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Heat Pump Water Heater Condensate Disposal System

Contract No. DE-FC26-99FT40652

Final Report

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Condensate Disposal System Index

Background / Description

Task 1 - Conceptual Design

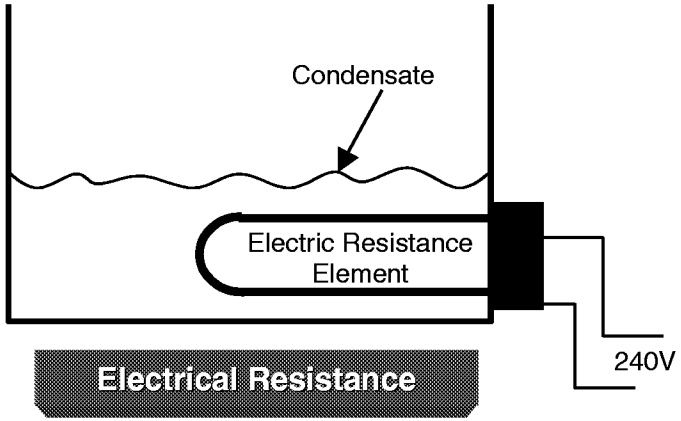
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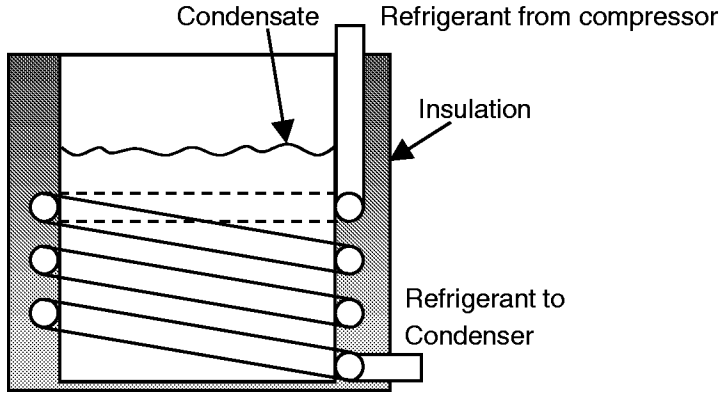
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Summary

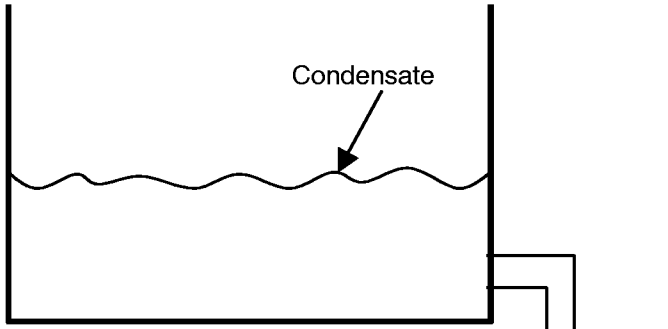
There are currently a number of options for handling the condensate generated from the Heat Pump Water Heater (HPWH).



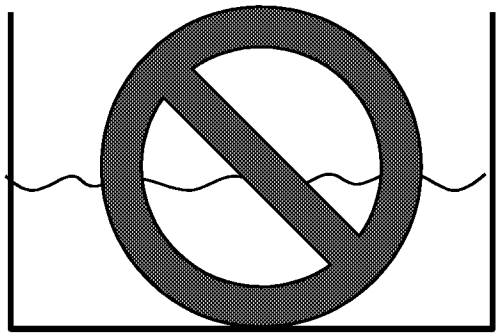
Electrical Resistance



Desuperheater



Drain



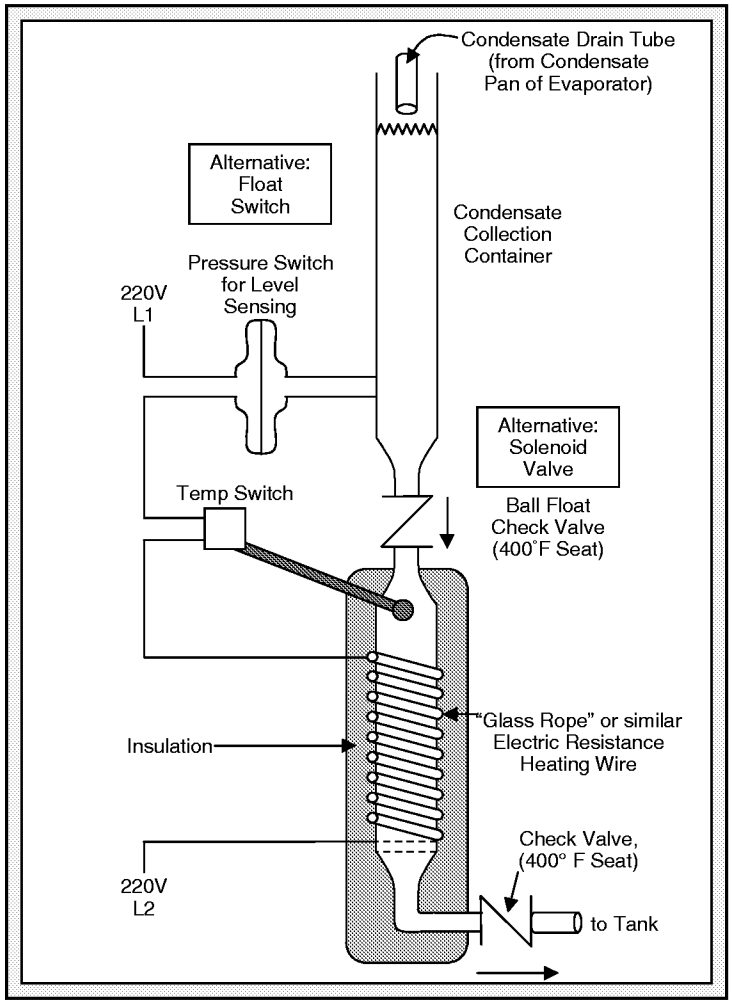
Control System

The other methods of disposal have undesirable qualities that are addressed with the CID.

Methods	Disadvantages	Condensate Injection Device
Drain	A condensate drain may require additional labor, materials, and modification of existing structures.	The CID is integral with the tank and does not require any additional plumbing.
Resistance Heating Desuperheater	In enclosed spaces, moisture is continually evaporated and then re-condensed on the coils.	Moisture is removed from the air and injected into the tank, no possibilities to recycle.
Resistance Heating Desuperheater	Does not provide additional benefit of dehumidification which is desired in some installations	Full dehumidification benefit is realized, moisture is removed from the air and injected into the tank
Resistance Heating Desuperheater	Energy is required to fully evaporate condensed moisture.	Only a small portion of the moisture is vaporized, requiring much less energy.
Desuperheater	Heat-pump capacity is reduced when evaporating condensate.	Energy used to vaporize moisture is captured and contributes to the heating capacity of the HPWH.
Control System	Control system limits operation of heat-pump to prevent condensate, thus increasing electric heating	The CID allows the formation of condensate to maximize the use of the HPWH

The condensate injection device (CID) shows promise as an improved technique for disposing of condensate from the Heat Pump Water Heater.

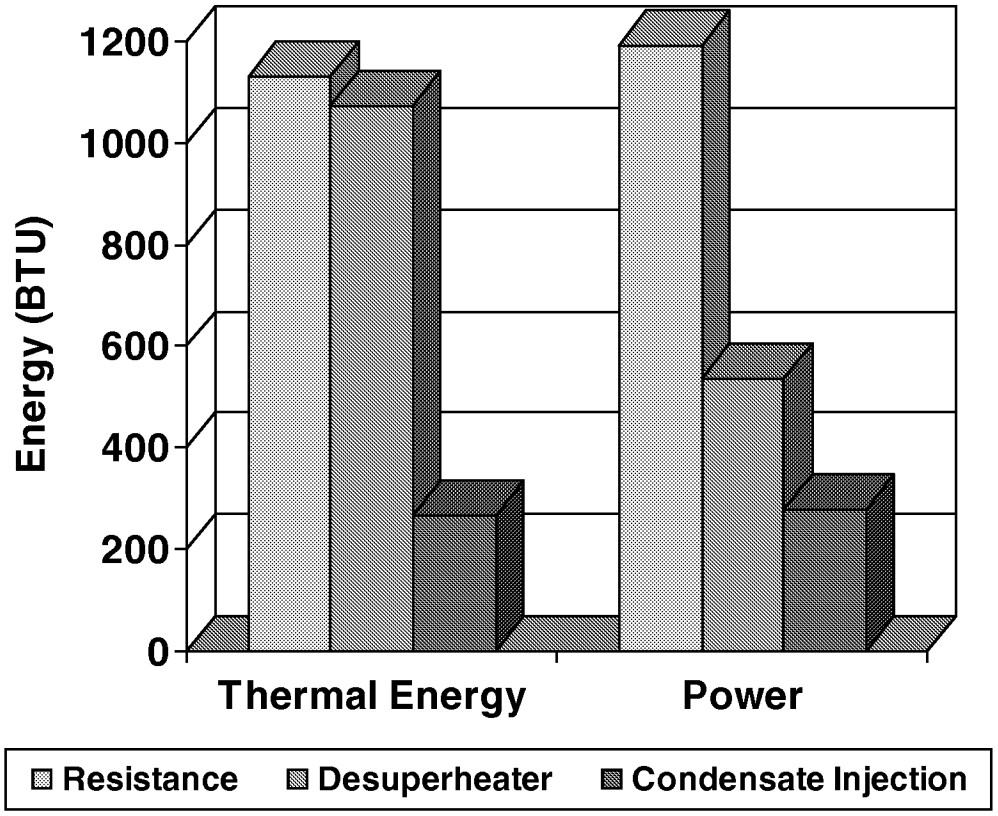
- No external plumbing or additional electrical connections are required.
- Integral with the HPWH, the spatial envelope of the water heater is maintained.
- Gain in condensate disposal efficiency contributes to the overall HPWH delivery efficiency relative to evaporative techniques.
- Elimination of condensate disposal issue increases market penetration of HPWH.



The estimated energy savings associated with the CID are large when compared to re-evaporation or de-superheater methods.

Benefits

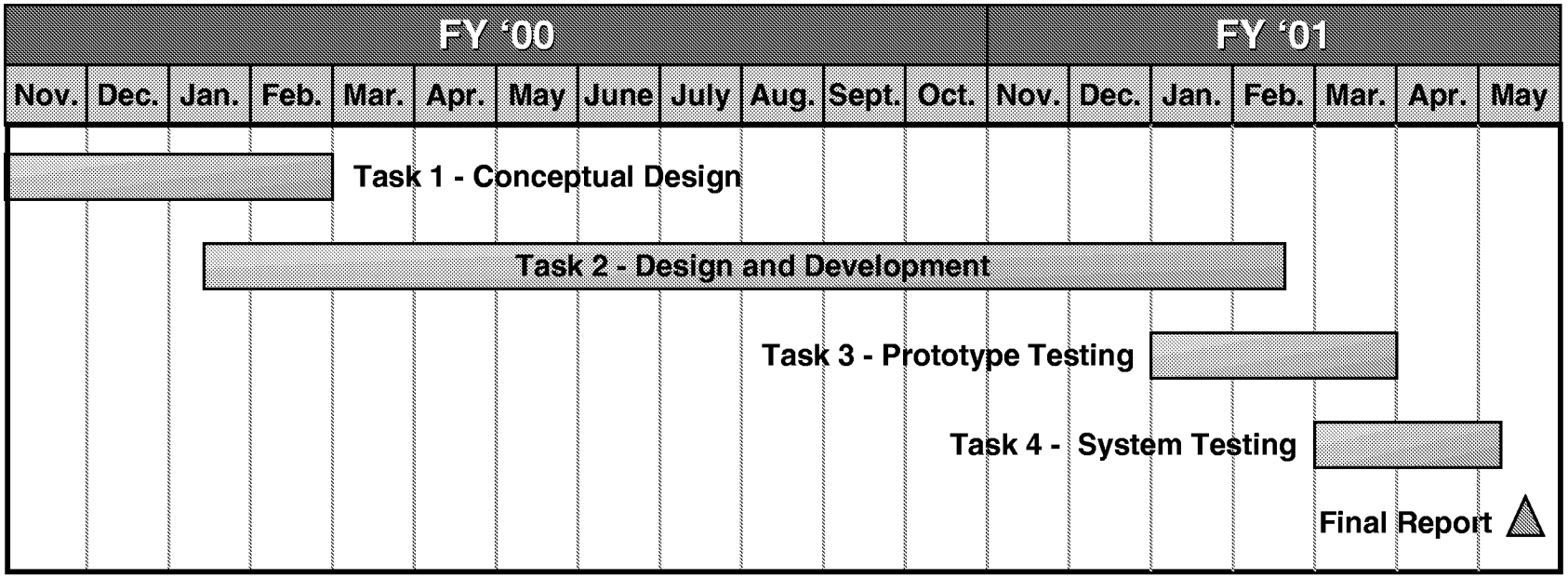
- 20% of the energy and power required by electric-resistance.
- Energy is captured by the water heater.
- Smaller impact on the ODE of the HPWH.
- Eliminates the moisture 'recycling' which occurs in an enclosed space.



