Softened Water Benefit Study

(aka) The Battelle Study

Water Quality Association

www.wqa.org

Executive Summary

This study tested devices fed with softened and unsoftened water under controlled laboratory conditions designed to accelerate the waterside scaling in the device and quantify the performance efficiency. The project specifically focused on efficiency improvements in household water heaters from use of softened water, and the subsequent effect on performance of fixtures, such as low flow showerheads and faucets, and appliances, such as laundry washers and dishwashers. For this study, Battelle tested 30 water heaters supplied by WQA over a 90-day period using a Battelle-developed and WQA-approved test protocol. Battelle simultaneously studied the effect of water hardness on performance of faucets, low-flow showerheads, dishwashers, and laundry washers. Using the empirical data generated from the water heater testing and the effect on performance of fixtures and appliances, Battelle developed a differential carbon footprint assessment for homes using unsoftened water vs. softened water.

Water Heater Results

Battelle set up and tested ten storage-type gas water heaters, ten storage-type electric water heaters, and ten instantaneous gas water heaters with the following specifications using an accelerated scaling methodology developed at Battelle.

- Gas Water Heaters (10), 40 gal, 38,000 Btu/h burners
- Electric Water Heaters (10), 40 gal, 4500 W heating elements
- Tankless Gas Water Heaters (10), 199,000 Btu/h burners

Five of each type of device were tested without any preconditioning of the water supply, and the other five were tested using a water softener to remove hardness constituents from the water supply. Five units were chosen for each of the groupings in order to be able to calculate 95 percent confidence intervals for the results.

At the start of the test, and at approximately one week intervals, the thermal efficiency of each water heater was measured to determine the change in efficiency as waterside scale built up in each water heater. Each water heater was instrumented to measure the inlet and outlet water temperature at 15-second intervals, the amount of hot water generated, and the amount of energy (gas or electric) used to produce the hot water. These data were used to calculate the average thermal efficiency of the water heater.

In summary, the electric and gas storage water heaters and the instantaneous gas water heaters on soft water performed well throughout the entire testing period. Although the pressure regulators and needle valves were tweaked throughout the testing to maintain constant testing conditions, all of the water heaters on soft water required minimal attention because the conditions were very stable. This is reflected in the efficiency data for these units that show the efficiency remained essentially constant over the duration of the testing with the variations being within the experimental error of the instrumentation and testing protocol.

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In contrast, none of the electric or gas storage water heaters or the instantaneous gas water heaters on unsoftened water made it through the entire testing period because the outlet piping system consisting of one-half inch copper pipe, a needle valve, and a solenoid valve became clogged with scale buildup. Although the pressure regulators and needle valves were tweaked throughout the testing to try to maintain constant testing conditions, all of the water heaters on unsoftened water were removed from the testing at some point due to the inability to maintain sufficient flow.

Table ES-1 – Summary of Results for Water Heaters

Water Heater Type	Water Supply	Average Thermal Efficiency, (%)		Equivalent Field Service (Years)	Average Annual Scale Accumulation[1] (grams/year)	Carbon Footprint[2] (kg CO_2/gal hot water)
		Test Start	Test End			
Instantaneous Gas	Unsoftened	80	72[3]	1.6	NA	0.052
	Softened	80	80	1.6	NA	0.050
Gas Storage	Unsoftened	70.4	67.4	2.0	528	0.066
	Softened	70.4	70.4	2.25	7	0.056
Electric Storage	Unsoftened	99.5	99.5	1.25	907	Not Determined
	Softened	99.3	99.3	1.25	14	Not Determined

Notes: [1] The submerged heating element in an electric water heater operates at very high temperatures which results in a high rate of scale buildup in electric water heater when compared to a gas water heater.

[2] Average over 15 years Equivalent Life.

[3] Deliming or Cleaning was performed at this point.

A summary of the results, discussed in the following paragraphs, is provided in Table ES-1. The instantaneous water heaters on unsoftened water had to be delimed at 1.6 years of equivalent field service, and the average efficiency of these units dropped from 80 percent at the start of the test to 72 percent when they were delimed. After deliming, the average efficiency of these units increased to about 77 percent, but was still below the 80 percent starting efficiency. The cost implications of these findings are addressed in this report.

The average efficiency of the gas storage water heaters on unsoftened water dropped from 70.4 percent at the start of the test to 67.4 percent at two years equivalent field service. These data were used to derive equations to predict the efficiency of gas storage water heaters as a function of water hardness and daily household hot water usage. The average rate of scale buildup in the gas storage water heaters on unsoftened water was about 528 gm/yr (1.16 lb/yr). The average rate of scale buildup in the gas storage water heaters on soft water was about 7 gm/yr (0.01 lb/yr), which is almost negligible.

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The electric storage water heaters on both softened and unsoftened water were able to maintain a constant efficiency throughout the entire test period because the heating elements were completely submerged in the water. However, the life of the heating element in unsoftened water is expected to be shortened due to scale buildup increasing the operating temperature of the element. The average rate of scale buildup in the electric storage water heaters on unsoftened water was about 907 g/yr (2.00 lb/yr). The average rate of scale buildup in the electric storage water heaters on soft water was about 14 g/yr (0.03 lb/yr), which is almost negligible.

