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Final Report

Potable Hot Water Heating System

Overview

This section of the report summarizes the continued testing performed on the Lab 4 steam fired "semi-instantaneous" potable hot water heater 5.2. This testing was conducted following the progress report provided in January. Details are provided in sections that follow if further information is desired.

The Lab 4 hot water heating system consists of two (2) steam fired water heaters (N+1) serving a 140° primary domestic hot water loop serving cage washers on the 2nd and 4th floors and a Leonard three way mixing valve assembly which provides 120° hot water to point of use sinks and hose bibs (secondary loop). The final secondary loop temperature control was tested with the 5.2 hot water heater under manual control to allow us to record operation of the Leonard mixing valve under varying flow conditions with the hot water supply temperature being maintained above 135°F.

Reported problems

1. Constant rapid cycling (open and closed) of both steam valves.
2. Erratic temperature control
3. Failure to reach specified temperatures.
4. Over temperature relief on flow shutdown.

Synopsis of work performed

1. Repeated testing was continued with various system modifications in an attempt to exhaust all possibilities of obtaining acceptable performance with the existing system as supplied by the manufacturer and installed by the contractor.
2. This report includes the details of the final two tests.
    a. Pneumatic controls modified using a two input controller and relocated sensors. This test shows the results of the best of all tested pneumatic control modifications.
    b. Manual control of the HW heater to allow testing of the Leonard mixing valve serving the 120° secondary point of use loop. This test was done to prove or disprove whether the Leonard control valves will function properly at varying flows when supplied with a hot water supply temperature above 135°.

Observations and technical notes (final pneumatic test)

1. A consistent theme with the pneumatic control has been that these controls do not recover to setpoint within a reasonable amount of time (and most times never recover) following an increase in flow. “Reasonable” as referred to here is within three minutes. While operating under pneumatic control (regardless of the modification) we were never able to approach reasonable and in most cases the system never recovered.
2. Beginning on the left side of the hot water heater temp in and out, note the following:
    a. The test begins with a supply flow on the 140° loop of recirculated flow only (about 25 GPM). The starting leaving water temperature is about 137°.
    b. Just prior to the 09:13 reading set, we opened one rack washer on the second floor resulting in 98 GPM flow (supposed to be 50 GPM per rack washer). Immediately the steam valves began hunting with a resulting hunt in the leaving water temperature over a 40° range. Steam valves have restrictors installed to slow the valve action.
    c. We opened a second rack washer just prior to the 09:30 reading set for a total flow of 146 GPM. Note that at this flow, the steam valves steadied out and stopped hunting.
    d. We opened the tunnel washer on the second floor just prior to the 10:00 reading set for a total flow of 170 GPM. This produced a hunt over about 10° from 115° to 125°. Restrictors are installed on the pneumatic signal line which dampens the “hunt”.
    e. Just prior to the 10:19 readings set, we opened four hose bibs on the 120° loop which increased flow on the 140° loop to 179.25 GPM which increased the hunt to about 22° (108°-130°). A full cycle up and down took approx. 30 seconds.
    f. For the 10:43 reading set, we opened an additional 16 hose bibs for a total flow on the 140° loop of 233 GPM. The hunt range increased by about a degree to 23° and the leaving water temperature hunted between 105° and 128° with a full hunt cycle taking about 30 seconds.
    g. Just prior to the 11:15 reading set, we began the test with reducing flow. Flow was reduced to one rack washer and 20 hose bibs for a total flow on the 140° loop of 163.8 GPM. Over the course of about 10 minutes following the flow reduction, the valves settled down a bit. The hunt range cycle time decreased to about 7° (118°-125°) and 70 seconds respectively. This pattern remained steady for about 2 hours.
    h. At 13:15 we further reduced flow on the 140° loop to 136.4 GPM with one rack washer and ten hose bibs in operation. At this flow the steam valves really settled down with virtually no hunting and maintaining about 131°F.
    i. Just prior to the 13:48 reading set, the rack washer was shut off leaving only ten hose bibs in operation plus recirculation flow. Total 140° loop flow was 70.5 GPM of which about 25 GPM was recirculated. Hunting increased in severity to about 50° (105°-155°).
    j. At 14:02, flow was reduced to five hose bibs only (46.7 GPM on the 140° loop including recirculated flow). The hunt range increased slightly to about 58°, the

hunt frequency remained the same and the hunt band shifted upward reaching about 170°. When reaching approximately 170°, the P&T relief valve on the heater began to open slightly and weep indicating either a faulty P&T relief valve or it is seeing a higher temperature than we measured on the outlet pipe. This valve has a setpoint of 210°.

k. At 14:20 all flow was turned off with the exception or recirculated flow of 25 GPM. In this condition, hunting worsened and routine quench and P&T valve operation occurred. The extreme cycling of the steam valves continued for approximately 30 minutes with no sign of stopping. Air was removed and the test terminated.