The prototype development of the condensate disposal system was accomplished using the following tasks.

Task	Title	Description
1	Conceptual Design Evaluation and Trade-Off Study	• Identify regulatory approvals, • Define engineering requirements, • Performed trade-off studies of various design options
2	Design and Development	• Design of components, • Selection of vendor-supplied components, • Assembly and sub-assembly design.
3	Sub-System Prototype Fabrication and Testing	• Bench test the device, • Short-term durability testing, • Modify the CID if necessary
4	HPWH System Testing and Evaluation	• Integrate the CID into the HPWH, • Validate operation and performance, • Test and compare other condensate management systems.

A majority of the project time was spent in the design and development stage of the program.



Background / Description

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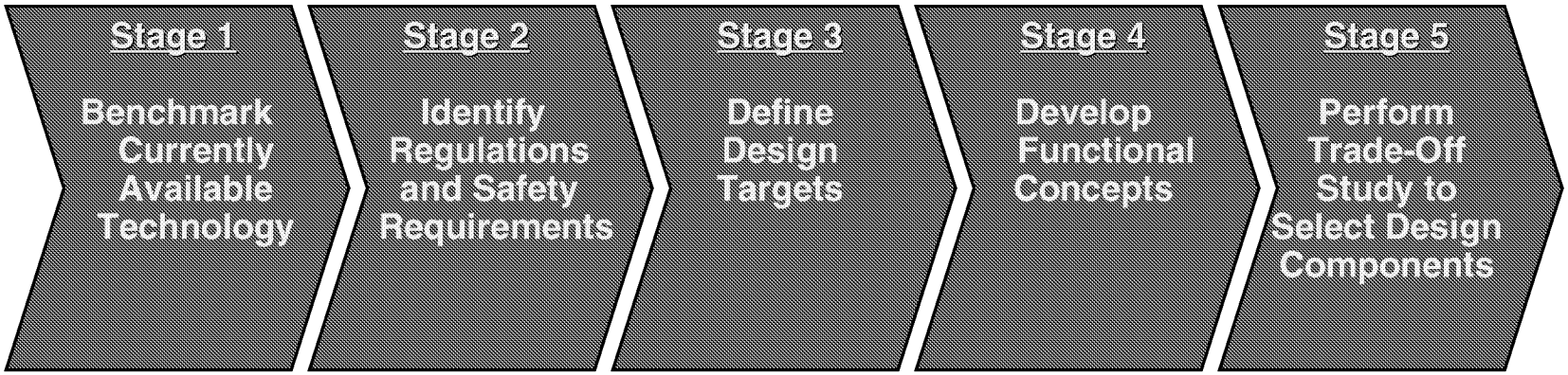
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Task 3 - Prototype Testing

Task 4 - System Testing

Summary

We completed the conceptual design in five stages.



Current technology exists that reclaims atmospheric water for consumption. However, the CID is unique in its application and approach.

- US 5,845,504. "Portable/Potable Water Recovery and Dispensing Apparatus"
  - Uses a refrigeration cycle to condense atmospheric water. Condensate is then treated in a bacteriostat with a carbon filter for purification.
- US 5,517,829. "Apparatus for Producing Filtered Drinking Water"
  - Uses a refrigeration cycle to condense atmospheric water. Condensate is then treated using chemical disinfectants and a filtration system.
- US 5,553,459. "Water Recovery Device for Reclaiming and Refiltering Atmospheric Water"
  - Uses a refrigeration cycle to condense atmospheric water. Condensate is then treated using filters and a photocatalytic coating on the evaporator coil.
- Many other patents exist on similar, refrigeration-based systems for purpose of generating potable water.

In the second stage, we identified four major regulatory bodies having requirements that may influence the design and application of the CID.

Regulatory Body	Regulatory Issues
US Environmental Protection Agency (EPA), State and Local Authorities	• Defines potability using Maximum Contaminant Levels (MCL's) for chemical and biological impurities in drinking water. • State and local bodies set standards in addition to EPA guidelines, if any.
Underwriter's Laboratories (UL), National Fire Protection Agency (NFPA)	• Tests the device to confirm that, regardless of the functional failure(s) a fire or other extreme hazard will not occur.
International Mechanical Code (IMC), State and Local Building Codes	• Ensures that proper methods are used for HVAC equipment condensate disposal.
International Plumbing Code (IPC), State and Local Plumbing Codes	• Defines methods, procedures, equipment necessary to ensure the the potable water supply is protected from contamination.

The EPA's National Primary Drinking Water Regulations (NPDWRs) are legally enforceable standards.

Type	Contaminant[1]	Limit (mg/L)	Potential Sources
Inorganic Chemicals (16 Total)	Antimony	0.006	electronics, solder
	Asbestos	7 million fibers/L	asbestos insulation or cement
	Cadmium	0.005	galvanized pipe, batteries, paint
	Copper	1.3	plumbing systems
	Lead	0.015	plumbing systems
Organic Chemicals (55 Total)	Benzo(a)pyrene	0.0002	water storage tanks
	Di(2-ethylhexyl)adipate	0.4	PVC plumbing systems
	Tetrachloroethylene	0.005	leaching from PVC pipes
	Vinyl Chloride	0.002	leaching from PVC pipes
Radionuclides (3 Total)	Beta particles and photon emitters	4 millirems / year	Naturally occurring, some man-made deposits
Micro-organisms (6 Total)	Legionella	99.9% killed/inactivated[2]	naturally occurring in water systems, multiplies in heating systems

[1]There are many contaminants, these selected few are related to the pluming system itself.
[2]Levels of Legionella are based on observed levels of *Giardia lamblia* that are found and killed or inactivated.

Secondary Standards are the EPA's non-enforceable guidelines. However, states may choose to adopt them as enforceable.

Secondary Contaminant	Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
pH	6.5 - 8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

UL certification is highly desirable, but not required, for household appliances.

- Two principal UL standards apply to the CID:
  - UL 499, *Standard for Safety for Electric Heating Appliances*, and
  - UL 834, *Standard for Safety of Heating, Water Supply, and Power Boilers-Electric*
- UL 499 serves as the primary standard of concern for the CID:
  - Electrically energized product that generates steam for other than space heating purposes, and
  - Has an electrical power rating of 15kW or less.
- Contacts at UL indicated they would likely use some of the tests described in UL 834 for compliance testing.
- Selecting UL certified components where possible will speed up the approval process for the CID.

The IMC only applies to equipment having a condensate drain, therefore it is not applicable to a HPWH using the CID.

307.2.1. Condensate disposal. Condensate from all cooling coils or evaporators shall be conveyed from the drain pan outlet to an approved place of disposal as follows:

1. Units larger than 6 tons nominal capacity shall discharge to a sanitary sewer drain, storm sewer drain, or a French drain constructed in accordance with Section 307.2.1.1. Where discharging to a sanitary sewer, such drains shall be indirectly connected in accordance with the plumbing code.
2. Units 6 tons and smaller nominal capacity shall discharge in accordance with Item 1, or shall discharge to a gutter, roof drain or other approved location.

- The focus of the code is to protect the equipment and building from harm, i.e.,
  - condensate draining onto a roof and puddling, or
  - sewer gases or sewage entering the equipment through a direct connection[1].

[1] International Mechanical Code Commentary

The IPC focuses on protecting potable water systems from contamination.

- We will need to show the CID, in combination with HPWH, does not contaminate the potable water supply.
  - **602.2 Potable water required.** Only potable water shall be supplied to plumbing fixtures that provide water for drinking, bathing or culinary purposes....Unless otherwise provided in this code, only potable water shall be supplied to all plumbing fixtures.
  - **608.3 Devices, appurtenances and apparatus**. All devices, appurtenances, appliances and apparatus intended to serve some special function, such as sterilization, distillation, processing, cooling, or storage of ice or foods, and that connect to the water supply system, shall be provided with protection against backflow and contamination of the water supply system. Water pumps, filters, softeners, tanks and all other appliances and devices that handle or treat potable water shall be protected against contamination.

We also reviewed other codes, but found they were not necessarily relevant to the design of the CID.

- American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section VIII, Division I, does not apply to vessels with an inside diameter less than six inches.
- National Fire Protection Agency (NFPA) 70, also known as the National Electric Code (NEC).
  - Required for the device to meet national building codes
  - Already required under the UL standards
- National Sanitation Foundation sets water standards that are more stringent than the EPA.
  - Primarily utilized for bottled water marketed as “healthful”
  - Completely voluntary certification
  - ANSI/NSF 61-1999, Drinking Water System Components, defines allowable materials for potable water, already covered under the IPC

Based on initial discussions with regulators, further development work and testing is needed to determine compliance with existing regulations.

- It was difficult for most people to determine whether the device complied with the existing regulations based on a concept description.
- There was consensus that if the CID could be shown to produce potable water its chances for acceptance would be high.
  - Contacts within the IPC and sanitation agencies were in agreement with this assessment.
- It is unclear whether the CID will be evaluated as a separate component or as part of a water-heating system.

With further development and testing we will approach the IPC and IMC for their assessment of the CID's compliance with the regulations.

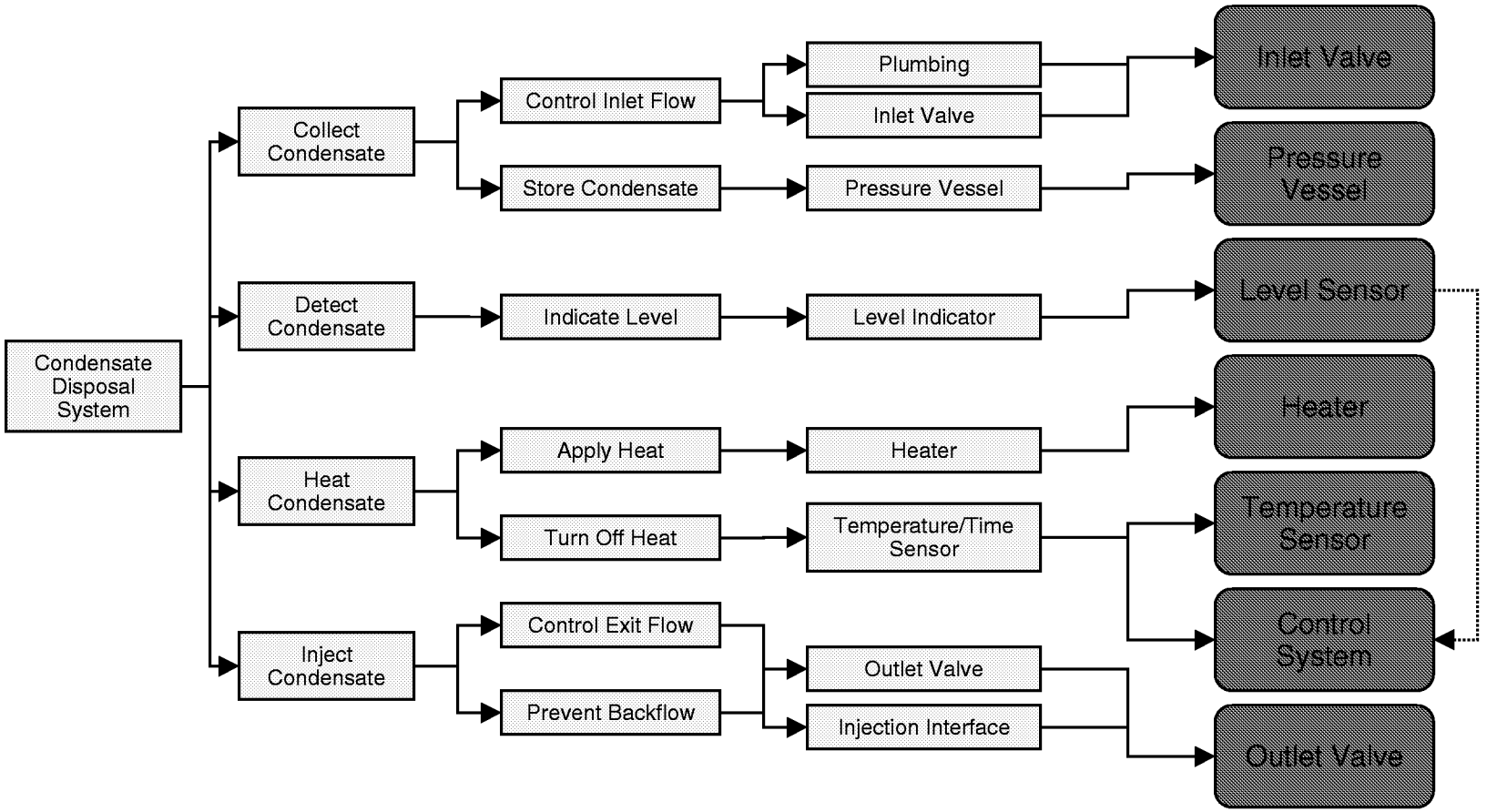
If the CID is considered non-compliant with respect to current IPC and IMC codes, there are at least two methods for obtaining compliance.

