December 2006.
[8] 2019 Illinois Statewide Technical Reference Manual for Energy Efficiency, Measure: "4.4.16 Steam Trap Replacement or Repair", Version 7.0, http://ilsagfiles.org/SAG_files/Technical_Reference_Manual/Version_7/Final_9-28-18/IL-TRM_Effective_010119_v7.0_Vol_1-4_Compiled_092818_Final.pdf, Accessed January 24, 2019.
[9] "Steam Traps." Review and Acceptance. Workpaper. T. DeCarlo and E. Kirchhoff. Energy and Environmental Analysis, Inc.; Southern California Gas. December 2006.

for 10 years, provided they are maintained according to prescribed maintenance requirements. The additional 4 years of useful life of venturi steam traps over the mechanical steam traps presents a wide opportunity for further appraisal of venturi steam trap technology. The technology presents an opportunity for large energy savings, which are lost because of undetected failed open or closed mechanical steam traps.

Further Research

Steam heating is very common in certain areas of the United States and is a widely used heating source in pre-1970 construction. Steam is also widely used in industrial process applications, due to its unique properties. When the steam pressure is held constant, and both water and steam are present, the temperature also remains constant. Further, the temperature is uniquely fixed by the pressure, and hence by maintaining constant pressure, control of process temperature can also be maintained. The conversion of a liquid to a vapor absorbs large quantities of heat in each pound of water. The resulting steam is easy to transport, and because it is so energetic, relatively small quantities of it can move large amounts of heat. This means that relatively inexpensive pumping and piping can be used, compared to that needed for other heating media. With these advantages, steam plays a significant role in heating and industrial process applications.

There are two types of condensate generation in steam systems:

1. Drip Leg - Condensate from unavoidable heat loss in the steam distribution system must be removed promptly to eliminate water hammer and degradation of steam quality and heat transfer capability
2. Heat Trace – Condensate from terminal equipment use of steam

In addition to these two condensate generation types, there are numerous other steam system parameters that influence operating pressure, system load, and system operations. There is no public knowledge of venturi steam traps selection among these variables. The institutional knowledge resides with the three venturi manufacturers. Therefore, a further study to document the path to venturi steam trap selection for energy efficiency programs will be essential, even though venturi steam traps remain an engineering solution.

The useful life of venturi steam traps is anecdotal and comes primarily from venturi steam trap manufacturers. The conceptual validation of safe and sound operation of traps from the tested three venturi manufacturers should be part of the further research.

The form in Table 4 was used to collect raw experimental data. Table 5 shows the Excel-based calculation tool used to calculate the results of steam loss, condensate load, and loss-to-removal ratios per test. The cells highlighted in green populated automatically based on standard steam tables. The cells highlighted in blue calculated values using the equations described in Appendix B. *Field Data Calculation Spreadsheet Methodology*.

Table 4: Raw Data Collection Form

			Test Run						
Data Collection Elapsed Time (min)			**0**	**5**	**10**	**15**	**20**	**25**	**30**
Mass of Water; start (SCALE)	W_1	lb							
Initial Water Temperature	T4	°F							
Steam Temperature; Inlet	T3	°F							
Steam Pressure Inlet	PI-1	psig							
Ambient Temperature	T_o	°F							
Barometric Pressure	P_a	Hg							

Table 5: Data Calculator Tool, shown for 1" Steamgard Venturi-Type Steam Trap Test at 125 psig