3. Stable temperature control is able to be achieved by controlling the pneumatic valves manually.

Conclusions on final pneumatic test

1. As supplied, the hot water heaters are not capable of controlling the primary supply water temperature within the specified tolerances.
2. Even with many modification and trial and error testing (the last using a two input controller), the hot water heaters cannot achieve control within the specified parameters.
3. The hunting and unstable operation occurs to a greater or lesser degree with all pneumatic configurations tested.
4. Using the pneumatic control system supplied, the various modifications made during testing and the final modified pneumatic control system, the heaters are not capable of controlling to recirculated flow only (about 25 GPM) without initiating a quench cycle and operating the P&T relief valve repeatedly.
5. Stable automatic control would likely be able to be achieved using DDC controls and accurate flow inputs to the controller (permanent ultrasonic flow meters). Programming would likely not be simple and an additional small steam valve could be necessary for control at very low flows.

Observations and technical notes (Leonard mixing valve test with manual heater operation).

1. The temperature spikes and dips above and below setpoint follow temperature spikes and dips on the incoming hot water supply but are typically less pronounced.
2. If control were completely smooth on the hot water supply, the mixing valve leaving temperature would not spike.
3. The spiking on the mixing valve outlet is directly related to the spiking on the hot water inlet. If the hot water inlet were smoother, the mixing valve outlet would follow suit.
4. The other mixing valve station may require repair. Further troubleshooting is required.
5. We found that the recirculated flow rate had to be significantly decreased on the 120° loop to allow the small Leonard valve to maintain the loop temperature during periods of

low flow. The flow had to be dropped to approximately 2.0 GPM to prevent the recirculated cool stream from overpowering the capacity of the small mixing valve.

6. Note that manual gauges on the water system are not likely in calibration and are of different ranges. Comparison of the pressure values using these gauges should be for approximate values only.

Conclusions on Leonard valve testing

1. The Leonard three way mixing valve controls approximately to within about ±5° (possibly better) as long as the hot water supply temperature remains above 135°F.
2. If the 140° supply water were maintained steady (without spikes) it is likely that the Leonard valves will control to within approximately ±5°.
3. With the supply water PRV's bypassed, the supply water pressure does not adversely affect the Leonard three way mixing valves.
4. The difference in supply pressures between the hot water and cold water supplies to the Leonard valve do not appear to negatively affect control of the leaving water temperature.

Possible solutions

1. Convert control to a DDC system (pneumatic control valves to remain) and incorporate permanent ultrasonic flow meters.
2. If all pneumatic control is to remain, add hot water storage volume, recirculation pumps (high volume) and control by storage tank temperature using immersion sensors.

Mechanical Service Corp.

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	This secion is a test of increasing flow from zero flow with the 140 deg loop only			This section is a test of increasing flow with the 120 deg loop in operation		Testing on the way down					
	Dave opened one (1) rack washer on 2nd floor. Flow steady not changing	Dave opened the 2nd rack washer on the 2nd floor. Steady flow.	Dave opened the tunnel washer on the second floor (3rd device). Steady flow.	Three cage machines open. Dave opened 4 hose bibs on the 120 deg loop	Three cage machines open. Dave opened a total of 20 hose bibs on the 120 deg loop	One rack washer on 2nd floor, 20 hose bibs open.	Repeat of readings. One rack washer on 2nd floor, 20 hose bibs open.	One rack washer on, on 2nd floor, 10 hose bibs open	Rack washers off, 10 hose bibs open	Rack washers off, 5 hose bibs open	Rack washers off, hose bibs off
Time:	9:13	9:50	10:00	10:19	10:43	11:15	13:00	13:15	13:48	14:02	14:20
B.F.Preventer PSI in 6th floor	70	66	64	64	60	66	66	70	70	72	72
B.F.Preventer PSI out 6th floor	54	50	48	48	43	48	58	50	53	55	62
Cold water out of 140 PRV	54	50	46	45	42	46	46	50	54	55	63
Cold water out of 120 PRV	58	54	50	50	44	52	54	56	60	60	68
Cold water PSI in at mixing valve	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger
Hot water PSI in at mixing valve	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger
Hot water PSI out of heater 6th floor	50	48	42	40	34	44	44	50	52	56	66
Main steam PSI	62	62	62	62	62	62	62	62	62	62	62
Condensate PSI before steam trap	0-26	10	4-20	0-42	0-44	0-40	0-10	4	0-30	0-40	0-50
Air signal out of controller before res and restrictors	4-15	9	7.5-11.5	5-16.5	6.0-16.0	8.5-11.0	8.0-10.0	5.5	0-17	0-13.0	0-14.0
Air signal at small valve positioner	4-10	9	8.5-11.0	6-12.0	7.0-12.0	9.0-10.5	9.0-10.5	5.5	0-8	0-7.0	0-7.0
Flow meter on 140 deg supply	98	146	170	165	172	95	94	96	24	21.7	2.9
Fuji flow meter on 140 supply to Leonard	0	0	0	14.25	61	68.8	68.3	40.4	46.5	25	25
Fuji 120 Supply to building	10	10	10	26	74.5	80	82	57	58	34	10
Cold water temperature in at mixing valve	72	62	57	55	55	55	56	56	56	56	57
140 deg hot water temp into Leonard	116	121	121	109	118	127	118	132	117	159-129	121-152
Recirc Temp in at mixing valve	117	114	113	110	106	106	111	112	113	111	111
Hot Temp out at mixing valve	119	115	112	107	117	116	113	115	112	129-110	115-120
Temperature in at heater	72	62	59	57	55	58	58	61	70	89	114
Temperature out at heater	140-99	122	116-124	110-130	106-125	118-124	118-124	131	108-153	117-169	114-189
Main steam											
Condensate											
Steam temp in	267	279	279	280	283	277	271	271	263	265	268
Condensate temp	209	229	210	219	237	209	213	225	231	228	214
Small valve positoin	25%	100% open	100%	100%	100%	100%	100%	100%	15%-100%	10%-100%	10%-100%
Large valve position	0-25%	25%	25%-50%	0-75%	0-85%	0-50%	0-50%	0%	0%	0%	0%
Quench or blowoff	No	No	No	No	No	No	No	No	No	Yes	Yes
Steady or hunting	Hunting	Steady	Hunting	Hunting	Hunting	Hunting	Hunting	Steady	Hunting	Hunting	Hunting