- Obtain an "approved device" status for the CID/HPWH through certified testing by an independent, third party laboratory
  - This may involve significant investment of time and money
  - Allowance is valid for several years, after which another validation test is required
- Seek to change the building code to accommodate the CID
  - This is regularly done when new technologies are developed
  - Involves thorough analysis and testing of the CID
- Seeking an "approved device" status will facilitate changing the applicable building codes.

In the third stage, we established design targets for the CID based on our knowledge and previous experience with the HPWH.

Metric	Design Target	Reasoning
Unit Cost	**$10.00 including parts, assembly and integration.**	The CID must not appreciably add to the overall cost of the heat pump water heater.
Condensate Throughput Rate	**8 oz./hr continuous**	Testing indicates this is the maximum likely condensate production rate for a 3600 Btuh HPWH.
Operating Pressure	**0-120 psi**	The CID must be capable of operating within the extremes of municipal water supply variations.
Product Lifetime	**15 years**	It is desirable to ensure the CID will exceed the life expectancy of the HPWH itself.
Operating Power	**10 amps at 240V**	Based on the power available to a standard electric water heater, accounting for the potential power requirements of the HPWH.
Regulatory Approvals	**UL, IMC, IPC**	This is based the required approvals for the device to be sold to consumers in the US.
Cycle Time above 212°F	**1 minute minimum**	This is the recommendation of the EPA for the sterilization treatment of water
Spatial Envelope	**Maximum 2.5" deep, 6" wide and 24" tall**	It is desired embed the CID within the HPWH's exterior jacket to minimize the impact the spatial envelope of the HPWH.
Maximum Temperature	**500°F**	The CID must not present a fire hazard given the insulating materials of the HPWH.

We developed a function-structure diagram for the fourth stage resulting in seven manageable sub-systems.



Using the function-structure diagram as our basis, we generated concepts using a methodology proven at ADL on numerous projects.

- A briefing package was created and distributed to all participants.
- Several sessions were held consisting of participants with relevant backgrounds;
  - mechanical design
  - materials science
  - regulatory/sanitary engineering
  - refrigeration and thermal sciences
- Potential technical challenges were discussed.
- Specific concepts were documented, discussed and evaluated.
- Concepts were ranked against the specifications to identify the best prospects for further consideration.

Finally, in the fifth stage, we completed a trade-off study to decide which concepts would make the most sense in the preliminary design of the CID.

- After review of all the concepts generated in the sessions, we downselected those concepts we felt had the most potential for the CID.
- We then performed a trade-off study on those concepts with the most potential.
- We identified the pros and cons associated with each concept.
- We estimated the manufactured cost based on available data for the production of 1000 units / year.
- We selected the concepts based on our judgement of the pros and cons and associated cost.

For the inlet valve, a check valve seemed to offer the least expensive design that would consistently work (as compared to the gravity seal).

Option	Pros	Cons	Cost
Check With Spring Support	• Positive Closure, • Should Function on Partially Full Vessel	• Mechanical system	$0.35
Gravity Seal (in bottom of CID)	• Lowest Cost, • Works on Partially Full Vessel	• Potential Filling Problems	$0.15
Bimetal or Nitenol Actuated Valve	• Definite Closure with Temperature Increase, • Works on a Partially Full Vessel	• Limited actuation	$0.75
Float Valve	• Positive Closure • Simple system	• Functions on a Full Vessel only	$1
Wax Motor or Solenoid Valve	• Complete Control of the Closing Process	• Complex mechanical system	$2.50

For the prototype development, a brass vessel was chosen because it is easy to machine and provides good corrosion resistance.

Option	Pros	Cons	Cost
Brass	• Low Cost, • Excellent machinability • Good Corrosion Resistance	• Higher Cost Than Aluminum	$2.50
Stainless Steel	• Excellent Corrosion Resistance and Chemical Inertness	• Expensive, • Difficult to Machine	$4
Copper	• Good Corrosion Resistance, • Excellent Thermal Properties	• Difficult to machine for prototype purposes	$1.50
Aluminum	• Excellent Thermal Properties, • Lowest Cost • Good Machinability	• Poor Corrosion Resistance (unless treated)	$1
High Temperature Polymer	• Excellent Corrosion Resistance	• High Temperature Requirements Make This Cost Prohibitive	$8

A capacitive level sensor avoids potential problems associated with mechanical parts and may be less costly when assembled.

Option	Pros	Cons	Cost
Capacitive	• Solid State Reliability, • No moving parts, • Easy Integration • Reduces water "pooling"[1]	• More costly, • Requires control system	$2
Float type with optical switch	• Very Low Cost, • Solid State Reliability	• Fabrication/Assembly • Moving Parts	$1
Float type with mechanical switch	• Low Cost	• Mechanical Contacts, • Fabrication/Assembly • Moving Parts	$2-$3
Differential Pressure Transducer	• Solid State Reliability, • No moving parts	• Costly, • Requires Plumbing, • Subject to Clogging	$4
Pressure Switch	• No Apparent Advantages	• Cost Prohibitive, • Inaccurate At Low Pressures	$5-$6

[1]Stagnant water in the bottom of the evaporator pan may be a source for bacteria and/or mold growth

A rope heater provides a cost-effective method of heating the CID vessel.

Option	Pros	Cons	Cost
Rope Heater	• Inexpensive, • Adhesive foil backed for easier integration. • UL, CSA compliance	• Low HTX effectiveness, • Integration Issues	$4
Resistance Wire	• Low Cost	• Integration Issues, • Fabrication/Assembly	$2
Band/Strip Type	• Improved HTX effectiveness over rope heater, • Easy Integration	• More costly, • Low contact area	$9
Flexible Heater (Silicone)	• Easy installation, • Integration with thermal sensors, • UL, CSA approved	• Costly	$10 - $15
Immersion	• Highly effective • Easy Integration • UL, CSA, VDE	• Cost Prohibitive, • Not recommended for dry systems.	$10 - $25

A bi-metal switch is a reliable and cost-effective temperature sensor. In addition, it serves as a mechanical shut-off device for the CID.

Option	Pros	Cons	Cost
External Thermal Switch	• Inexpensive, • Easy Integration	• Temperature Limited to 170º C Maximum • Thermal Response Lag	$1.75
Current Sense Resistor	• Lowest Cost, • No Additional Components Needed	• Requires Definite R/T Characteristics, • Subject To Drift	$0.50
External Thermistor	• Solid State Reliability, • Easy Integration	• More costly, • Temperature Limited to 150º C Maximum	$3
Immersed Thermal Probe	• Direct Measurement of Vessel Contents	• Cost Prohibitive	$8
Differential Pressure Transducer	• Direct Interpolation of Water Temperature and Tank Pressure	• Cost Prohibitive	$10

The simplest control system algorithm activates the CID only when it is full.

Option	Pros	Cons	Cost
Automatic, Event Triggered	• Minimal Energy Consumption, • CID only operates after completely full • Lowest Cost	• Condensate subject to stagnation	$1
Combination of Automatic and Pre-Set	• Offers the most design flexibility in minimizing energy waste and preventing stagnation	• CID needs to operate with a partially full vessel.	$1
Operation at Pre-Set [Timed] Intervals	• prevents stagnation	• CID needs to operate with a partially full vessel. • Potential energy waste • More complex control	$1

A single, spring-backed check valve meets the design requirements for the outlet valve at the lowest cost.

Option	Pros	Cons	Cost
Single Check With Spring Support	• Lowest Cost, • Integrated Pressure Relief	• No Fail-Proof Redundancy	$0.25
Double Check With Spring Support	• Low Cost, • Redundancy • Integrated Relief Valve	• Added Cost in Respect to Single Check Valve	$0.75
Actuated Valve	• Definite Closure	• Cost Prohibitive • Requires Pressure Relief Valve • Actuator Subject to Breakage	$2
Integrated 3-Way Valve	• Positive Closure, • Integrates both inlet and outlet valves into one unit	• Costly • Integration and Design Issues	$2.50

Based on the selected components, our initial manufactured cost estimate for 1000 units / year totals $14.85.

Component	Cost
Vessel / Hardware	$4.50
Rope Heater	$4.00
Capacitive Level Sensor	$2.00
External Thermal Switch	$1.75
Inlet / Outlet Spring Valves	$0.60
Micro-processor	$1.00
Assembly / Labor	$1.00
TOTAL	$14.85

This cost exceeded our initial design target of $10, but we may have been over-optimistic. A $15 cost target may represent a more realistic design target.

Background / Description

Task 1 - Conceptual Design

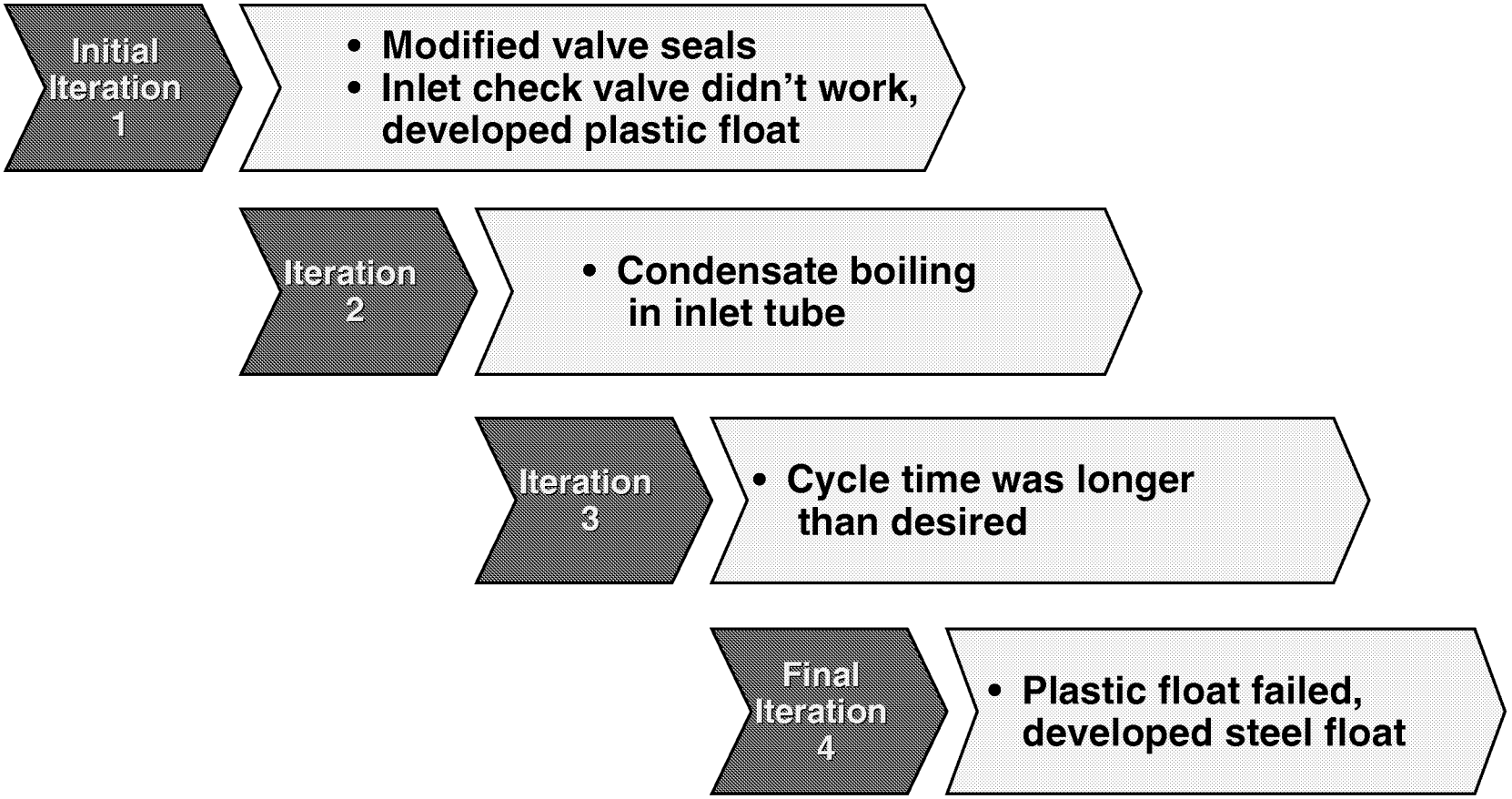
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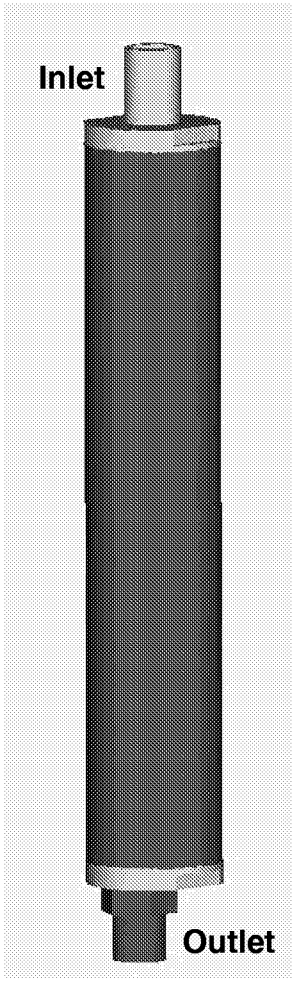
Task 4 - System Testing

Summary

We performed a number of design iterations in the development of the final CID prototype.



