Evaporator Accuracy

Subject and Scope

In the use of Mesurflo flow controllers in water source heat pumps, what level of accuracy is required?

1. Applicability

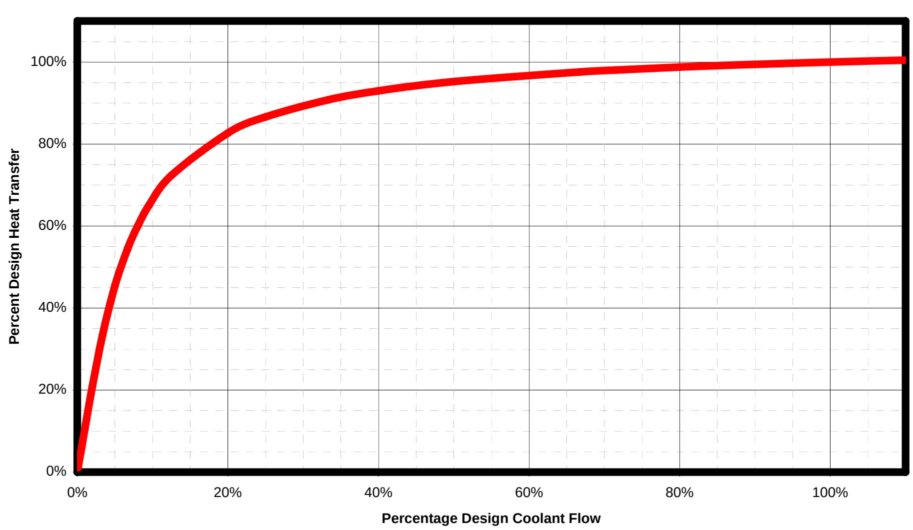
This Technical Tip applies to all water source heat pumps and air conditioners.

2. Summary

The impact of flow control device accuracy on heat exchanger performance is non-linear. The variation in heat transfer from a heat exchanger resulting from variation in flow rate is less than the percentage change in the flow rate. A ±10% flow control will provide better than ±5% on heat transfer variation. The following discussion will provide analysis and data to prove this.

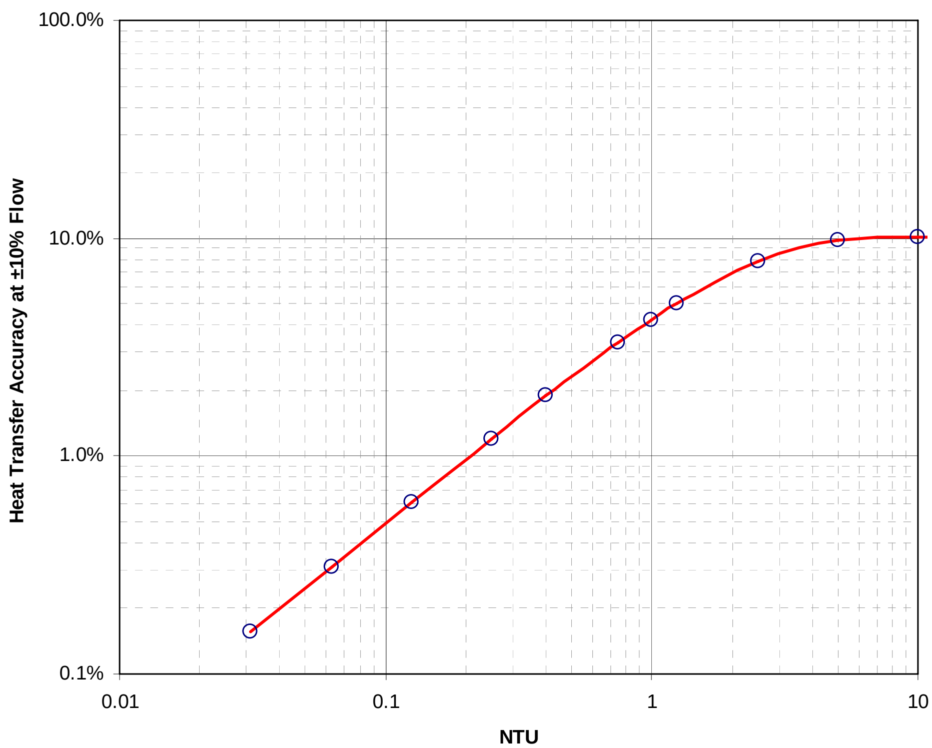
3. Background

The water flow in a water source heat pump (or air conditioner) is used as either source or sink for heat. Automatic flow control devices are intended to be used to regulate the flow of water to the heat pump ensuring that high pressures do not cause this excessive flow and result in either catastrophic failure (erosion) or starving of other heat pumps in the distribution system. The accuracy of the flow rate required is a frequent topic of discussion. The change in heat transfer due to variations in flow of a condenser or evaporator is provided below.
This curve demonstrates the physical limitations in heat exchanger design. As



flow is increased the heat transfer continues to increase, however, the rate slows down. This
is referred to as diminishing returns. This curve can be derived from the effectiveness-Number of transfer units (NTU) equations. The relationship used to create this graph is valid for all types of heat exchangers that operate with a condensing or evaporating fluid.