	Dave opened one (1) rack washer on 2nd floor. Flow steady not changing	Dave opened the 2nd rack washer on the 2nd floor. Steady flow.	Dave opened the tunnel washer on the second floor (3rd device). Steady flow.	Three cage machines open. Dave opened 4 hose bibs on the 120 deg loop	Three cage machines open. Dave opened a total of 20 hose bibs on the 120 deg loop	One rack washer on 2nd floor, 20 hose bibs open.	Repeat of readings. One rack washer on 2nd floor, 20 hose bibs open.	One rack washer on, on 2nd floor, 10 hose bibs open	Rack washers off, 10 hose bibs open	Rack washers off, 5 hose bibs open	Rack washers off, hose bibs off
	Small valve only in operation. Hunts between 4-15 psig and back over approx 30 seconds. Leaving temp fluctuates during this time 139 down to 99 deg and back. Pressure gauge accuracy in question. No flow on 120 loop.	Small valve open 100%, 2/3 valve open 25%. Valves steady and not hunting.	Small valve open 100%. 2/3 valve hunting slowly between 25% and 50% and back. One cycle up and down in approx 15-20 seconds	Four hose stations open to allow the small Leonard valve to operate. One full hunt cycle = approx 30 seconds	Twenty hose stations open. One full hunt cycle is approx 30 seconds. 18 psig air is full open on the 2/3 valve.	Hunting but the range of the hunt is less than at full flow. 1/3 valve remains open while the 2/3 valve hunts. One full hunt cycle is approx. 70 seconds	Hunting but the range of the hunt is less than at full flow. 1/3 valve remains open while the 2/3 valve hunts. One full hunt cycle is approx. 70 seconds	No hunting at this flow.	Upon closeoff of the last washer, the steam shut off and the leaving temp rose to 154, dropped to 107 and then called for steam again. T&P valve needs to be replaced (blows off at 170 vs 210 setpoint.	Upon closeoff, the 1/3 valve hunted slowly. P&T relief operated at approx 168 deg and reseated several times. The P&T appears not to fully open but to weep.	One minute after closeoff, the P&T fully opened and the quench opened. We reached 180 deg on the leaving heater temp. Relief cycle continued.
									Recirc pump flow only. Readings taken approx 10 minutes following flow change. Mike reports that if the P&T lifts the heater enters a repeating cycle.		After 30 minutes, the P&T and quench continued to cycle again and again. No flow other than recirc flow.