We designed and developed an initial prototype of the CID based on the concepts selected in the trade-off study.



- Vessel is a single, brass pipe 7.2” long and 1” OD, sized to . dispose condensate at a rate of 0.5 lb / hour (assuming a 15 minute cycle).
- The inlet check valve was designed to be neutrally buoyant through the use of a properly sized spring. The weight of water above the CID opens the valve. When the CID is full, the valve closes.
- The top and bottom caps are brass. The caps thread into the interior of the brass vessel.
- A 300 watt rope heater is tightly wrapped around the exterior of the vessel and secured at each end.
- A bi-metallic thermostat is attached to the bottom of the vessel (near the outlet).

After initial bench-top testing, we identified several design issues.

- The teflon seats used in the inlet and outlet valves were too hard to enable reliable sealing.
  - High temperature EPDM o-rings were substituted to improve sealing to temperatures of 400° F (internal).
- The neutrally buoyant inlet check valve proved inadequate because it did not facilitate the escape of air trapped inside the vessel. Thus condensate was not able to enter the vessel.
  - A large inlet orifice was incorporated to facilitate the simultaneous influx of water and exhaust of trapped air.
  - The float was fabricated of Ultem 2300 (30% GF PEI) for low bulk density, high temperature resistance and ease of fabrication.

Upon further testing, we discovered that the condensate collected in the inlet tube would begin boiling.

- We determined that the undesirable boiling was caused by heat transfer through the metal cap.
  - Heat transfer through the float was also possible but unlikely due to the thermal resistance of the plastic.
  - A leak in the float valve seal could create the appearance of boiling in the inlet tube.
- Replacing the brass inlet cap with a plastic inlet cap greatly reduced the heat transfer from the vessel to the inlet tube.
- Ultem 2300 was used to construct the cap. This was later switched to Ryton (60% GF PPS) for improved temperature and steam resistance.

This eliminated the boiling of the incoming liquid and significantly reduced the time required to complete condensate injection.

After subsequent testing, we were still not satisfied with the amount of time that was required to heat the vessel.

- A thermally conductive adhesive was used to attach the rope heater to the vessel.
  - The adhesive contains aluminum oxide and has good thermal conductivity properties while maintaining electrical insulation.
  - The adhesive decreased the contact resistance between the vessel wall and the rope heater.
- The vessel wall was reduced in thickness, reducing the thermal mass (inertia) of the system, thus decreasing the time required to cool the CID.
- Insulation was also applied, but significantly increased the process time due to a much slower cooling of the CID after injection so it was abandoned.
- The total average process time is approximately 10 minutes start to finish. Much of this time was the cool down period (in an ambient environment).

During our preliminary lifecycle tests, the Ultem float design proved inadequate for extended periods of use.

- A number of plastic floats were fabricated and tested to make certain the failure was not a single occurrence. They all eventually failed.
- Failure was occurring at the solvent bonded joint of the float.
- Solvent bonding is regarded as the superior thermoplastic bonding means. It is unlikely other bonding methods would prove more successful.

An evaluation of alternative float designs led to a drawn stainless-steel float.

- We evaluated other alternate materials.
  - Did not find identify any materials from which a solid geometry would float.
  - Some porous ceramics may hold possibility, but would require significant development effort and added CID cost.
- We investigated stock, spherical floats (off-the shelf)
  - All were much larger than the inside diameter of the CID.
  - If incorporated, they would prevent the CID from being embedded in the jacket of the HPWH.
- A two-piece stainless steel float looked attractive.
  - The lower portion of the float is fabricated through a deep draw process.
  - In production, the upper portion could be stamped.
  - The two components are oven-brazed or soldered together.

The current prototype of the CID includes the drawn metal float.

- The inlet o-ring was relocated from the vessel inlet to reside on the float to simplify manufacture and to improve the capture of the o-ring
- The float design offers significant potential for cost reduction when designed for manufacture.

Manufactured costs are difficult to estimate since the design has been finalized. Rough estimates suggest the manufactured cost of the CID is about $14.00 for 1000 units / year.

Component	Cost
Vessel, Float, and Misc. Hardware	$5.00
Rope Heater	$2.30
Capacitive Level Sensor	$2.50
External Thermal Switch	$1.40
Inlet / Outlet Caps and Valves	$1.55
Micro-processor[1]	--
Assembly / Labor	$1.00
TOTAL	$13.75

[1]The current HPWH has a micro-processor

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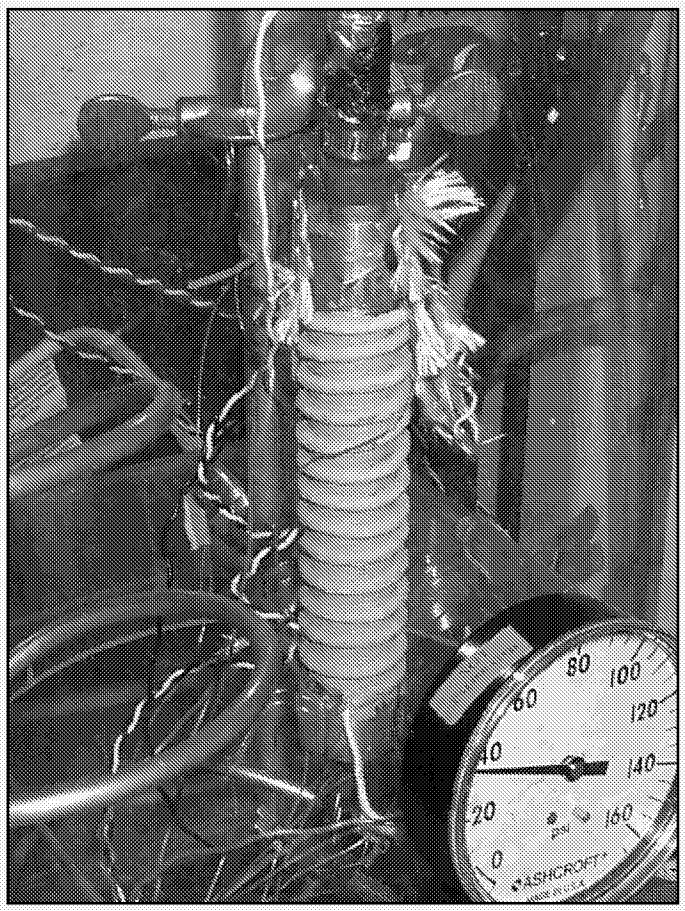
Summary

Using the fabricated final prototype, we designed and performed a bench-top durability test.

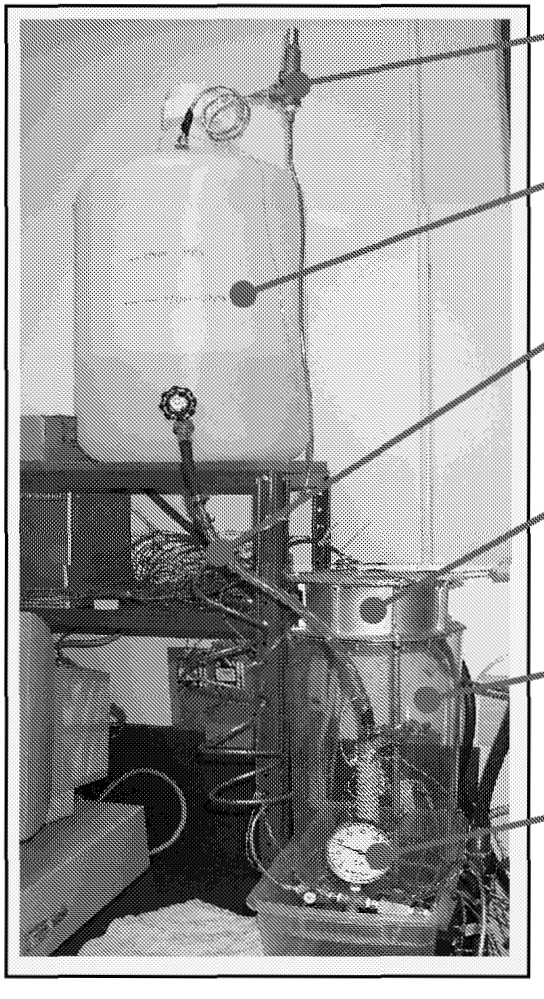
Durability Test

- Heating and cooling occurred in ambient air
- Used forced cooling with ambient air to increase he number of completed cycles
- Completed roughly 5000 cycles (equivalent to 5 years of use with about 3 cycles per day)

Bench-Top - Ambient Air-Cooled



The bench-top test apparatus was designed to cycle the CID as rapidly as possible.



- A pressure-regulating valve provided a constant back-pressure for the CID.
- A 10-gallon tank provided a constant source of spring water to the CID.
- Water drained from the supply tank to the inlet of the CID through a 3/8” plastic tube.
- A 300 cfm fan blew air directly over the CID after each cycle (controlled using a power relay) to accelerate cooling.
- A Lexan cylinder housed the CID and directed the cooling air flow.
- A bladder tank (not shown) maintained a minimum back pressure of 40 psig on the system.

Thermocouples were placed on the CID at critical points.

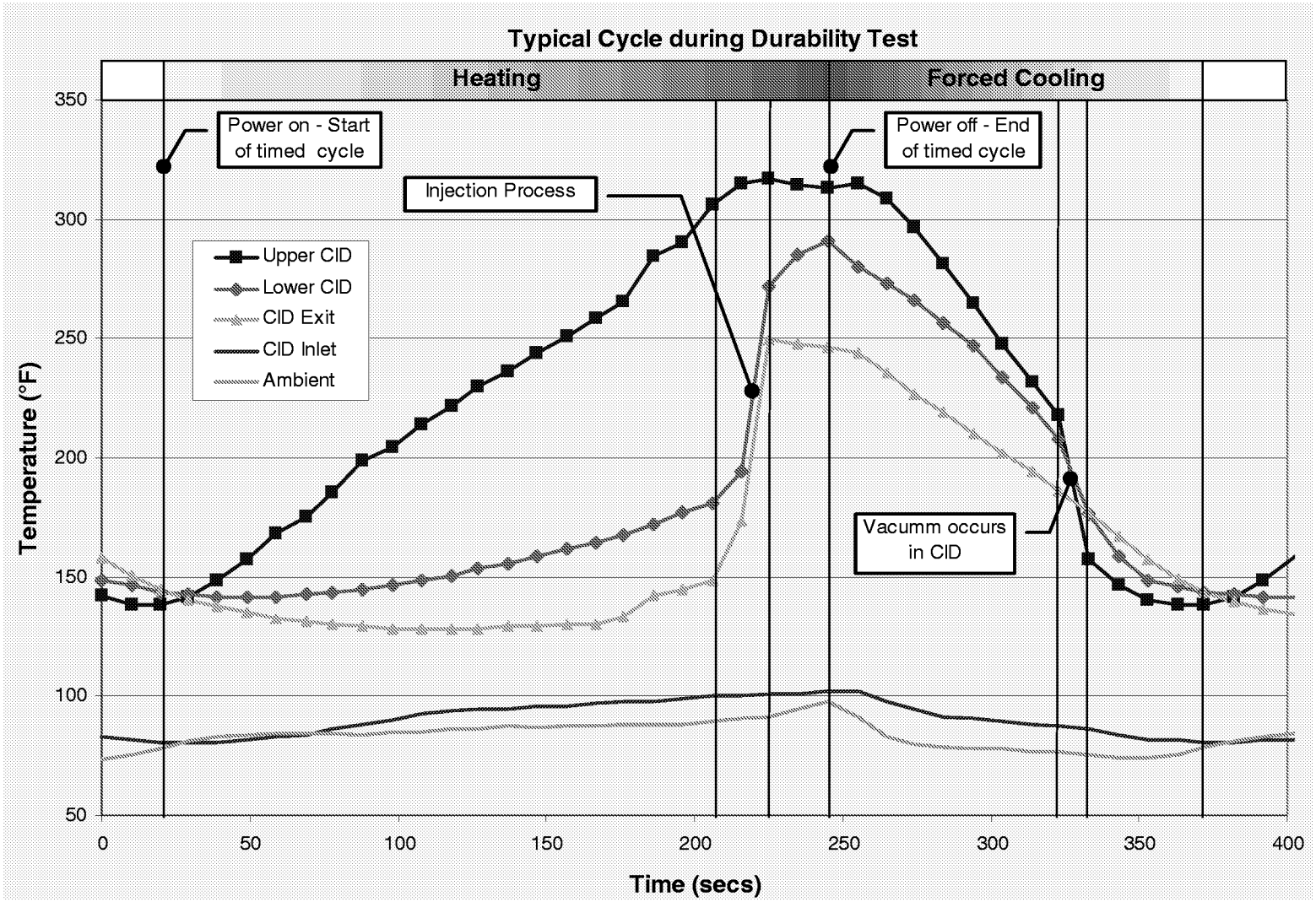
- Ambient air temperature
- Inlet to the CID (the temperatures should not cause boiling)
- Upper portion of the CID vessel (prevent thermal damage to the plastic cap
- Lower portion of the CID (location of thermal-cut out switch)
- Exit of the CID (should be saturation temperature based on system pressure)