Inspection of this curve indicates that at the design point, 100% flow, of the heat exchanger a change in coolant flow rate will result in a much smaller change in heat transfer. From this it is also obvious that the impact of a change in flow is dependent upon the choice of design point. The effectiveness – NTU relations allow us to determine the accuracy of a flow control device necessary to achieve a specific range of heat transfer control. The technique used to establish the accuracy of heat transfer rate as a function of flow is described in the next section. The graph below presents the heat transfer variation due to a ±10% variation in flow.



4. Details

The heat capacity, C, of a fluid is the product of the mass flow rate and the mass specific heat capacity of the fluid. For fluids that undergo a change of state there is no change in temperature with absorption of heat therefore the heat capacity of the side changing state is taken to be infinite.

The minimum fluid, C_{MIN}, is the fluid with the smallest value of heat capacity. For this reason the minimum fluid in a condensing or evaporating heat exchanger (as in a water source heat pump) is always the water.

The maximum possible heat transfer, Q_{MP}, is the heat capacity of the minimum fluid times the result of inlet temperature of the hot fluid minus the inlet temperature of the cold fluid, $Q_{MP}=C_{MIN}*(T_{WATER,IN}-T_{REFRIGERANT,IN})$.

The actual heat transfer, Q_{ACT}, is the heat that will be transferred by the heat exchanger under the conditions specified. It is also equal to the heat capacity times the temperature difference of the water, $Q_{ACT}=C_{MIN}*\ \ T_{WATER}$.

Effectiveness ( ) is defined as the ratio of the actual heat transfer to the maximum possible heat transfer.

The Number of Transfer Units, NTU, is defined as the overall heat transfer coefficient, UA, divided by the minimum heat capacity, C_{MIN}.

The definition for effectiveness may be expressed as follows:

$$\varepsilon = \frac{Q_{ACT}}{Q_{MP}} = \frac{C_{MIN} * \Delta T_{WATER}}{C_{MIN} * \left(T_{WATER,IN} - T_{REFRIGERANT,IN}\right)} = \frac{C_{MIN} * \Delta T_{WATER}}{C_{MIN} * \Delta T_{MP}}$$

The actual heat transfer can be determined from:

$$Q_{ACT} = \varepsilon * Q_{MP} = \varepsilon * C_{MIN} * \Delta T_{MP} = \varepsilon * \left(\frac{UA}{NTU}\right) * \Delta T_{MP}$$

The effectiveness for a heat exchanger with an evaporating or condensing fluid may be expressed as:

$$\varepsilon = 1 - e^{-NTU}$$

Substituting this expression to the one above:

$$Q_{ACT} = \left(1 - e^{-NTU}\right) * \left(\frac{UA}{NTU}\right) * \Delta T_{MP}$$

This expression provides a means of determining the heat transfer of a heat exchanger as a function of NTU and two constants, UA and T_{MP}. After the heat transfer is calculated the following expression can be used to determine how large a change in NTU will make a change of ±5% in heat transfer:

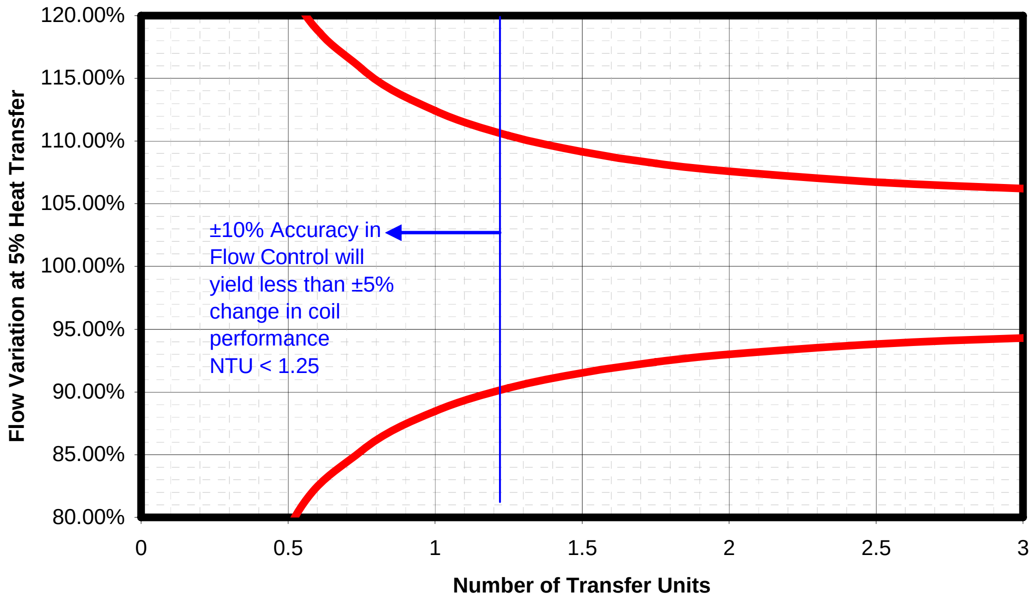
$$NTU' = -\log\left(1 - \frac{\Delta T_{WATER}}{T_{WATER,IN} - T_{REFRIGERANT,IN}}\right)$$

Since we are holding UA constant the ratio of C_{MIN}’ to C_{MIN} is as follows:

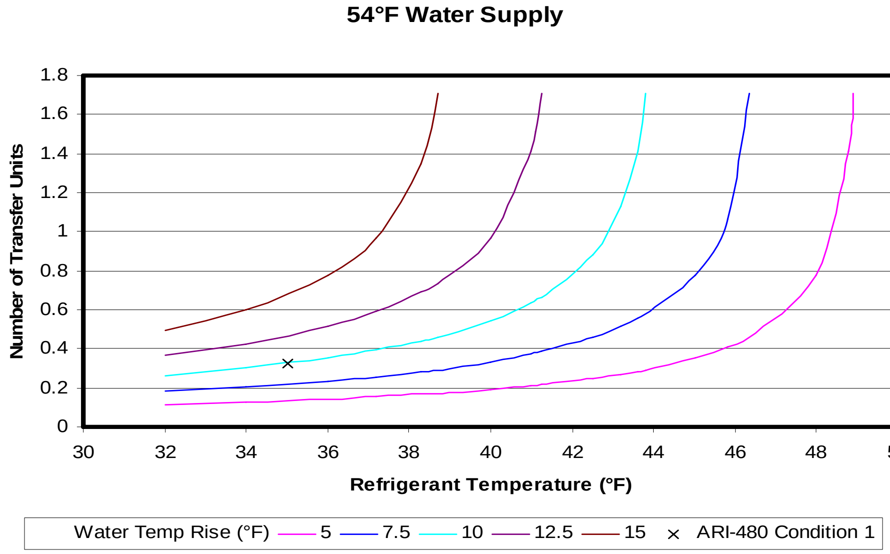
$$\frac{C'_{MIN}}{C_{MIN}} = \frac{NTU}{NTU'}$$

For fluids such as water the density and specific heat have such a minimal change the ratio of C'_{MIN} to C_{MIN} is the same as the volumetric flow ratio.

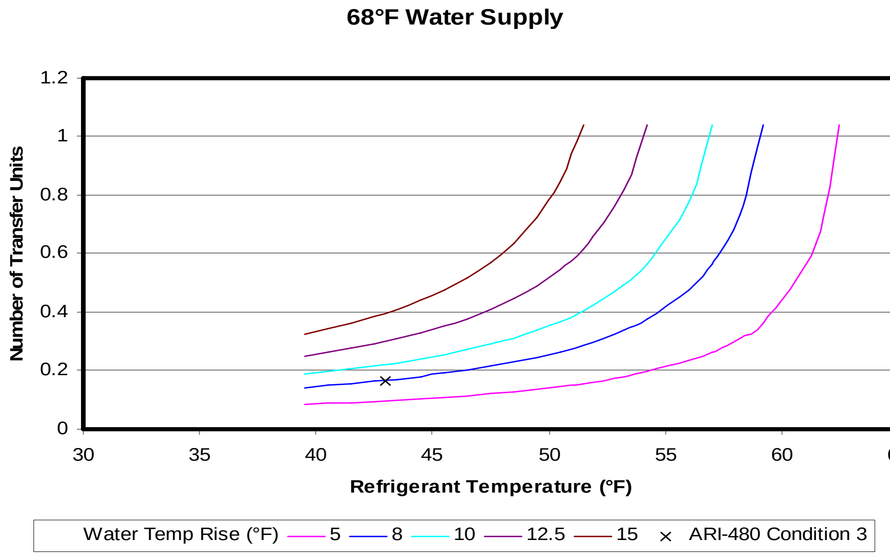
The graph below relates the required accuracy in flow to maintain heat transfer within a ±5% range of nominal. Below an NTU of 1.25 a ±10% change in water flow will meet the requirement. As NTU decreases further even lower flow accuracy is required to meet the ±5% range.



