Circulator Motor Efficiencies and the Game Changing Power of Delta-T Operation

We in the hydronics industry are being challenged every day to design and install the most energy efficient heating systems possible. This great challenge gives us a tremendous opportunity since we have products available today to make these super-efficient systems a reality.

But the key word here is system, and the dictionary describes a system as a group of interacting, interrelated, or interdependent elements forming a complex whole.

It’s our job to make sure the components we select work together, as a system, to produce the best, most effective and most efficient end-product for the homeowner.

This paper focuses on one seemingly innocuous piece of the system, the circulator, and shows how the choice of circulator can affect the system’s overall energy consumption.

For decades, installers had one type of circulator available to them – a standard fixed-speed circulator. Although three-speed circulators are now common, they are still fixed-speed circulators, since they run at a single speed at a time. The user has to select the appropriate speed for a particular application.

Since 2004, Taco has produced and sold the 00-VDT variable speed circulator, which varies its speed to maintain the heating system’s Delta-T, or the water temperature differential between the supply and return piping. More recently, Taco introduced its high efficient Bumble Bee circulator which also works on Delta-T but features a more efficient ECM motor. Finally, there has been an influx of variable speed ECM circulators from Europe that vary speed based on Delta-P, or system pressure differential.

The attraction of variable speed circulators is their affect on energy efficiency, in terms of both electrical usage and overall system performance. A standard circulator used for zoning, like the Taco 007, has a split capacitor AC induction motor with a power consumption of 81 watts. The Taco Bumble Bee uses a permanent magnet electronically commutated DC motor (ECM) that consumes 0 to 42 watts. Seems like a big difference, no? Once numbers are plugged in, we can get a more accurate view of actual electric savings.
The formula for estimating electrical consumption is simple:

Watts ÷ 1000 = kilowatts (KW)
KW x hours of daily usage = kilowatt hours per day (KWh/day)
KWh/day x # of day in use = total kilowatt hours
Total KWh x cost per KWh = cost to operate

The Taco Bumble Bee variable speed ECM circulator runs between 0 and 42 watts, depending on the heating load. Let’s presume a wintertime average of 19 watts. This average is based on the international standard that a circulator will run at full speed (design load) 6% of the time, at 75% of design load 15% of the time, 50% of design load 35% of the time, and 25% of design load 44% of the time:

\[
19 \div 1000 = .019 \text{ KW}
\]

How many hours does a circulator run per day? Obviously, it’ll run longer during the colder periods, less when it’s warmer. For a wintertime average we’ll assume 12.5 hours a day to determine the KWh/day:

\[
.019 \times 12.5 = .2375 \text{ KWh/day}
\]

For the cold-weather areas of the continental US, winter runs from mid-October through mid April, a six month period totaling 182.5 days:

\[
.2375 \text{ KWh/day} \times 182.5 = 43.34 \text{ total KWh}
\]

And finally, let’s presume a rate of $0.12 (12 cents) per kilowatt hour, which is the national average:

\[
43.34 \times .12 = \text{ $5.20 per year to operate a Taco Bumble Bee ECM based circulator.}
\]

Pretty good, huh?

**Note:** If using a European Delta-P style ECM circulators you also have to account for the energy consumed when the circulator is in the “standby” or “sleep” modes. Since these European circulators vary their speed based on Delta-P – or difference in pressure – these circulators always need to be constantly “on,” so that they may sense changes in system pressure and/or to remember its proper “Auto-Adapt” settings. These circulators will consume 5 watts of electricity every minute of every day, even when there’s no call for heat. The impeller doesn’t move water at 5 watts, but the circulator is still using power. This can add $1.37 per winter or an additional $3.63 if the circulator isn’t shut-off completely for the summer. Doesn’t seem like much, but it could add 77% to the pumps total electrical operating cost per year to run a Delta-P circulator compared to a Taco Delta-T controlled Bumble Bee.
Now that we know how much a Bumble Bee costs to operate let’s compare it to the standard in the industry, the Taco 007, to see how much electricity one could actually save. A simple, single speed Taco 007 consumes 81 watts:

\[
81 \text{ watts ÷ 1000} = .08 \text{ KW}
\]

\[
.08 \times 12.5 = 1 \text{KWh/day}
\]

\[
1 \times 182.5 = 182.5 \text{ total KWh}
\]

\[
182.5 \times .12 = \text{ $21.90 per year to operate a Taco 007 single speed circulator.}
\]