Although not entirely continuous, the bench-top CID completed over 5000 cycles over a 21-day period.

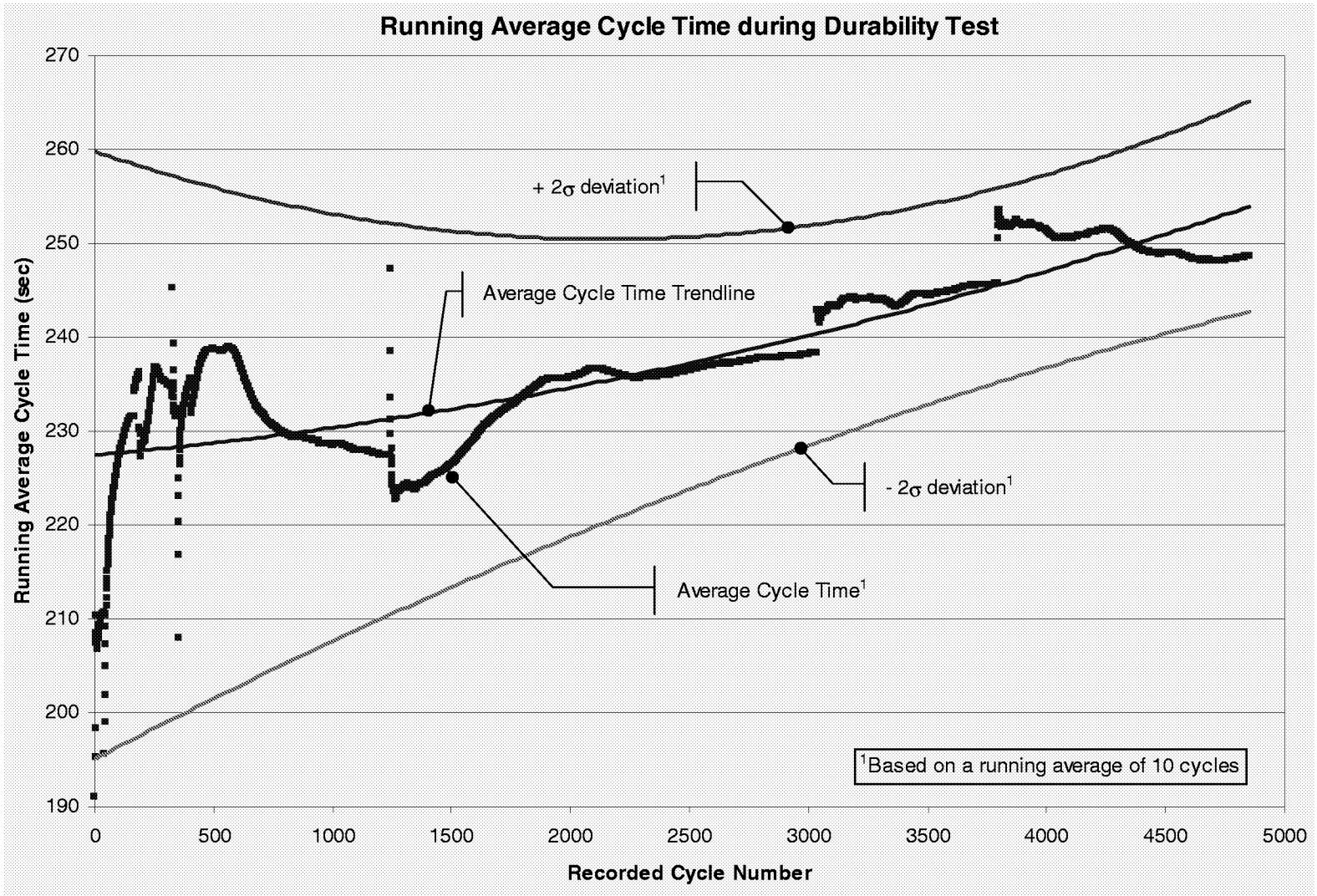
Cum. Cycles	Start Date	End Date	Comments
7	2/5/01	2/5/01	Exceeded 2σ during last cycle.
42	2/5/01	2/5/01	PRV was adjusted, system lost pressure, and CID overheated.
174	2/6/01	2/7/01	Exceeded 2σ during cycle (software stopped), CID continued to operate.
278	2/7/01	2/7/01	Estimated from time elapsed and prior mean cycle time.
305	2/7/01	2/8/01	Shut down to adjust software.[1]
442	2/7/01	2/10/01	Software stopped after three alarms, however, CID continued to operate.
512	2/10/01	2/10/01	Estimated from time elapsed and prior mean cycle time.
536	2/10/01	2/10/01	Shut down to adjust software. [2]
3982	2/10/01	2/22/01	Three successive alarms occurred. CID shut-down.
5044	2/22/01	2/26/01	Boiling observed in inlet tube. Test halted.

[1] Prior to the adjustment, the software was programmed to shut down the CID if the cycle time exceeded 2σ from the total mean cycle time. We decided this was excessive and therefore changed the logic to limit the CID to three successive alarms. An alarm occurred when the CID exceeded 2σ (based on a running average of 10 cycles).
[2] Determined that software bug prevented the CID from shutting down after three alarms had occurred.

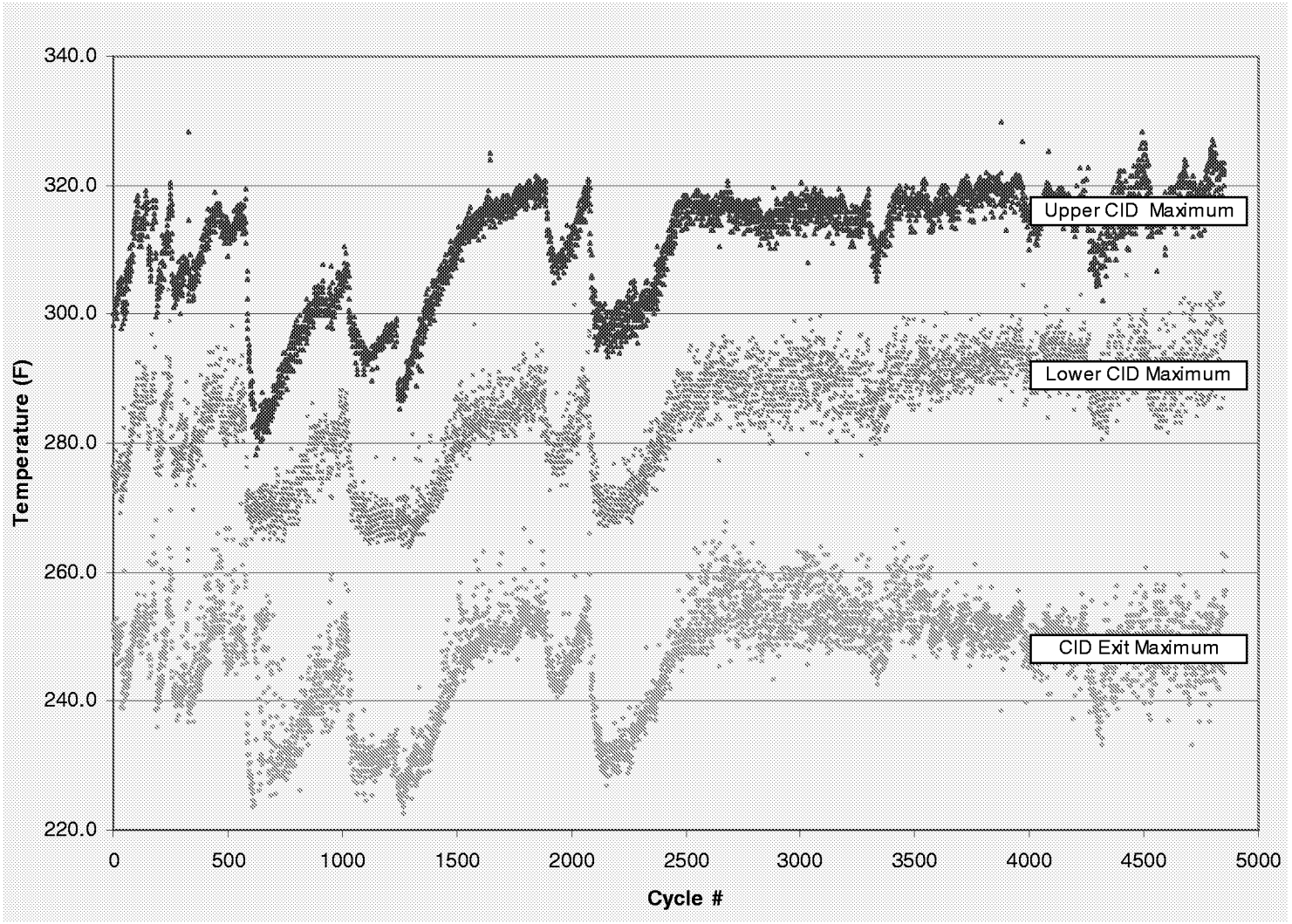
The typical heating time of the bench-top CID was about 240 seconds.



