New Hampshire home with cold-drafting external chimney.

Beyond AFUE toward hydronic heating system efficiency

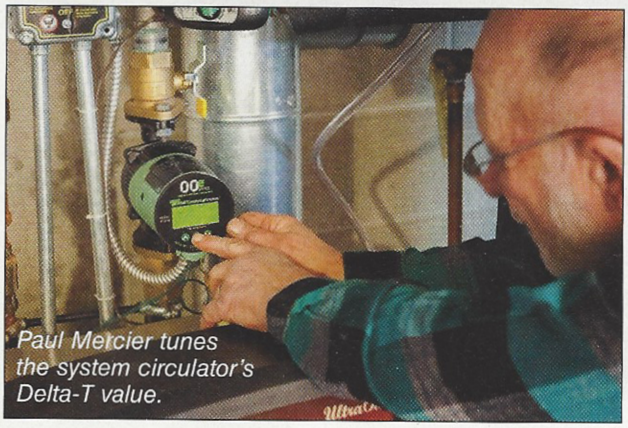
By Paul D. Mercier, Sr., Mercier Engineering

With the introduction of super-efficient, variable speed, ECM-driven Delta-T circulators for residential use, I've taken a keen interest in selectively applying them for use in radiant and other hydronic heating applications. The results have exceeded my expectations. Bear with me a moment, and I'll explain what I've found from various installations.

As just a bit of background, I'm a semi-retired "high-tech" manufacturing process engineer who also worked in the family heating business for over 50 years (You can't raise 10 kids on a single job!). But before I jump into an explanation of my study, I'll add that I've also been aware of but haven't yet tried to use non-ECM, variable Delta-T (ΔT) circs. I know they're out there, but I've simply not tried them. I'll also note that I've only used ΔP as an expedient means of converting a two-pipe reverse-return steam system into a single-zone forced hot water system.

My "process brain" has led me to appreciate and prefer Delta-T systems. And, by using a ΔT circulator with a super-efficient ECM motor, you get the best of both worlds – the best pumping strategy with greatest efficiency.

With a ΔT variable speed circulator, the pump varies its speed to maintain the designed-for ΔT. That means the Delta T will always be 20 F or whatever you dial it in for (5 F - 50 F) — even with heating load or outdoor temperature changes. A circulator changing its speed based on ΔP, however, will vary its speed to maintain a fixed system pressure differential. That is the case whether the ΔP is dialed in based on estimated system head loss or is automatically selected. The ΔT system will fluctuate, often decreasing energy expended to do the job optimally.



Paul Mercier tunes the system circulator's Delta-T value.

How does a reduced ΔT affect the system? Consider the impact on a modulating-condensing boiler. If the system is designed for a 20 F ΔT, but gets only a 12 F - 15 F ΔT, the amount of run-time the boiler spends below the point of flue gas condensation will be affected. Keep in mind that these boilers are designed for the higher ΔT and provide greatest energy performance under those conditions.

If the boiler is supplying heat to radiators, and the boiler's reset control is telling it to fire to a high limit of 142 F on a 20 F day, a ΔP circ programmed on an estimated system head loss may wind up sending 130 F water back to the boiler. That's right at the condensing point, making the boiler work at, say, 87 percent annual fuel utilization efficiency (AFUE) or higher, by design. But a circulator programmed to deliver a 20 F ΔT will send water back to the boiler at 122 F, creating more condensate, allowing a boiler to hum along at 89 percent AFUE.

For the jobs I've been doing lately, we opted to see how far and effectively the ECM ΔT circulators would perform as stand-alone system circulators, co-joined with zone valves to govern flow to any number of hydronic zones. Having now designed and installed several oil-fired ΔT-based distribution systems — initially using Taco's earliest ECM-powered circs, and now the VT2218 circulator, coupled with Zone Sentry zone valves — we've monitored and serviced these now for about two years. They

Continued on page 63

Continued from page 62

all live in variously-sized and aged single-family homes, from a 1,300-square-foot, 50-year-old seasonal house to a 2,800-square-foot, 10-year-old home. All are identically-sized and similarly configured systems within our 7,000-plus degree-day New Hampshire zone. I'll note that there's an ongoing discussion within our trade community about AFUE, particularly in what these ratings do not measure related to system performance. "Idle time" or "stand-by" losses are logically presumed to be non-contributory and detractive. Focusing only on boiler AFUE as an accurate depiction of system efficiency is fundamentally flawed.

AFUE is only one of many indications of system performance. Most heating systems are affected by a wide range of variables. We also learn, by reading about how these tests are performed, that accuracy is very difficult to achieve, so we've done some research of our own. And yes, inconsistency plagues even the best attempts to achieve accuracy; we confirmed it through our own field tests.