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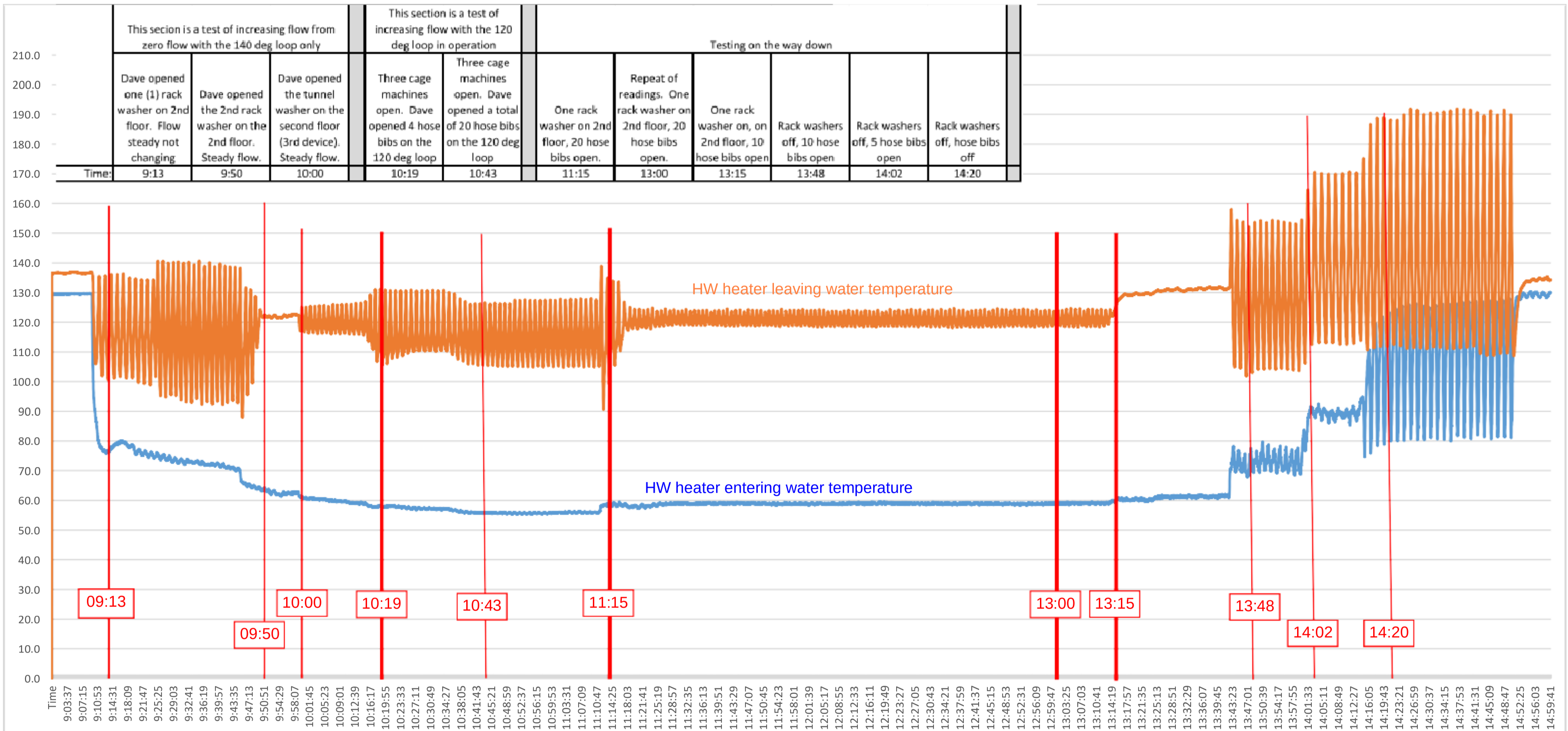

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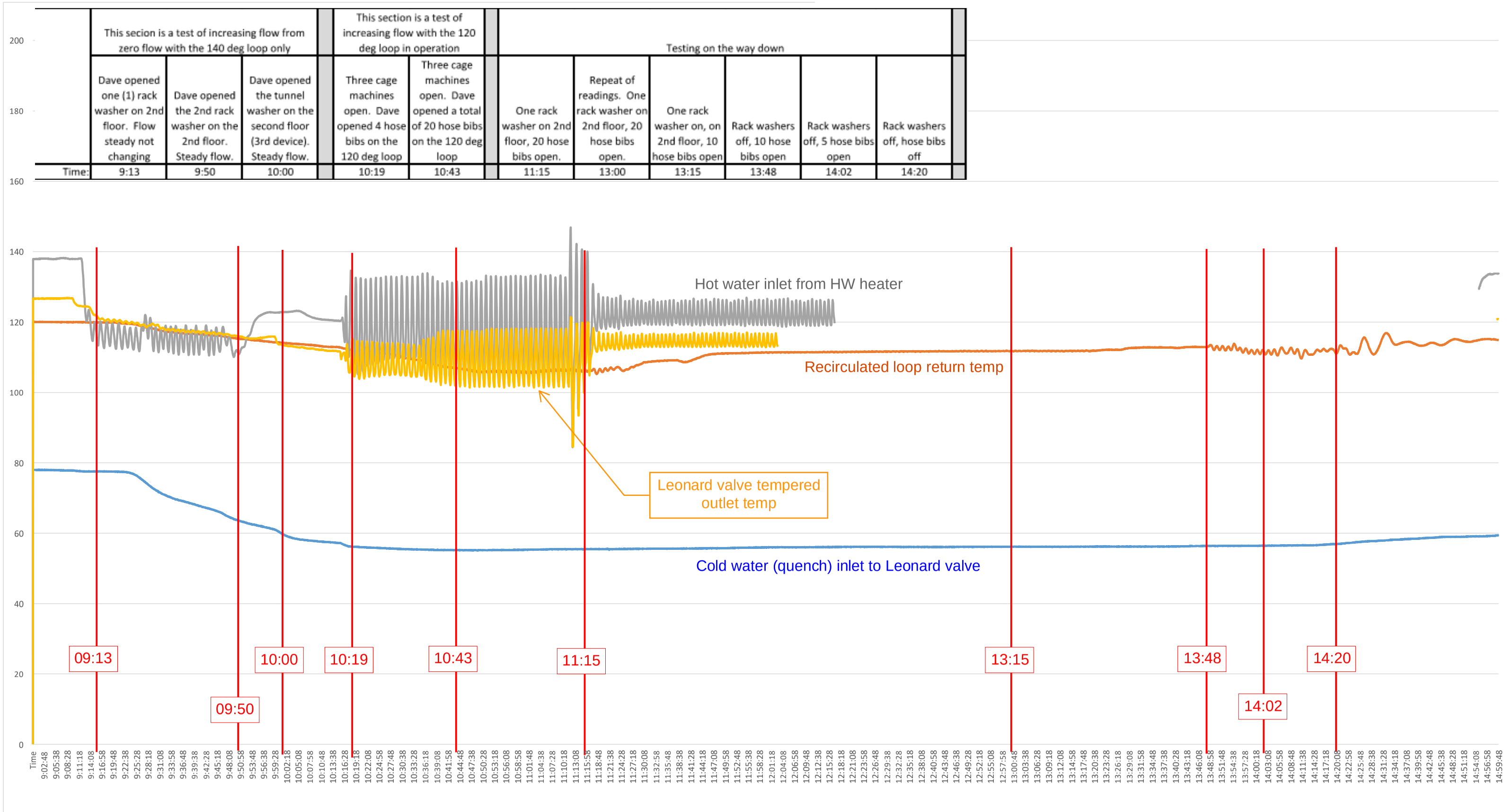
Time:	9:13	9:50	10:00	10:19	10:43	11:15	13:00	13:15	13:48	14:02	14:20