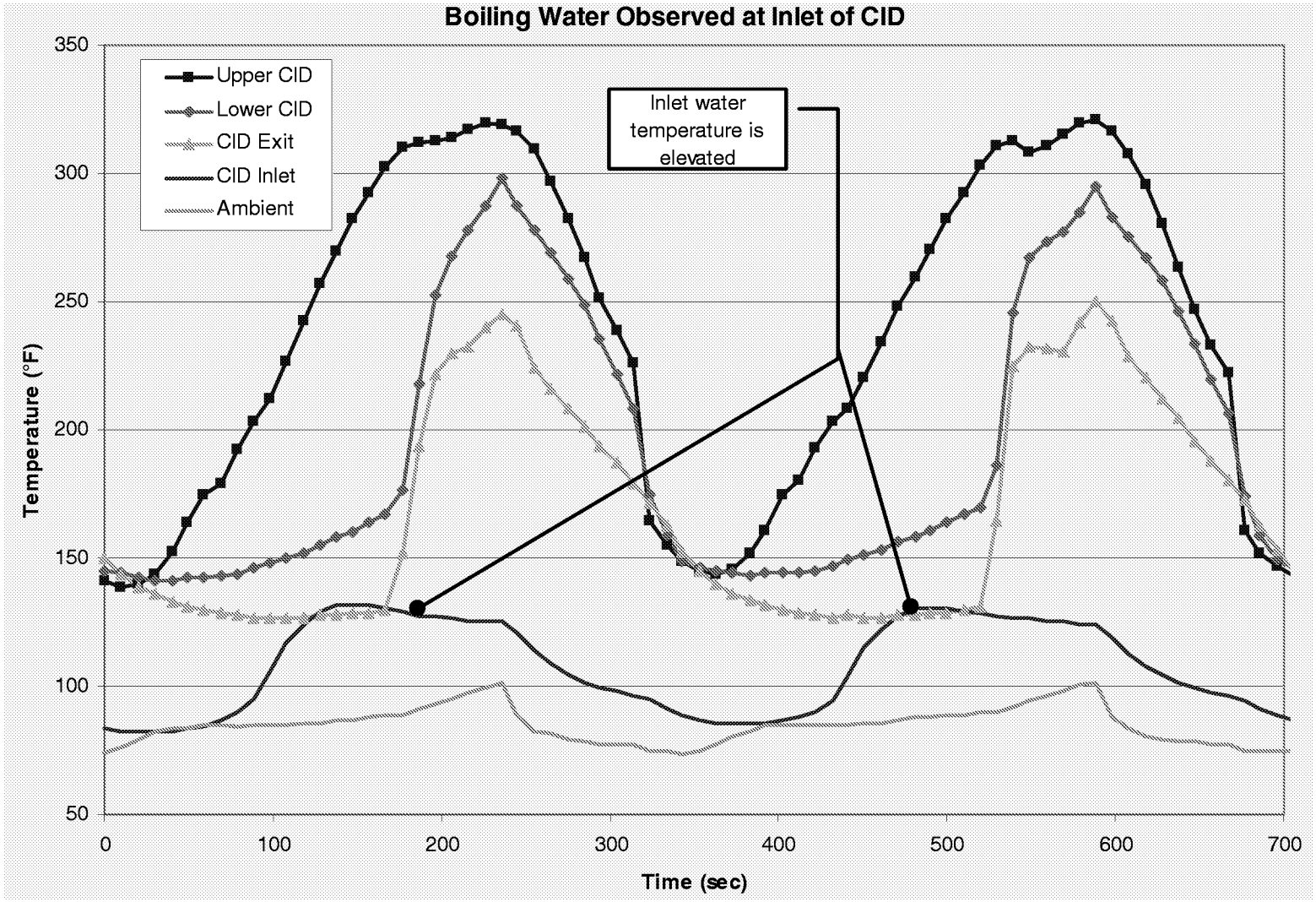
Over the entire test, the cycle time increased by 20 seconds, from around 230 seconds to about 250 seconds.



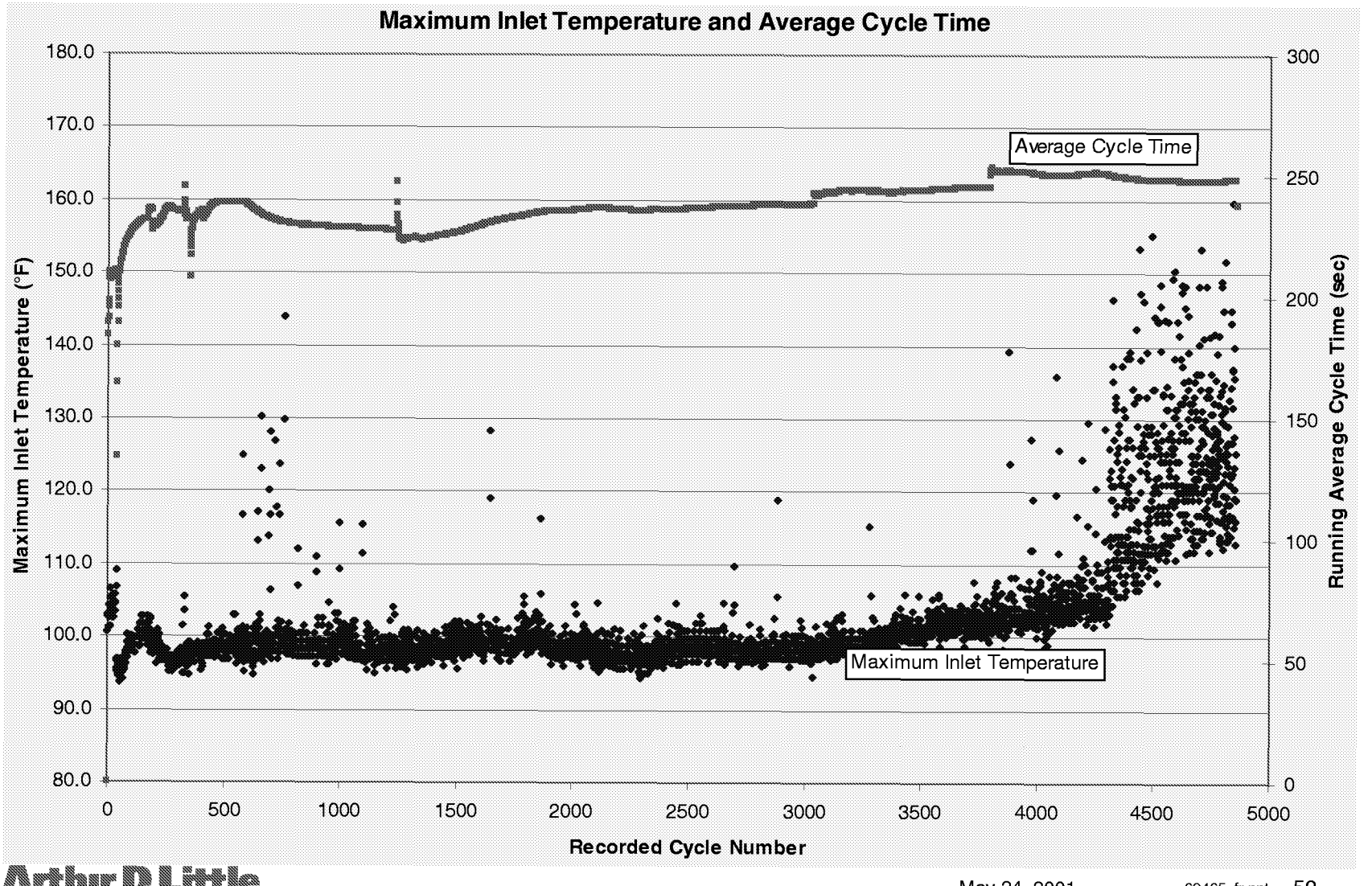
All of the temperatures remained within desired operating limits. The maximum temperature near the plastic cap never exceeded 340°F (170°C).



Near the end of the durability test, we observed water boiling out of the top of the CID prior to each cycle.

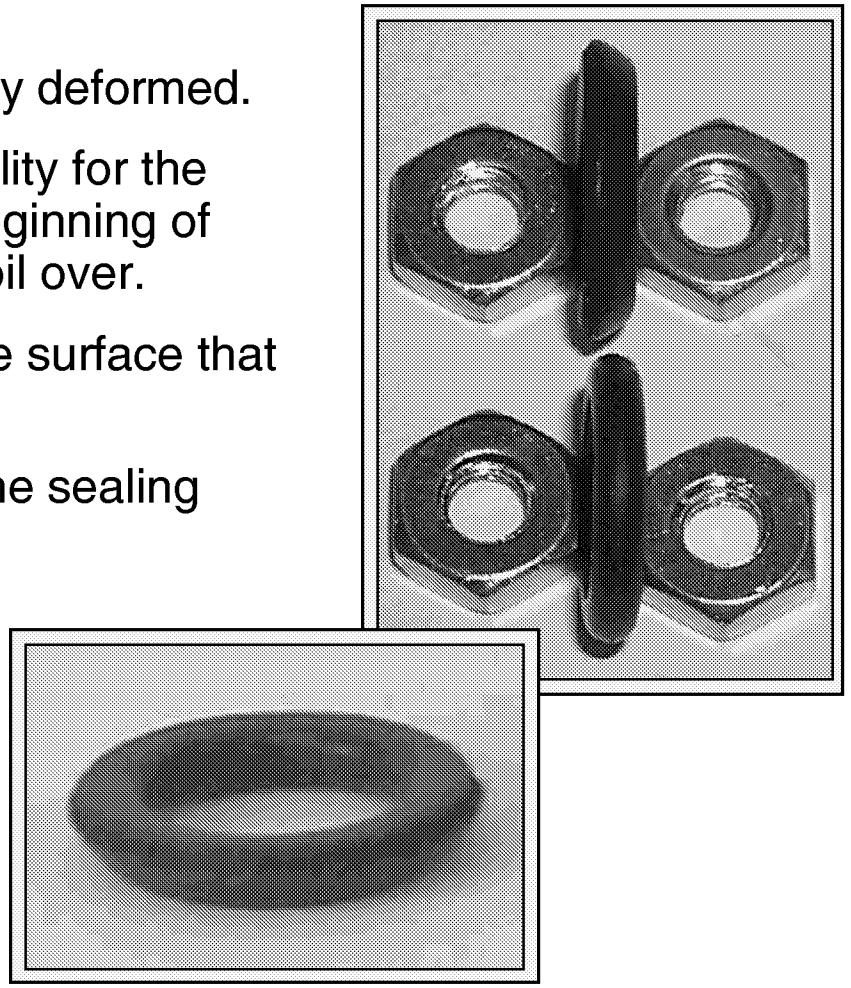


The boiling over of the CID raised the inlet temperature, but did not noticeably effect the cycle time of the CID.



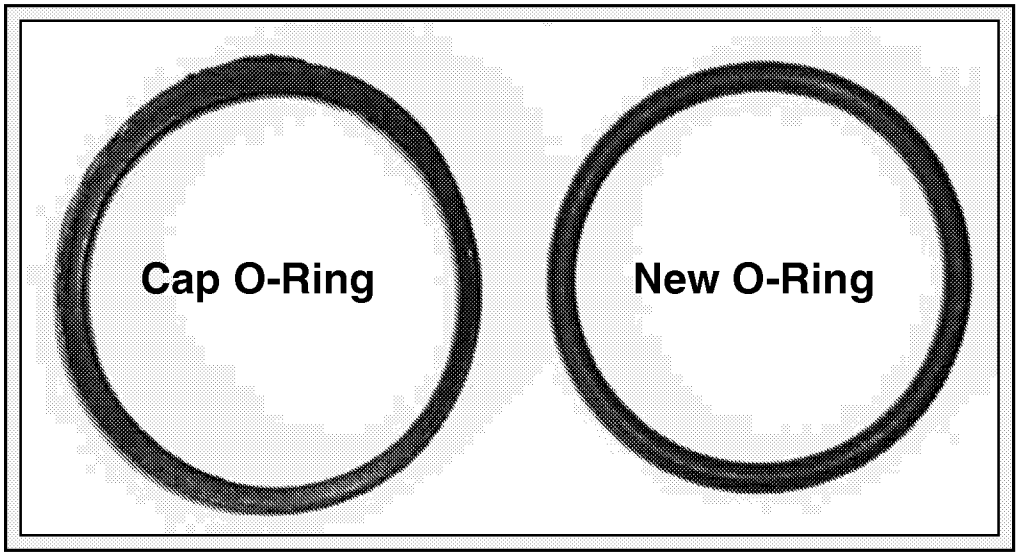
Upon disassembly, the o-ring on the float showed signs of damage.

- The o-ring on the float was permanently deformed.
- It's shape may have decreased the ability for the CID to provide a positive seal at the beginning of each cycle, thus allowing the CID to boil over.
- The o-ring shows signs of pitting on the surface that was exposed to the water vapor.
- We suspect the pitting contributed to the sealing problem.



The o-ring around the top of the plastic cap also showed signs of failure.

- The o-ring around the plastic cap was permanently deformed.
- It is presumed this was caused by a combination of:
  - the high temperatures of the metal near the top of the cap, and
  - the compression force of the threaded cap and vessel interface.