Information	Test: 1" Steamgard			Comments:			
	Test Date: 7/31/2018			Start time - 8:00			
	Location: GTI			A few bubbles every ~10 seconds.			
	Manufacturer: Steamgard						
	Serial #: SG-EP-C CS/QB			Start time - 10:39			
	Type of Trap: Venturi			Condensate pump primed. Condensate valve closed. Constant bubbling/calorimeter squeaking. Similar weight-gain rate increase.			
	Size: 1 inch NPT; 300 lbs/hr			Test Run			
	Calorimeter Material: Carbon Steel			1	2	3	Average
Test Data	Mass of Calorimeter; empty	W_t	lbm	43.0	43.0		43.0
	Mass of Water; start	W_1	lbm	60.5	60.8		60.7
	Mass of Water; finish	W_2	lbm	138.0	136.1		137.1
	Mass of Water; added	ΔW	lbm	77.5	75.3		76.4
	Test Time	ΔT	sec	1800.0	1800.0		1800.0
	Ambient Temperature	T_o	°F	70.0	77.0		73.5
	Steam Temperature; Inlet	T_s	°F	346.1	348.5		347.3
	Initial Water Temperature	T_1	°F	69.8	75.8		72.8
	Final Water Temperature	T_2	°F	170.6	180.8		175.7
	Barometric Pressure	P_a	Hg	29.3	29.3		29.3
	Steam Pressure Inlet	P_s	psig	121.0	123.0		122.0
Thermodynamic Prosperities							
	Specific Heat of Calorimeter Material	C_p	btu/lbm-°F	0.12	0.12		0.12
	Initial Enthalpy of Water	h_{f1}	btu/lbm	37.88	43.87		40.88
	Final Enthalpy of Water	h_{f2}	btu/lbm	138.56	148.77		143.66
	Enthalpy of Saturated Liquid	h_{fs}	btu/lbm	317.27	319.78		318.52
	Enthalpy of evaporation	h_{fgs}	btu/lbm	874.63	872.66		873.65
Calculations	Initial Mass of Water	W_1	lbm	60.5	60.8		60.7
	Final Mass of Water	W_2	lbm	138.0	136.1		137.1
	Energy Content of Initial Water	W_s	btu	16,903.1	16,774.9		16,839.0
	Energy Content of Final Water	W_f	btu	24,662.5	23,273.8		23,968.1
	Heat Gain of Calorimeter	W_t	btu	528.8	550.8		539.8
	Steam Loss	W_L	lbm/hr	-16.5	-13.6		-15.1
	Water Discharged with Steam	W_w	lbm/hr	171.5	164.2		167.9
	Condensate Load	W_c	lbm/hr	155.0	150.6		152.8
	Steam Loss per Total Trap Discharge	W_L/W_w	%	9.6	8.3		9.0

Table 6 is adopted from SoCalGas 2006 workpaper. It lists the operating pressure range and prevalence of steam traps in the pressure range. This information was critical to design the experimental study. GTI selected 25 psig, 65 psig, and 125 psig as operating pressures due to major population of steam traps. The results of 25 psig can be extrapolated to lower operating pressures since heating applications operate at lower than 25 psig. Table 7 shows the test matrix used for horizontal configurations and Table 8 shows the matrix used for the vertical configurations.

Table 6: Average Inlet Pressure Calculation," from SoCalGasWorkpaper, December 2006

Pressure range (psig)	Number of Steam Traps	Average Pressure in Range (psig)	(Average pressure) X (Number in Range)	Average Pressure in Category (psig)
Industrial Low Pressure (≤ 5 psig)				
<5	234	2.5	585	
5	0	5	0	
6 to 9	24	7.5	180	
10	515	10	5150	10.9
11 to 14	249	12.5	3112.5	
15	517	15	7755	
Industrial Medium Pressure (> 15 psig)				
16 to 19	37	17.5	647.5	
20	28	20	560	
25	33	25	825	
30	73	30	2190	
40	61	40	2440	
50	26	50	1300	
60	60	60	3600	
61 to 99	175	80	14000	85.9
100	45	100	4500	
101 to 124	117	112.5	13162.5	
125	14	125	1750	
150	54	150	8100	
200	2	200	400	
250+	26	425	11050	
Commercial (based on Dry Cleaners)				
74	20	74	1480	
80	30	80	2400	82.8
100	15	100	1500	

Table 7: Test Matrix of Horizontal Configurations. 128 distinct test cases

Pipe Size: 1"								
Test Pressure:	125 PSIG				65 PSIG	25 PSIG		
HORIZONTAL	**Condensate Load:**				**Condensate Load:**	**Condensate Load:**		
Trap Station	**High Load**	**Mid Load**	**Low Load**	**No Load**	**High Load**	**High Load**	**Mid Load**	**Low Load**
Mechanical-TD (6):								
Mechanical (5):								
Mechanical (4):								
Venturi (3):								
Venturi (2):								
Venturi (1):								