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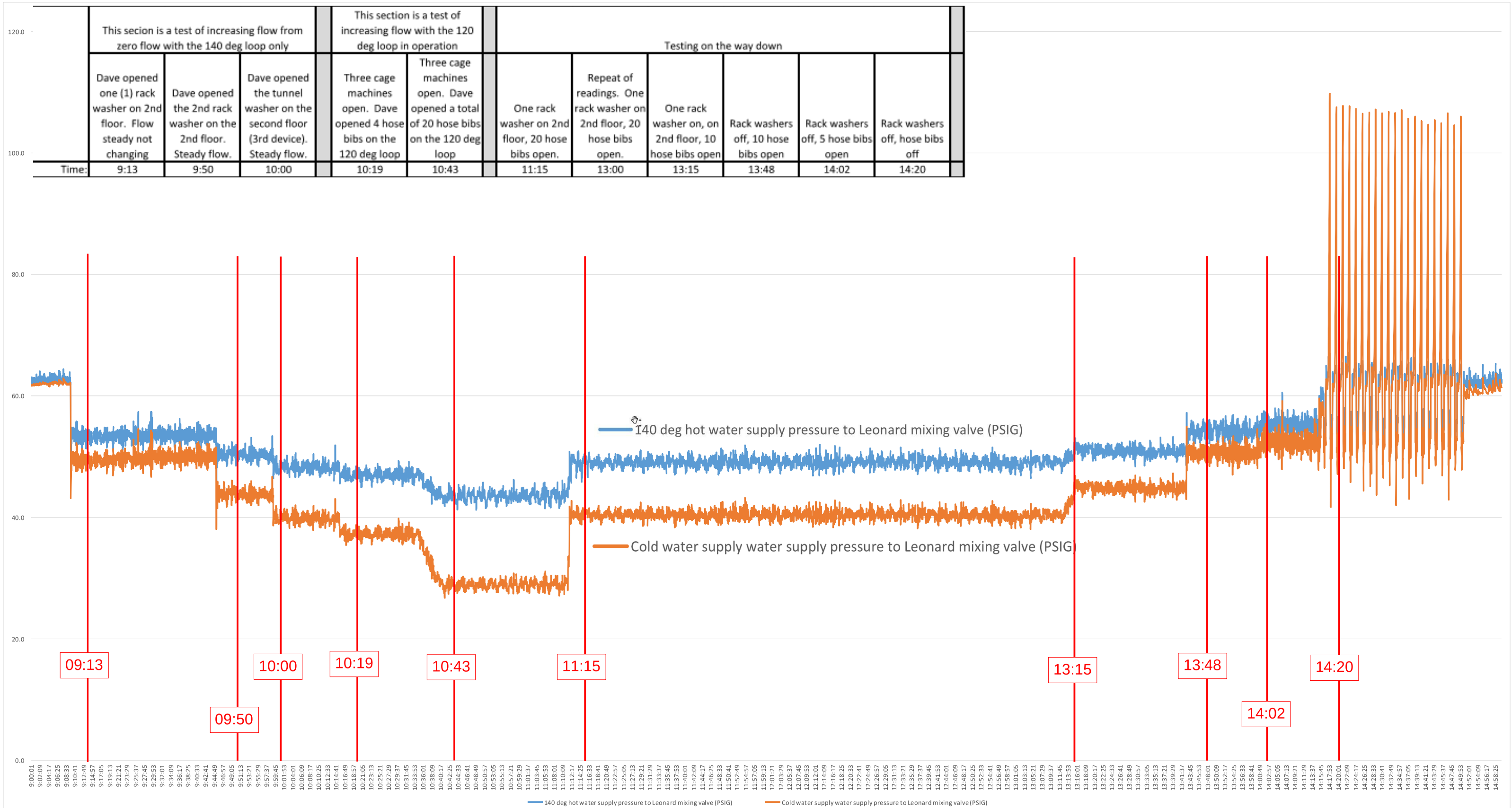
Time:	9:13	9:50	10:00	10:19	10:43	11:15	13:00	13:15	13:48	14:02	14:20