Background / Description

Task 1 - Conceptual Design

Task 2 - Design and Development

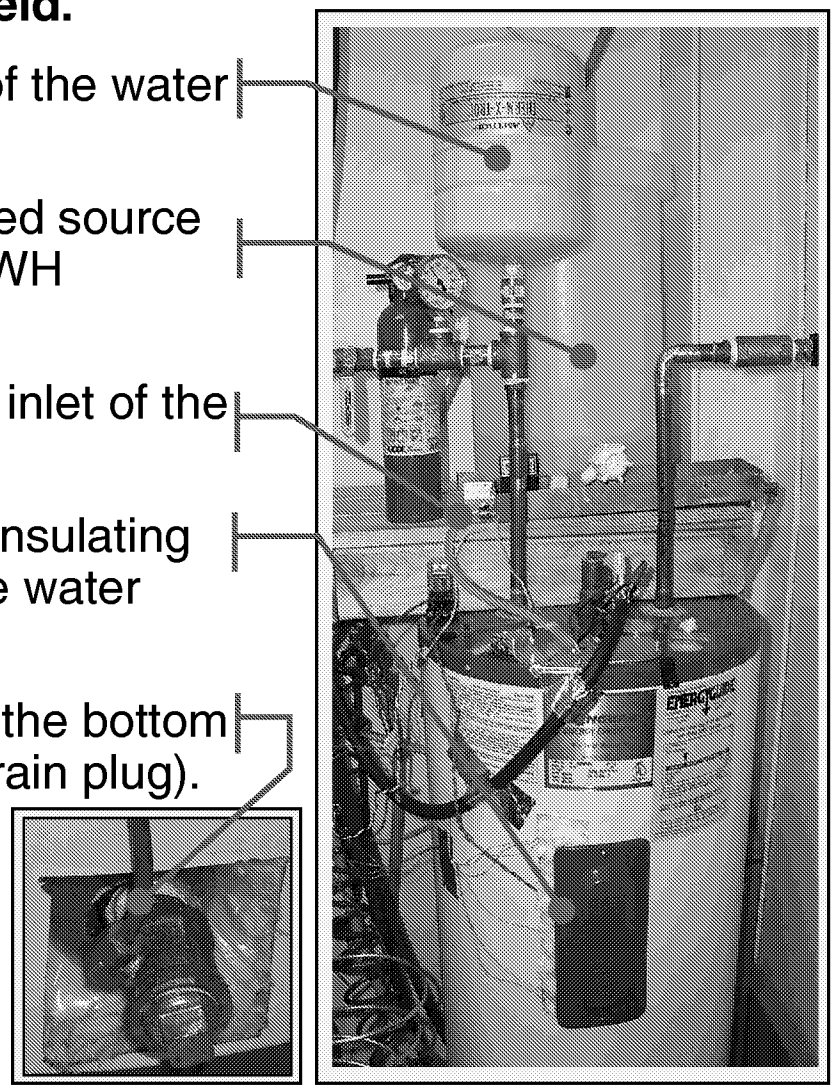
Task 3 - Prototype Testing

Task 4 - System Testing

Summary

The integrated water heater test was designed to cycle the CID at a rate similar to what we expect in the field.

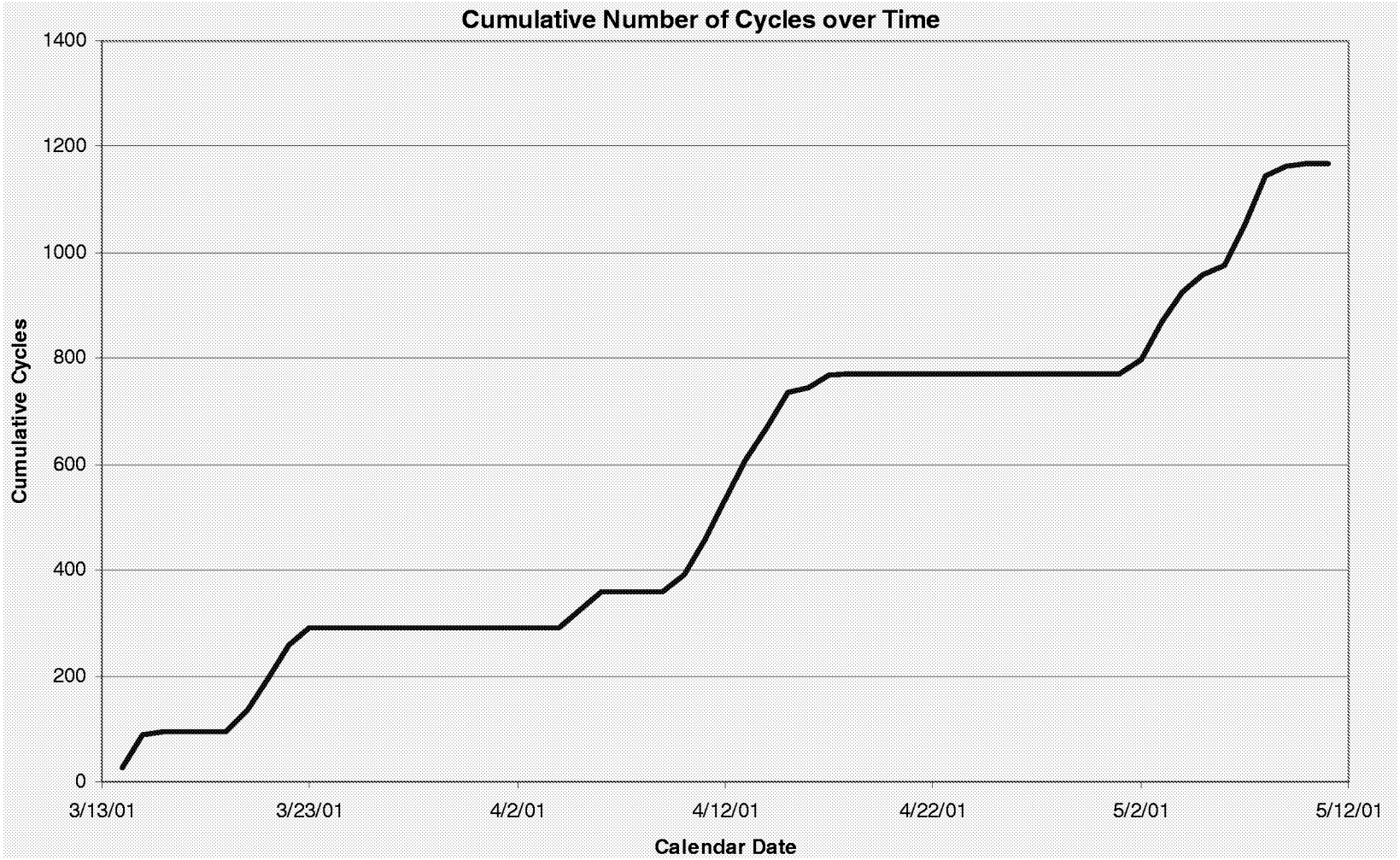
- A bladder tank allows expansion of the water (an incompressible fluid).
- A 5-gallon tank provides a regulated source of spring water to a simulated HPWH evaporator pan.
- Water drained from the pan to the inlet of the CID through a 3/8” plastic tube.
- The CID was enclosed within the insulating jacket of a conventional resistance water heater.
- The condensate was injected into the bottom of the water heater (through the drain plug).



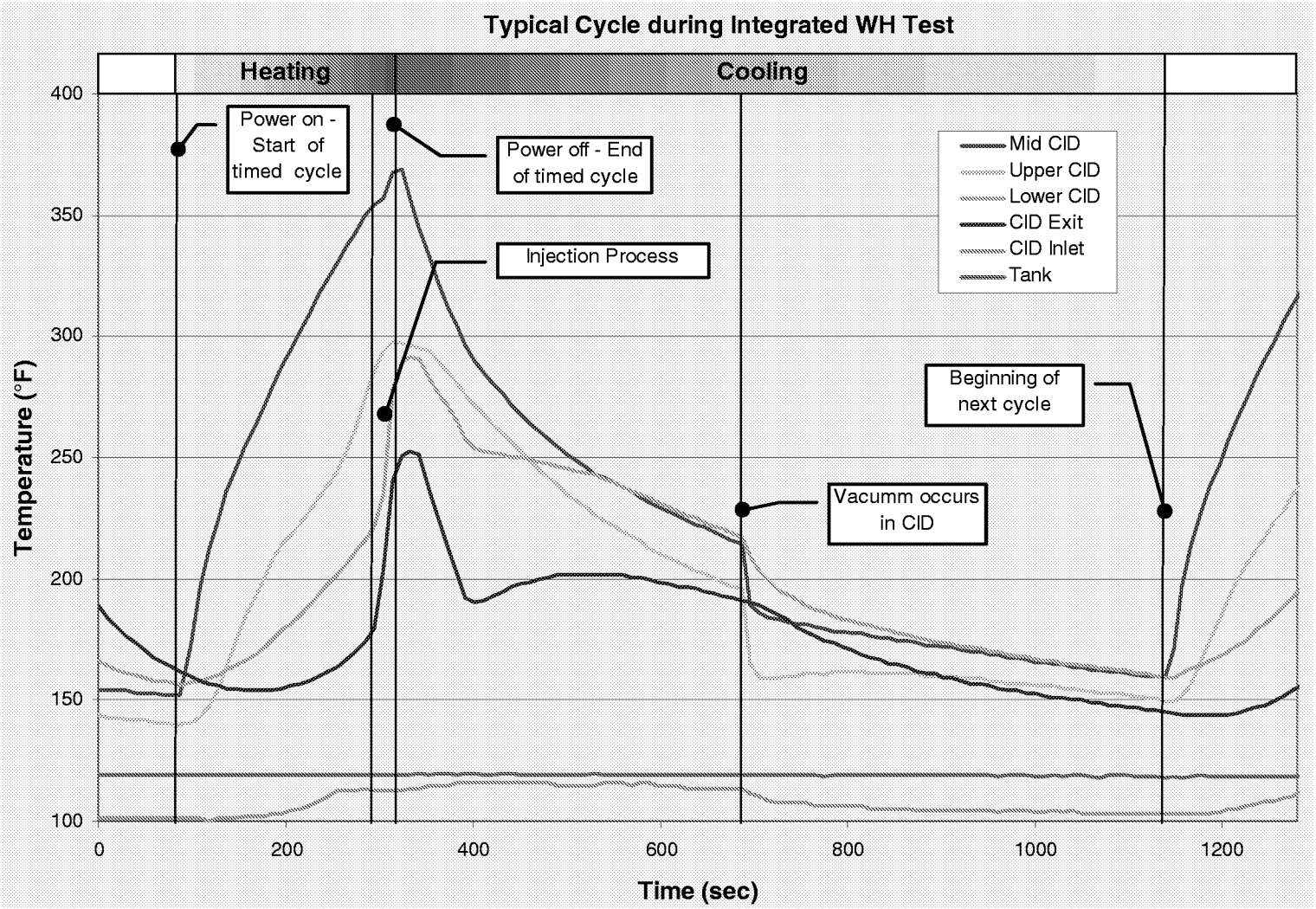
As with the bench-top test, thermocouples were placed on the CID vessel to monitor the maximum temperatures experienced during the cycles.

- Inlet tube to the CID, the water temperatures should not cause evaporation
- Upper portion of the CID vessel, prevent damage to the plastic cap
- Mid-span of the heating element, prevent combustion of insulating materials
- Lower portion of the CID, location of the thermal-cut out switch
- Exit of the CID, should be the saturation temperature corresponding to the system pressure

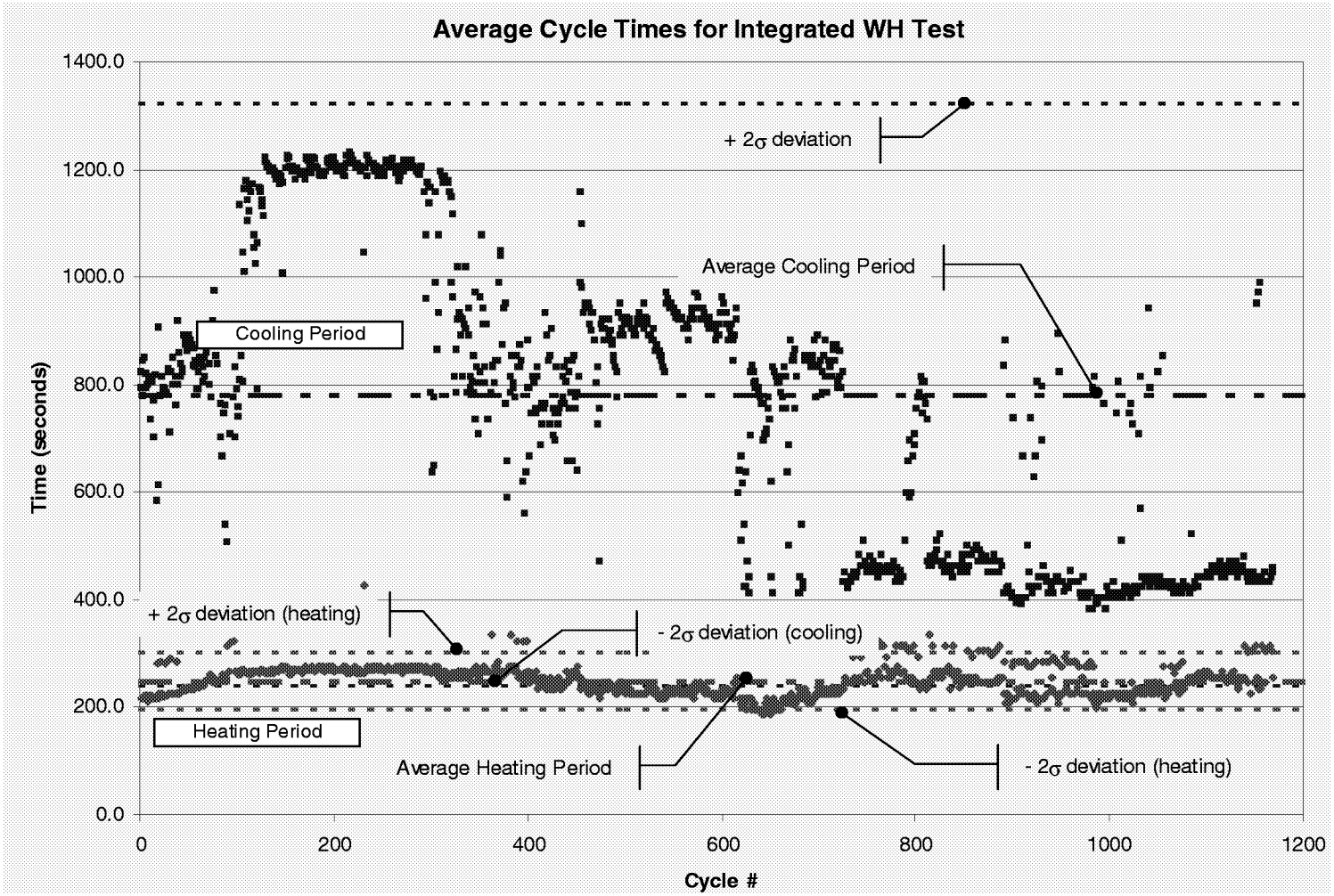
We varied the condensate flow rate over a two-month period and completed 1170 cycles with the integrated CID.