Compared to the estimated $5.20 annual consumption of a Taco Bumble Bee, that’s a difference of more than 75%. In actual dollars, however, it’s only $16.70 per year. Yes, it is more, but broken down over a 6 month heating season the savings is only $2.78 per month per circulator.

It’s good to look at numbers.

Now, if you take a look at “payback,” or return on investment, at a savings of $16.70 annually, it’s estimated that it will take 8-10 years for the electrical savings to offset the higher upfront cost of the more expensive variable speed ECM style circulator when compared to a Taco 007.

But what if we zone with multiple circulators? In theory the per-circulator savings would be compounded by the number of pumps used. However, properly designed systems which use variable speed circulators should include high efficiency zone valves, like the Taco Zone Sentry which draws only 1.4 watts when on, to control the flow to the zones rather than have a circulator for each zone. Also, using a variable speed Delta-P circulator for a single zone makes no sense, since there will never be any changes in pressure across the zone so the pump is basically a fixed speed pump. That’s a lot to pay for no benefit.

However, it is important to note that due to its unique Delta-T mode operation, both the Taco 00-VDT and the Taco Bumble Bee will vary speed when used as a zone pump. The circulator will run faster during colder outdoor temperatures in order to deliver more BTU’s to the system.

That covers the electrical savings analysis for ECM circulators. Now let’s look at the effect their operation has on the system. There are two types of variable speed circulators on the market today – one that varies its speed based on Delta-P, or system pressure differential, and one that varies its speed based on Delta-T, or system temperature differential.

What’s the difference, and which one is better?
Well, first, understand that the universal hydronics formula states:

\[ GPM = \text{BTUH} \div \Delta T \times 500 \]

GPM is the gallons per minute flow rate the system requires at a given point in time, BTUH is the heating load at a given point in time, Delta-T (\(\Delta T\)) is the designed-for temperature drop of the fluid; and 500 is a constant representing 100% water.

You’ll note there is no “Delta-P” in that equation. That’s because “Delta-P” has nothing to do with heat delivery.

When it comes to heat delivery, we care first and foremost about providing the right amount of BTU’s at any given point in time. And since BTU delivery is a function of flow rate, it’s imperative we deliver the correct amount of flow at that given point in time. In a zone valve system, as zone valves close, the amount of energy required to satisfy the heating load goes down. Therefore, the flow rate needed to deliver the required heat goes down.

In a system with a fixed speed circulator, the speed of the circulator can’t change. The only thing that can change within the system, the only variable left, is the system Delta-T, which will actually get smaller. So a system designed to a Delta-T of 20 degrees may never actually see a 20 degree Delta-T when in operation. Depending on how many zones are calling, the actual system Delta-T could be anywhere from a maximum of 16 degrees to a minimum of about 7 degrees or less.

With a Delta-T variable speed circulator, however, the circulator will slow its speed to maintain the designed-for Delta-T. And that means the Delta-T will always be 20 degrees, even as the heating load changes due to closing zone valves, or due to changes in the outdoor temperature. A circulator changing its speed based on Delta-P, whether the Delta-P is dialed in based on estimated system head loss or is automatically selected, will vary its speed to maintain a pressure differential in the system. It doesn’t know how much heat is needed in each zone; if there are five zones in a home, a Delta-P circulator becomes a “however many zones are open at any given point in time” speed pump.