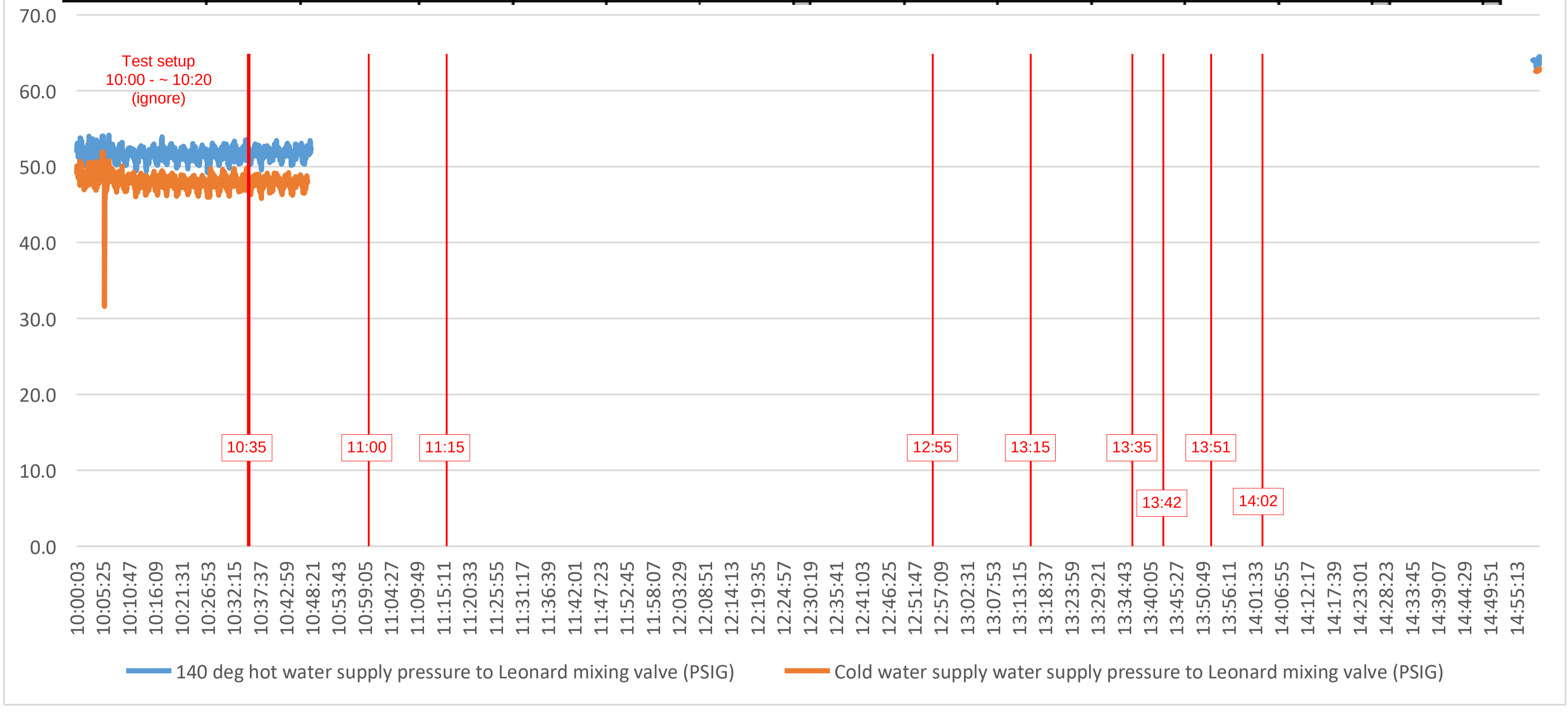


	Test on increasing 120 loop flow						Test on decreasing 120 deg loop flow						Flow off
	Manual control, static condition	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 20 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 0 hose bibs open.	Manual control. Tunnel washer closed, hose bibs closed, recirc only	All water off. Recirc only. Adjusted steam to trim supply out of heater to 140 deg
Time:	9:00	10:35	11:00	11:15	12:55	13:15	13:35	13:42	13:51	14:02	14:12	14:30	15:00
B.F.Preventer PSI in 6th floor	72	70	66	64	62	62	63	66	68	70	70	72	72
B.F.Preventer PSI out 6th floor	66	50	48	46	47	47	46	48	52	54	54	62	64
Cold water out of 140 PRV	66	50	50	47	45	43	46	48	52	52	52	63	64
Cold water out of 120 PRV	66	54	54	50	48	46	48	52	56	56	56	66	68
Cold water PSI in at mixing valve	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Loggger	Logger
Hot water PSI in at mixing valve	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger	Logger
Hot water PSI out of heater 6th floor	74	50	50	48	44	40	42	46	52	50	52	62	64
Main steam PSI	62	62	62	62	62	62	62	62	62	62	62	62	62
Condensate PSI before steam trap	0	8	24	24	32	40	34	24	18	12	4.0	0	0
Air signal out of controller before res and restrictors	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Air signal at small valve positioner	4.5	6.25	6.5	6.75	8	8.75	8.25	6.75	6.5	6.0	5.5	0	3.75
Flow meter on 140 deg supply	25.5	77.6	76.9	75	75	73	75	75	77	77	77	25	25
Fuji flow meter on 140 supply to Leonard	3.4	8.4	18.6	34.7	46	56	48	34.7	18.1	8.6	0	0	0
Fuji 120 Supply to building	9.5	11.6	28	45	64	79	67	49	27	11	0	0	0
Cold water temperature in at mixing valve	74	55	56	56	56	55	55	55	56	56	56	58	60
140 deg hot water temp into Leonard	128	147	148	139	144	148	148	145	148	146	144	134	133
Recirc Temp in at mixing valve	94	99	98	100	112	112	112	113	13	112	112	112	108
Hot Temp out at mixing valve	104	118	120	120	121	123	122	120	120	122	109	116	112
Temperature in at heater	102	70	66	66	64	64	64	65	67	69	73	126	128
Temperature out at heater	128	145	146	138	143	148	146	144	147	144	141	135	142
Main steam													

	Test on increasing 120 loop flow						Test on decreasing 120 deg loop flow						Flow off