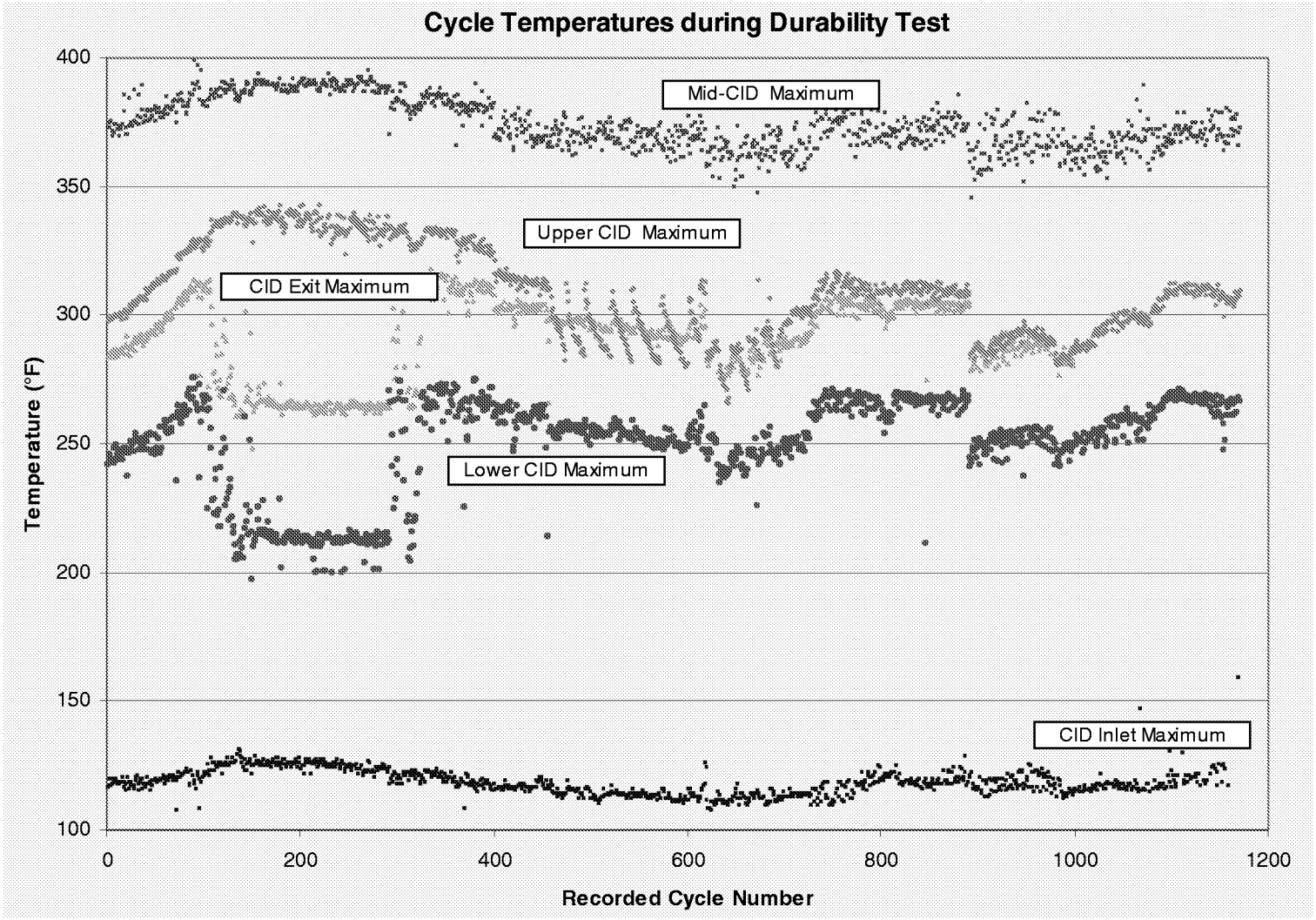
The typical heating cycle matched the profile of the the bench-top CID. As expected, the cool-down period was longer (due to lack of active cooling).



As found with the bench-top test, there was little variation in the heating period. However, the cooling period varied widely.



The temperatures remained within the limits we identified as the design targets.



Condensate Disposal System Index

Background / Description

Task 1 - Conceptual Design

Task 2 - Design and Development

Task 3 - Prototype Testing

Task 4 - System Testing

Summary

We have successfully demonstrated the CID concept.

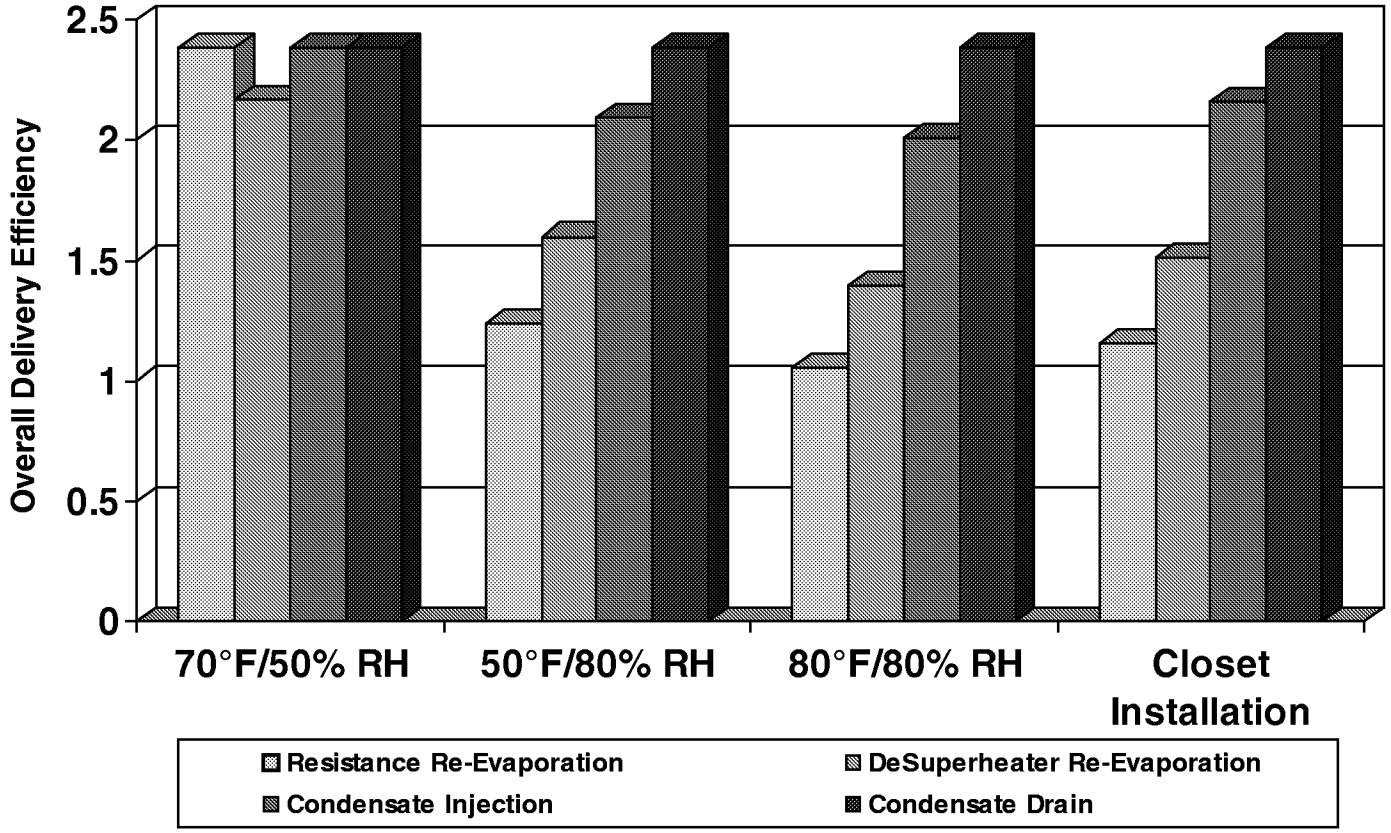
- We have identified the major regulations that will influence the design and application of the CID.
- We have designed and developed the initial CID prototype that satisfies the functional requirements.
- We have demonstrated the CID's durability and performance characteristics.

The completed tests demonstrate the CID requires far less energy than the electric resistance re-evaporation method.

Test	Throughput	Re-Evaporation Energy	Actual Energy	Energy Savings
Ideal CID (133 seconds)	0.553 lb / hr[1]	583 Btu / hr	142 Btu / hr	4
Bench-Top 230 seconds	0.49 lb / hr[1]	516 Btu / hr	217 Btu / hr	2.4
Bench-Top 250 seconds	0.48 lb / hr[1]	504 Btu / hr	231 Btu / hr	2.2
Integrated 240 seconds	0.36 lb / hr2	376 Btu / hr	164 Btu / hr	2.3

[1] Based on a ten-minute cool-down period.
[2] Based on the actual average cool-down period of 15 minutes.

We estimate a significant improvement in the ODE relative to other condensate management systems.



Analysis assumes:

1. Heat-pump capacity of 5600 Btu/hr, COP of 3.0
2. No backup use of upper or lower electrical resistance heater elements.
3. Desuperheater losses of 500 Btu/hr (consistent with laboratory test results)
4. Water draw of 64.3 gallons/day
5. Tank standby losses of 7000 Btu/day
6. Closet surrounded by 70°F/50% RH

Beyond the energy savings, the development of the CID will lead to further market acceptance of the HPWH.

- Allows people to install the HPWH in virtually any location that current conventional electric water heaters are installed.
- Provides the dehumidification benefit that many consumers desire.
- Prevents the recycling of condensate experienced in enclosed spaces.

We have identified a number of concepts that may decrease the cost and increase the reliability of the CID.

- Using a thin aluminum, steel or copper vessel with internal fins would increase the heat flux in and out of the vessel, and may reduce the temperatures that the CID experiences.
  - Increase the throughput of the CID with a reduced cycle time.
  - Increase the energy efficiency of the device.
- There are a number of options available for either eliminating the o-ring or reducing it's exposure.
  - Design the float to act as a heat barrier between the steam and the o-ring.
  - Use graphite gaskets or other similar material designed for use in steam environments.
- By replacing the plastic cap with a metal cap, we could significantly reduce the initial production cost of the CID.
  - The stainless steel float combined with the proper gasket material may alleviate excess temperatures in the inlet tube.

Future activities must seek to accurately asses the degree of regulatory risk associated with the CID as well as incorporate further design refinements for mass production.

- Work with the regulatory bodies in defining how the CID is governed under the scope of the various regulations and standards.
  - Develop a fully functional CID for demonstrating and discussing the CID process and it's implications to the regulations.
  - Meet with representatives from UL, IMC, IPC, and the EPA.
- Obtain laboratory evidence supporting the safety of injecting condensate from the HPWH into the water storage tank.
  - Identify the key water-quality contaminants,
  - Test the HPWH and CID under laboratory conditions to assess the potential hazard.
- We have been selected by the California Energy Commission to complete additional work in obtaining laboratory evidence that supports the safety of the CID.