Diminishing returns also occur relative to the size of a heat exchanger. The ideal heat exchanger would bring the temperatures of the water to the temperature of the refrigerant, or 100% effectiveness. The difference that exists in real heat exchangers between the outlet water temperature and the refrigerant temperature is called the approach temperature. As the temperature of the water approaches the refrigerant temperature the size of the heat exchanger approaches infinity. In the plot below lines of constant T_{WATER} are plotted on the range of refrigerant temperature and NTU. This plot demonstrates above an NTU of approximately 1 very limited returns exist for increasing the size of an evaporative heat exchanger. Design rating condition 1 from ARI standard 480-1999 is also plotted on this graph at a value of approximately 0.33.

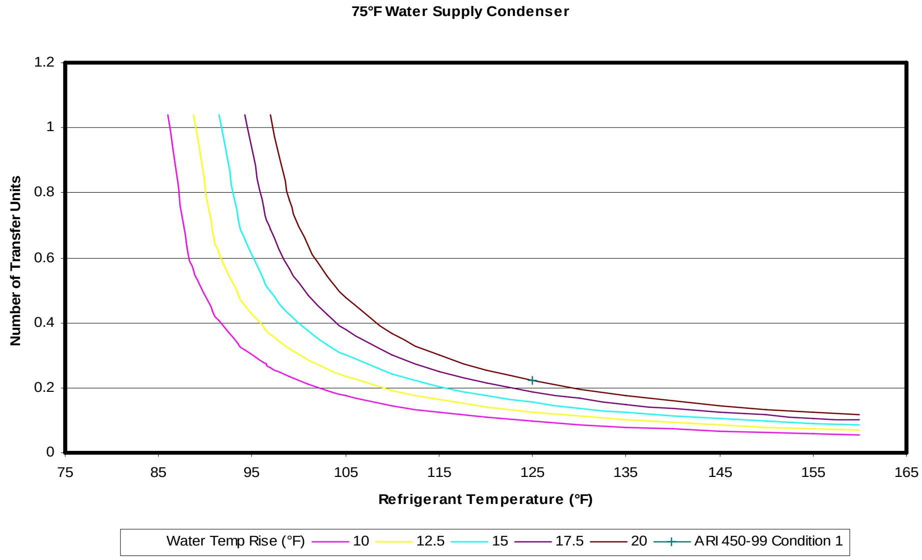


The design rating condition 3 from ARI standard 480-1999 is plotted on the graph below, the NTU value is approximately 0.17.

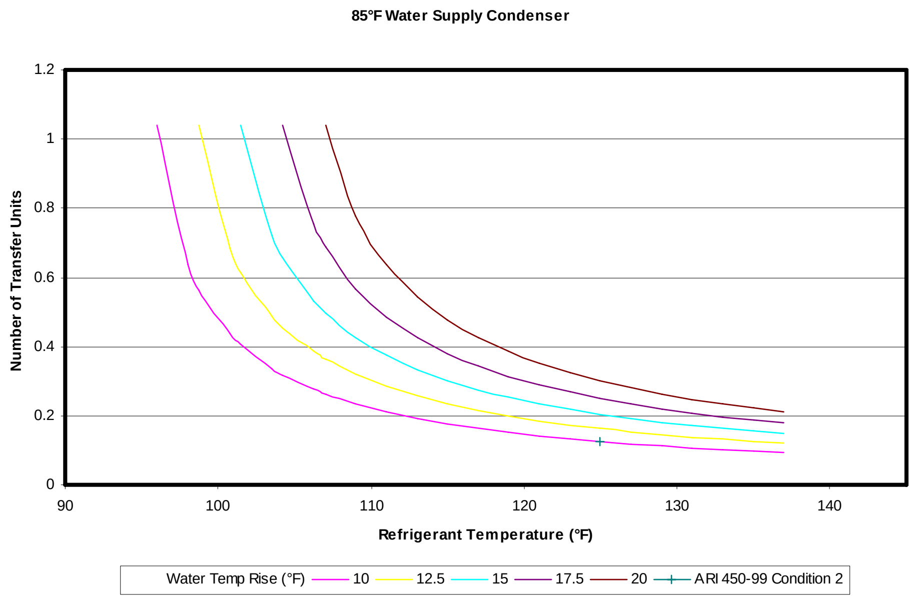


This plot can easily be made for a variety of conditions to demonstrate that above an NTU of 1 the increase in size of an evaporative heat exchanger relative to the incremental heat transfer is prohibitive.