	Manual control, static condition	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 20 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 0 hose bibs open.	Manual control. Tunnel washer closed, hose bibs closed, recirc only	All water off. Recirc only. Adjusted steam to trim supply out of heater to 140 deg
Condensate													
Steam temp in	199	265	269	268	276	280	279	275	272	268	263	252	248
Condensate temp	200	251	262	258	270	281	273	259	250	236	223	208	202
Small valve positoin	25%	80%	90%	100%	100%	100%	100%	100%	75%	50%	50%	0%	15%
Large valve position	0%	0%	0%	0%	25%	50%	30%	0%	0%	0%	0%	0%	0%
Quench or blowoff	No	No	No	No	No	No	No	No	No	No	No	No	No
Steady or hunting	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady
	Manual control. Dddirect air signal to signal supply line to both valves.	This is the big jump since we are bringing on the tunnel washer. Tunnel washerr on 09:07 AM. Let system stabilize before taking reading	Increase temperature to 150 degrees to start test	Temperature dropped to 139 degrees	Bring temoerature to 150 degrees before opening 5 more hose bibs at 12:50pm.Tem perature dropped to 143 degrees	Bring temperature back up to 150 degrees before opening 5 more hose bibs temperture dropped to 147 degrees	Dropped hose bibs at 13:25.	Dropped five hose bibs at 13:40	Dropped five hose bibs at 13:50	Dropped three hose bibs at 13:58	Dropped the remaining two hose bibs at 14:08. Note that 120 recirc line was slightly cooled by passing through the small Leonard valve. The flow was not measurable but set to approx 2 GPM earlier.	Dropped tunnel washer at 14:21. Immediately removed air from steam valve to prevent overshoot.	Cracked 1/3 valve at 14:36. Shut off air at 15:04 as we passed 140 deg.
		For this set of readings, we had to turn off the 120 recirc pump because it was overpowering the small valve. Turned on the											

	Test on increasing 120 loop flow						Test on decreasing 120 deg loop flow						Flow off
	Manual control, static condition	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 20 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 0 hose bibs open.	Manual control. Tunnel washer closed, hose bibs closed, recirc only	All water off. Recirc only. Adjusted steam to trim supply out of heater to 140 deg
		pump and the leaving temp dropped to 100 and total flow went to 20 GPM. Throttled recirc puump discharge to a net gain of 2 GPM. This allowed the small Leonard to make temperature.											