From our observations, there are five key factors that contribute to total system energy efficiency:

- The boiler (heat engine) energy conversion efficiency or AFUE.
- The physical attributes of the specific boiler complimentary to system operation.
- Efficiently moving heated water to the zone distribution point(s).
- The effective matching of radiation factors to heating demand.
- The control algorithm(s) to match energy creation with varying system demands.

All of our initial efforts have been with oil-fired hydronic systems and is the focus of my work (and this article). However, much of this effort is very applicable to other-fueled hydronic systems. The ability to vary output (energy creation rate) of heating equipment plays an important role. This has been achieved in gas-fired boilers by "modulating" combustion with sophisticated valving and controls. Typically, they adjust from 20 to 100 percent of capacity – from "idle" to "full speed" using an automotive analogy.

But there's a challenge. Direct modulation of oil-fired systems isn't feasible under normal circumstances. A fixed (capacity) firing rate via pressurized, nozzle induced fuel atomization is the norm. The only option is to adjust the operating temperature and cycling of an oil-fired hydronic boiler with controls to follow heating demand. This is reasonably well-managed with modern "cold-start" boiler aquastats, external temperature sensors, etc.

Referring back to our five factors to total system efficiency, circulation is number three on the list, but in reality is the foundation of any hydronic system improvement. Taco reports accurately that Delta-T circulator-only systems improve fuel use by up to 15 percent. They also reduce

"I prefer close-coupled piping my indirect water heaters, set for priority," Mercier said.

electrical consumption by up to 85 percent when compared to non-ECM, single-speed circs.

Unfortunately, we do not have the benefit of data recording equipment, so our observations are admittedly empirical. In other words, they are based on and verifiable by observation, experience and the reviewing of a lot of customer utility bills. I'll point out that we have had the additional benefit of developing and operating our personal integrated dual-fuel (oil-wood) hydronic system for the past 40 years that features a wholly convective inter-system loop (no circulator) and manually controllable convective zones. No electricity, no problem!

This personal hydronic convection experience is designed into our near-boiler piping configuration, complementing and optimizing Delta-T delivery. Disable the system circulator and actuated zones will continue to convect, albeit at a significantly reduced level. This is very dependent upon zone piping layout however, and the effect will vary widely.

Energy storage capacity or "thermal mass" in both iron and water complements hydronic operation, smoothing cycling and enhancing convection. Our boiler-of-choice has been the Weil-McLain Ultra Oil with the Beckett NX Burner for the past 10 years. (Only one "no heat" service call – a failed aquastat.) It also happens to be the heavyweight champion at over 600 pounds for a three-section, 100 MBH, 87 percent triple-pass boiler. A 30-plus year service life is not unreasonable from our experience with these and other oil-fired boilers.

Ironically our system packaging typically also reduces floor space, simplifies piping, valving, and wiring and controls as well. We also accentuate serviceability: every service and control component is within an arm's reach.

Our general system observations are:

• Dramatically reduced burner cycling, extending boiler and component service. This thing "seldom runs" is the first customer observation and is "so quiet" (compared to their prior unit, obviously).

• Multiple individual zones cycling between burner cycles, drawing from thermal mass storage (iron and water).

• Reduced average boiler operating temperatures.

• A pressure-fired burner seems to stabilize operation under particularly "cold-chimney" conditions, a frequent event in our "frosty north" external chimneys.

• The "close-coupled" HTP SuperStor Ultra (typically provided with our systems) acts as an integrated boiler protection device, being the shortest path in fail-mode convection.

System radiation, outside the scope of our ΔT system development, is still important in that it completes the hydronic heating system "package." Anything beyond basic series and split loops must be considered as affecting total system distribution energy. The more sophisticated the radiation scheme, the greater the installed cost and the projected system life-cycle operating cost.

The control algorithm has surprisingly become a non-issue in our system result. The high-mass oil boiler that we install uses a Hydrolevel 3250-Plus aquastat and paired with the Taco VT2218 Delta-T logic provides seamless operation. Despite not being physically interconnected, they work well under the thermal damping provided by the boiler's high mass. If any tweaking is necessary it can be done by adjusting the circulator's ΔT and/or boiler aquastat settings.

In our experience, residential Delta-T hydronic distribution steps beyond evolutionary advantage, becoming revolutionary in its impact. It will benefit any forced hot water system in degree, and thus is not a question of if it will become generally appreciated and applied, but when. Adding thermal mass into the equation further enhances system performance.

The "AFUE Wars" between boiler manufacturers and installers dissolves when Delta-T distribution is applied to improve fuel and electrical efficiencies. Combining the two is a sure path to improving any hydronic system's total efficiency. ■

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