Fixtures and Appliances

Ten low flow showerheads were installed on the hot water supply coming from the instantaneous gas water heaters; five were tested on unsoftened water and five were tested using softened water. The low flow showerheads on unsoftened water were removed from testing as they clogged up to the point of not allowing adjustment to a 1.25 gpm flow rate at any time during the test. All of the low flow showerheads on softened water made it through the testing without any problems. However, the low flow showerheads on unsoftened water clogged after an average of 3,203 gallons of water flow through them. At the end of testing, the low flow showerheads were disassembled and the amount of scale buildup was documented with photographs of the components.

Ten low flow faucets were also installed on the hot water supply coming from the instantaneous gas water heaters; five were tested on unsoftened water and five were tested using softened water. The low flow faucets on unsoftened water were also removed from testing as they clogged up to the point of not allowing adjustment to a 1.25 gpm flow rate at any time during the test. All of the low flow faucets on softened water made it through the testing without any problems. However, the low flow faucets on unsoftened water clogged after the equivalent of 19 days of water flow through the faucets assuming an average household uses about 50 gallons of hot water per day. The collection of scale on the faucets using unsoftened water appears to be the result of scale breaking loose from upstream portions of the plumbing and being trapped in the strainers.

Six dishwashers (Kitchenaid) and laundry washers (General Electric) were purchased to test the effect of unsoftened water on the performance of the appliances. The electronic controls for this equipment were integrated into the automated data acquisition and control system designed for the testing. The wash and dry cycles of the dishwashers and the wash cycles of the laundry washers were controlled automatically with the units going through eight cycles every 24 hours. The clothes washers were loaded with 7 lbs of restaurant hand towels. The dishwashers were loaded with eight place settings of dishes and flatware. At the end of the 30 days of testing, the dishwashers and clothes washers were examined before a teardown analysis was initiated. The units using softened water were almost completely free of any water scale buildup. In contrast, the units using unsoftened water (26 grains per gallon) had noticeable water scale buildup on all of the interior surfaces after only 30 days of testing. Although both of the dishwashers and clothes washers completed the same number of wash cycles (240), the appearance of the inside of the units using unsoftened water shows that it needs to be delimed and cleaned due to the buildup of scale and deposits. On the other hand, the units using soft water look like they could be cleaned up to look like new with just a quick wipe down.

Carbon Footprint

Battelle assessed that carbon footprint of the water heaters by evaluating the energy consumption within the home and the resulting greenhouse gas emissions. The results parallel those for the energy consumption, in that where there are energy efficiency differences there are also carbon footprint differences. For the storage-type gas water heaters, there was a reduction in carbon footprint of 14.8% over a fifteen year water heater service life with softened water compared to 26 gpg hard water, when considering both the natural gas used for water heating and the electricity used for water softening. For the instantaneous water heaters, there was a reduction in carbon footprint of 4.4% over a fifteen year water heater service life, when considering both the natural gas used for water heating and the electricity used for water softening.

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Conclusions

For gas storage and instantaneous water heaters, the use of a water softener to eliminate or minimize the scale forming compounds in water will result in the efficiency of the water heater remaining constant over the life of the unit. In contrast, gas storage and instantaneous water heaters using unsoftened water had a noticeable decrease in efficiency over the testing period resulting in higher natural gas use. This natural gas savings associated with the use of softened water will lead to direct energy and economic savings, as seen in the summary results in Table ES-2. In addition, because of the need to have the instantaneous water heater delimed or cleaned periodically, the economic savings can lead to recovery of the cost of a water softener and operating supplies in a period as short as a year, if the inlet water is sufficiently hard. Further, there are environmental benefits to the use of a water softener: the lower use of natural gas leads to reductions in the carbon footprint which are related to the decrease in total energy consumption. The increase in total energy consumption (as a result of a reduction in heat transfer efficiency) is related to the hardness: higher water hardness will lead to greater energy consumption without the use of a water softener, and consequently greater energy costs.

Table ES-2 – Estimated Savings for Gas-fired Water Heaters Using Softened Water Over 15 Years Life

Cost Elements	**Water Hardness** (grains per gallon)						
	0	5	10	15	20	25	30
Instantaneous Gas Water Heaters							
Percent Life Cycle Energy Cost Savings, %[1]	NA	5.4	5.4	5.4	5.4	5.4	5.4
Percent Total Life Cycle Cost Savings, %[1]	NA	14.0	22.5	31.2	39.6	48.4	57.0
Estimated Usage before Deliming Required, Years[2]	NA	8.4	4.1	2.7	2.0	1.6	1.4
Gas Storage Water Heaters							
Life Cycle Operating Efficiency Reduction From Baseline, %[3]	0.0	4.3	8.5	12.8	17.0	21.3	25.5
Percent Life Cycle Energy Cost Savings, %[4]	NA	3.1	6.6	10.3	14.5	19.0	24.2

Notes: [1] Derived from Table 5-2
[2] Derived from Table 5-1
[3] Derived from Table 5-3
[4] Derived from Table 5-4

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Electric storage water heaters did not record any difference in the electricity consumption between units receiving softened or unsoftened water. However, the life of the heating element on the electric water heater receiving unsoftened water would be expected to have a shorter life.

Low flow showerheads and faucets using unsoftened water clogged in less than seven days of accelerated life testing, whereas those units using softened water made it through the test without any problems.

The dishwashers and clothes washers on either soft or unsoftened water made it through 30 days of accelerated scale testing, but the units on unsoftened water had noticeable scale buildup on all surfaces that had contact with unsoftened water.