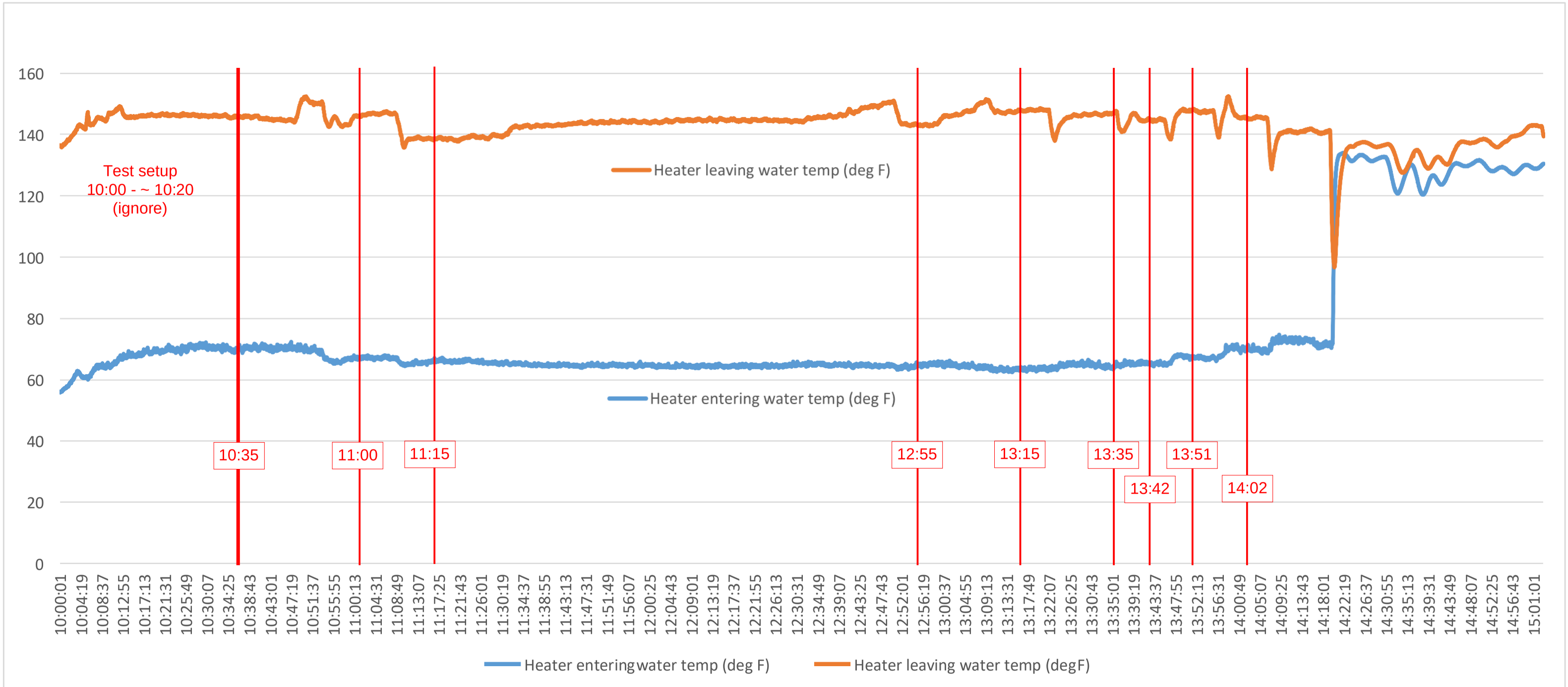
	Test on increasing 120 loop flow						Test on decreasing 120 deg loop flow						Flow off
	Manual control, static condition	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 20 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 0 hose bibs open.	Manual control. Tunnel washer closed, hose bibs closed, recirc only	All water off. Recirc only. Adjusted steam to trim supply out of heater to 140 deg
Time:	9:00	10:35	11:00	11:15	12:55	13:15	13:35	13:42	13:51	14:02	14:12	14:30	15:00



Leonard 3-way mixing valve test
HW heater under manual control

4/10/19

	Test on increasing 120 loop flow						Test on decreasing 120 deg loop flow						Flow off
	Manual control, static condition	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 20 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 0 hose bibs open.	Manual control. Tunnel washer closed, hose bibs closed, recirc only	All water off. Recirc only. Adjusted steam to trim supply out of heater to 140 deg
Time:	9:00	10:35	11:00	11:15	12:55	13:15	13:35	13:42	13:51	14:02	14:12	14:30	15:00



Leonard mixing valve test
HW heater under manual control

4/10/19

	Test on increasing 120 loop flow						Test on decreasing 120 deg loop flow						Flow off
	Manual control, static condition	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 20 hose bibs open.	Manual control. One tunnel washer open for flow. 15 hose bibs open.	Manual control. One tunnel washer open for flow. 10 hose bibs open.	Manual control. One tunnel washer open for flow. 5 hose bibs open.	Manual control. One tunnel washer open for flow. 2 hose bibs open.	Manual control. One tunnel washer open for flow. 0 hose bibs open.	Manual control. Tunnel washer closed, hose bibs closed, recirc only	All water off. Recirc only. Adjusted steam to trim supply out of heater to 140 deg
Time:	9:00	10:35	11:00	11:15	12:55	13:15	13:35	13:42	13:51	14:02	14:12	14:30	15:00