Pipe Size: 3/4"								
Test Pressure:	125 PSIG				65 PSIG	25 PSIG		
HORIZONTAL	**Condensate Load:**				**Condensate Load:**	**Condensate Load:**		
Trap Station	**High Load**	**Mid Load**	**Low Load**	**No Load**	**High Load**	**High Load**	**Mid Load**	**Low Load**
Mechanical (5):								
Mechanical (4):								
Venturi (3):								
Venturi (2):								
Venturi (1):								

Pipe Size: 1/2"								
Test Pressure:	125 PSIG				65 PSIG	25 PSIG		
HORIZONTAL	**Condensate Load:**				**Condensate Load:**	**Condensate Load:**		
Trap Station	**High Load**	**Mid Load**	**Low Load**	**No Load**	**High Load**	**High Load**	**Mid Load**	**Low Load**
Mechanical (5):								
Mechanical (4):								
Venturi (3):								
Venturi (2):								
Venturi (1):								

Table 8: Test Matrix of Vertical Configurations. 6 distinct test cases

Pipe Size: 1" - Vertical		
Test Pressure:	125 PSIG	
	Condensate Load:	
Trap Station ID	High Load	No Load
Venturi (3)		
Venturi (2)		
Venturi (1)		

Based on ASME PTC 39-2005, *Steam Loss Test Calculations*:

Equation 1

$$Total\ Discharge\ Flow, \Delta W\left[\frac{lbs}{hr}\right] = \frac{W_2[lbm] - W_1[lbm]}{\Delta T[sec]} * \frac{1}{3600}\left[\frac{sec}{hr}\right]$$

Sensible Heat Gains within the calorimeter may be calculated by:

Equation 2

$$Sensible\ Heat\ Gain\ of\ Calorimeter, E_t[Btu] = C_P * W_t * (T_2 - T_1)$$

where:

$$C_P\left[\frac{Btu}{lbm * °F}\right] = Specific\ Heat\ of\ Calorimeter\ Material = 0.122$$

$$W_t[lbm] = Mass\ of\ Empty\ Calorimeter = 43.0$$

$$T_2\ [°F] = Final\ Water\ Temperature$$

$$T_1\ [°F] = Initial\ Water\ Temperature$$

$$\Delta T[sec] = Test\ Time$$

$$W_i[lbm] = Mass\ of\ Water\ (i = Initial(1)\ or\ Final(2))$$

Thermodynamic properties may be calculated based on steam tables.

Latent Heat Gains within the calorimeter may be calculated by:

Equation 3

$$Energy\ Content\ of\ Water(i = Initial(s)\ or\ Final(f)), E_{w,i}[Btu] = W_i * h_{fi}$$

where:

$$h_{fi}\left[\frac{Btu}{lbm}\right] = Enthalpy\ of\ Water\ (i = Initial(s)\ or\ Final(f))$$

Thereby, steam loss from the skid into the calorimeter may be calculated by:

Equation 4

$$Steam\ Loss, W_L\left[\frac{lbs}{hr}\right] = \frac{W_s - W_f + E_t}{h_{fgs} * \Delta T} * 3600\left[\frac{sec}{hr}\right]$$

where:

$$h_{fgs}\left[\frac{Btu}{lbm}\right] = Enthalpy\ of\ Evaporation$$

The balance of the calorimeter load is discharged condensate, which may be calculated by:

Equation 5

$$Water\ Discharged\ with\ Steam, W_W\left[\frac{lbs}{hr}\right] = \frac{\Delta W * \Delta T}{3600\left[\frac{sec}{hr}\right]} - W_L$$

To find the specified condensate load entering the steam trap assembly, calculate:

Equation 6

$$Condensate\ Load\ \left[\frac{lbs}{hr}\right] = \left(RPM[\frac{rev}{min}] * V[\frac{lbs}{rev}] * 60[\frac{min}{hr}]\right)$$

where:

$$Condensate\ Injection\ Pump\ Setting, RPM\ \left[\frac{rev}{min}\right]$$

$$Pump\ Displacement, V\ \left[\frac{lbs}{rev}\right] = \ 0.00173913$$

Based on ASME PTC 39-2005 Section 4-7.2:

1. Acquire and wear all necessary Personal Protective Equipment, which includes: hard hat, safety glasses, steel toe shoes, and high temperature gloves.
2. Perform visual inspection on the Venturi test apparatus to ensure test valves are closed and bypass valves are open during start-up.
3. Contact Lab Manager if the boiler has any alarm.
4. Verify that the steam inlet valve to the test skid is open. Start the electric boiler at the desired operating differential pressure setpoint.
5. Once boiler set point reaches the desired pressure, monitor the test skid as it reaches steady-state flows and consistent inlet steam temperature and pressure readings. Refer to a steam table to verify saturated steam flow (e.g., saturated steam at 125 psig will show approximately 352°F).
6. Prime the positive displacement VFD condensate feed pump to feed into the skid.
7. Adjust the condensate load via the electronic motor RPM setting. Refer to test matrix for corresponding RPM-to-flow rate settings (e.g., 0.105 lbs/hr per RPM), then modulate the pump settings to achieve the desired condensate load.
8. Monitor the test apparatus for steady-state operation with the desired condensate load, via the inlet temperature and pressure at TI3 and PI1, respectively.
9. Slowly modulate the opening of the first test steam trap:
    a. Mechanical traps require warming through and for condensate to charge the trap before becoming fully operational. Intermittent steam will release through the bypass until ready.
    b. Venturi traps may release steam while in bypass. Pay attention to the steam inlet pressure and temperature to catch potential wet steam or condensate backup in the vertical column. This is indicated by a sudden drop in inlet steam temperature (e.g. the measurement is liquid condensate temperature and no longer of steam).
10. Verify that the process flow to bypass has regained steady-state conditions.
11. Begin charging the calorimeter with cool process water:
    a. Ensure the hose is properly connected to source.
    b. Tare the calorimeter scale to 0, ensuring the bubble-level at the base of the scale is aligned with the center black circle.
    c. Close the calorimeter tank drain valve and open the water inlet valve.
    d. Charge with approximately 60-70 lbs. of cool process water, in order to cover the temperature probe's height within the calorimeter. Note that 1 gallon (gal) of water = 8.34 lbs. The calorimeter tank can safely hold 30 gal or 240 lbs of water. Operational conditions should not exceed 200°F.
12. Close the bypass valve and hit "Start" on the timer to begin test. Record the real-time of this test to match to ambient temperature and pressure measurements at the O'Hare weather station. Measure subsequent time durations of the trial in time elapsed (seconds).

13. Within the first 5 minutes of trial operation, obtain a thermal IR image of the steam trap of interest using the FLIR One camera accessory. Label the test conditions appropriately.
14. Record steam inlet pressure and temperature, calorimeter temperature and weight, and any observations as events (e.g., significant "bubbling" into the calorimeter indicates steam loss) every 5 minutes and note the elapsed time.
15. Monitor the calorimeter to prevent from exceeding the calorimeter's operational limits.
16. At the conclusion of each trial (<u>between 10-60 minutes or until safety limits are reached, whichever occurs first</u>), stop the timer, turn the bypass valve to drain, and turn off the stir motor to await the last steam loss to settle in the calorimeter.
17. Record the final calorimeter weight and temperature.
18. Refer to the process flowchart in Figure 8 as necessary.