The system Delta-T, however, will still fluctuate depending upon the programming, and will more than likely be less than what was designed for.

It’s also important to note that with any manually-programmed Delta-P circulator, both the circulator and the heating system will operate on a fixed pump performance curve. When a Delta-P circulator is programmed to a specific “maximum system head pressure,” a new pump performance curve is drawn. The circulator will slow down as zones close, but the speed will be pre-determined by the new performance curve. What that means is that the circulator will run at a specific speed no matter what the BTU load of the structure is at any given point in time. If that particular speed is too low, the circulator will be unable to deliver sufficient heat. If the speed is too high, the system will over pump, causing a narrower-than-desired Delta-T.
How does a lower-than-designed-for Delta-T affect the system? Let’s consider the impact on a modulating-condensing boiler. If the system is designed for a 20 degree Delta-T, but is only getting a 12 to 15 degree Delta-T, the amount of run-time the boiler spends below the point of flue gas condensation can be affected.

Presume the boiler is serving a radiator job, and the boiler’s reset control is telling it to fire to a high limit of 142 degrees on a 20 degree day. A Delta-P circulator programmed on an estimated system head loss may wind up sending 130 degree water back to the boiler. That’s right at the condensing point, making the boiler work right around 86% thermal efficiency.

However, a circulator programmed to deliver a 20 degree Delta-T will send water back to the boiler at 122 degrees. This lower return water temperature will create more flue gas condensation and make the boiler work at around 89% thermal efficiency.

Do those three percentage points make a difference in fuel consumption? To estimate the difference in gas usage over the course of one hour, with heating load of 50,000 BTU’s at a 20 degree outdoor temperature, divide the heating load by the BTU/H content per therm of gas, and then divide by the thermal efficiency of the boiler:

At 86% efficiency:

\[50,000 \div 100,000 \text{ BTU/therm} = 0.5 \div 0.86 = .5814 \text{ therms of gas burned during that hour.}\]

At 89% efficiency:

\[50,000 \div 100,000 \text{ BTU/therm} = 0.5 \div 0.89 = .562 \text{ therms of gas burned during that hour.}\]

That’s two-tenths of a therm per hour difference. No big deal, right? Well, at an average rate of $0.95 per therm, the difference in cost for that one hour is almost 2 cents worth of natural gas. If we multiply that over the course of heating season, the annual fuel savings is worth about $50.00 to $60.00, which is roughly 3 1/2 times the electrical savings realized by an ECM motor based circulator.

This is a classic case of “stepping over a dollar to save a dime.”

Also consider a cast-iron oil or gas fired boiler. The arithmetic is less clear cut due to the boiler’s high thermal mass, but consider both the steady state and the cycle efficiency of a cast iron boiler with 160 degree return water vs. 168 degree return water. Obviously, during the dead of winter, the boiler will have longer burn cycles with the lower return water temperature, which will greatly reduce short-cycling. But the burn cycles will also lengthen during the milder temperatures as well, due to the consistent system Delta-T. If you combine a Delta-T variable speed circulator with an outdoor reset control that will also vary the boiler’s firing differential, then you have a cast iron boiler that will be as efficient as it can possibly be.
How much energy will be saved? In actual heating systems we have been seeing total savings on fuel bills from 5-15% depending on the type of fuel, system equipment and piping configuration. An ECM style pump may save an average of $16 per year in electricity but that same pump when operated on true variable speed Delta-T operation can save hundreds of dollars.

To sum up, it’s important to look at the system as a whole, rather than the sum of its parts. When designing and installing a heating system, we are in fact creating a group of elements that interact, that are interrelated and are interdependent, and they do form a very complex whole that is designed to keep people comfortable while minimizing energy usage. The system’s relative success or failure depends on how well these elements work together to perform the system’s stated function. When it comes to comfort, it’s all about supplying the right amount of BTU’s to the right rooms at the right time. And the amount of BTU’s provided at any given point in time is directly related to Delta-T, not Delta-P.