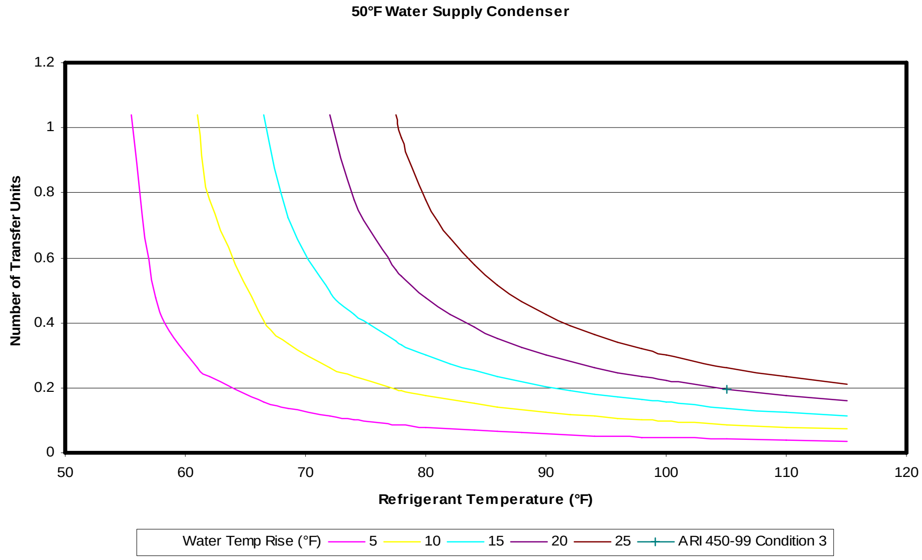
The same analysis as made for an evaporator can be made for a condensing heat exchanger as is found in water source air conditioners. Typical plots of condenser performance are provided below. The first plot includes ARI 450-1999 condition 1 for which the NTU value is approximately 0.22.



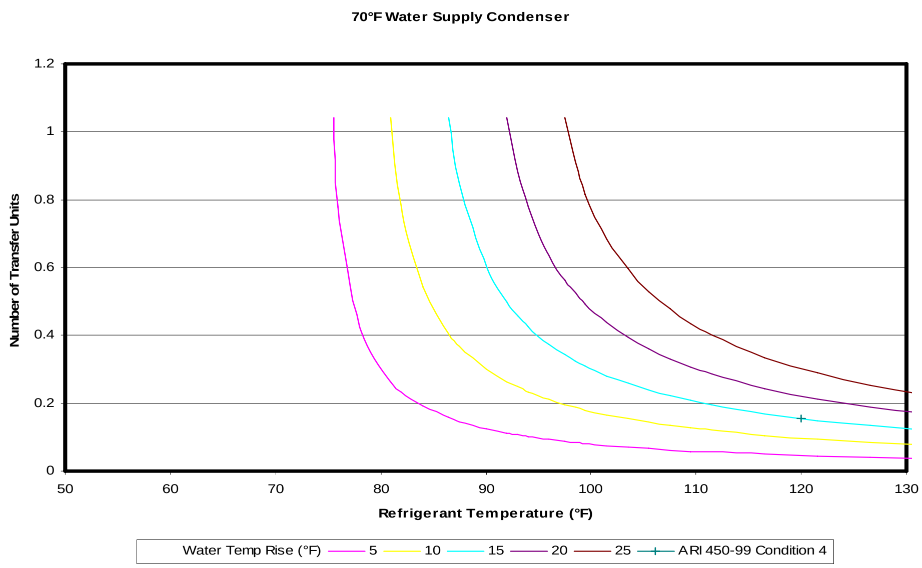
The next plot is for 85°F inlet water temperature and includes ARI 450-1999 condition 2.



The next plot is for 50°F inlet water temperature and includes ARI 450-1999 condition 3.



The next plot is for 70°F inlet water temperature and includes ARI 450-1999 condition 4.



The results of this method of determining reasonable NTU ranges for the design point of water cooled condensers and evaporators correlates well with literature from coil manufacturers and the ARI test conditions. While neither directly specifies a level of NTU both provide temperatures and / or flow rates that can be used to determine design point NTU's.

5. Support

For additional information or questions on the content of this Technical Bulletin please contact Hays Customer Service.