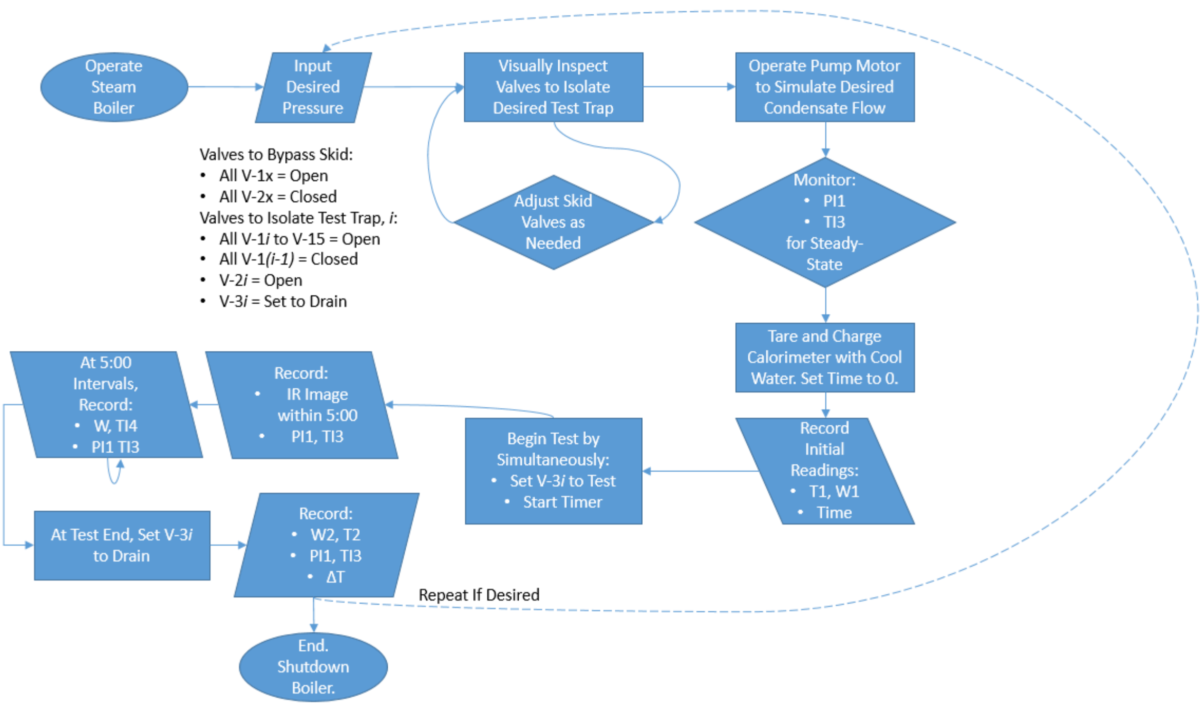

Figure 8: Experimental Procedure Flowchart

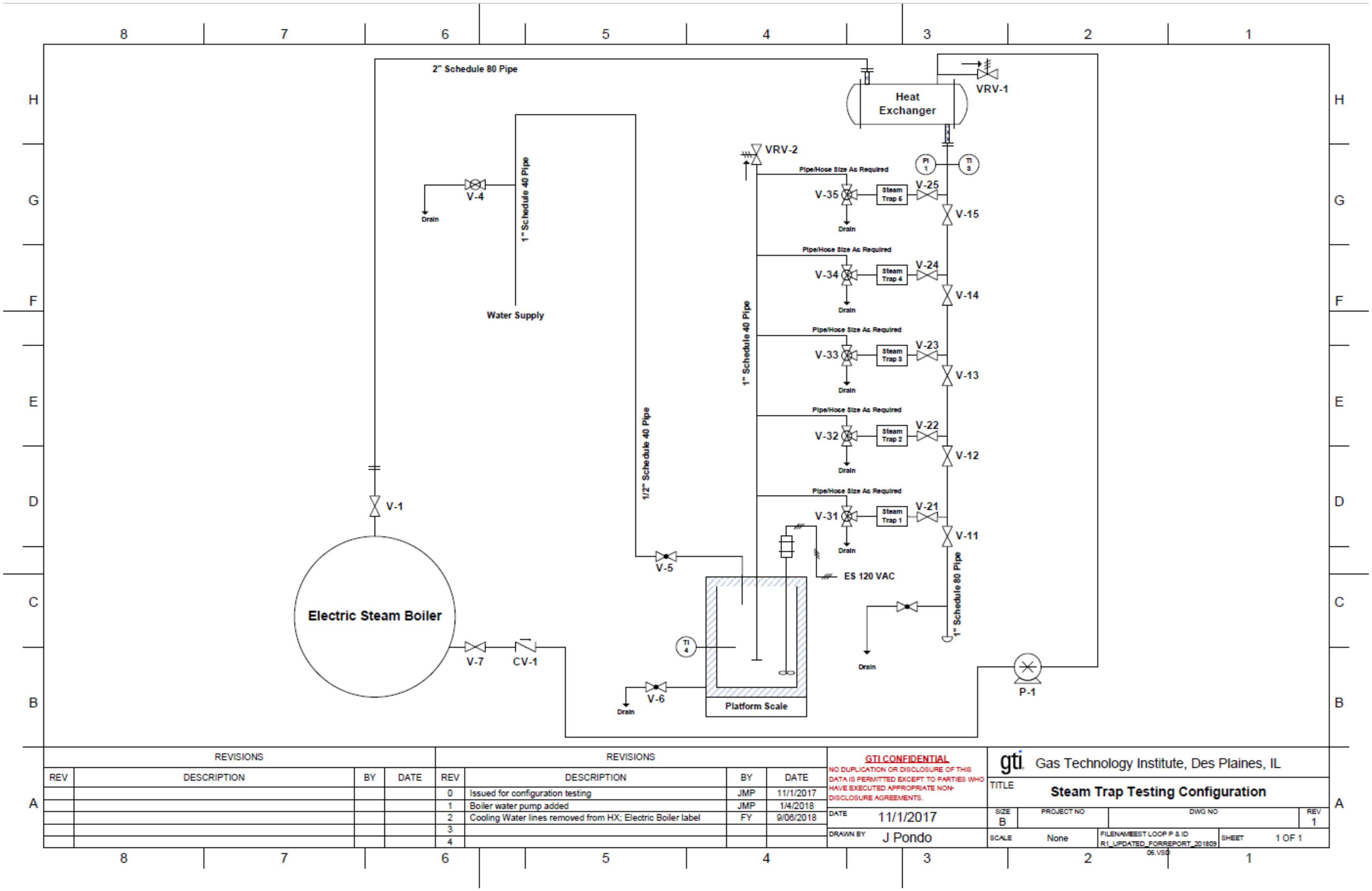
2" Schedule 80 Pipe
Heat Exchanger
VRV-1
VRV-2
PI 1
TI 3
Pipe/Hose Size As Required
V-35
Steam Trap 5
V-25
V-15
V-34
Steam Trap 4
V-24
V-14
V-33
Steam Trap 3
V-23
V-13
V-32
Steam Trap 2
V-22
V-12
V-31
Steam Trap 1
V-21
V-11
Drain
V-4
1" Schedule 40 Pipe
Water Supply
1/2" Schedule 40 Pipe
1" Schedule 80 Pipe
V-1
V-5
ES 120 VAC
Electric Steam Boiler
V-7
CV-1
TI 4
V-6
Platform Scale
P-1
REVISIONS
REV | DESCRIPTION | BY | DATE
0 | Issued for configuration testing | JMP | 11/1/2017
1 | Boiler water pump added | JMP | 1/4/2018
2 | Cooling Water lines removed from HX; Electric Boiler label | FY | 9/06/2018
3
4
GTI CONFIDENTIAL
NO DUPLICATION OR DISCLOSURE OF THIS DATA IS PERMITTED EXCEPT TO PARTIES WHO HAVE EXECUTED APPROPRIATE NON-DISCLOSURE AGREEMENTS.
gti Gas Technology Institute, Des Plaines, IL
TITLE Steam Trap Testing Configuration
DATE 11/1/2017
DRAWN BY J Pondo
SIZE B
PROJECT NO
DWG NO
REV 1
SCALE None
FILENAMEEST LOOP P & ID R1_UPDATED_FORREPORT_20180906.VSD
SHEET 1 OF 1

Figure 9: Vertical Orientation Test Skid