HVAC Flow Control Methods

An HVAC piping system is designed to convey a heat transfer fluid to multiple air handlers, providing cooling (chilled water) or heating (hydronic heating) loads in a building. A typical HVAC system consists of a primary loop and a secondary loop. The primary loop contains the chiller or boiler along with primary circulating pump(s). The secondary loop draws fluid from the primary loop and consists of a secondary pump along with the supply header piping, various air handlers, and return header piping. The primary and secondary loops are connected so that there is a mixing of fluid between the loops.

The key to designing an HVAC circulating water system is to control the flow rates to the various air handlers in order to maintain the temperature in the conditioned spaces. There are two types of methods to achieve this goal; one is a constant volume system, the other a variable demand system. Each method is described in detail at the end of this case study.

In this analysis, we will see how to achieve significant cost savings by using a variable demand system vs. the more traditional constant volume system. This analysis will be performed using version 2009 of the PIPE-FLO program.

To follow the analysis, you can download the file "HVAC Control.pipe" by clicking the link in the "Attachments" section at the bottom of this article and saving the file to your default PIPE-FLO projects folder.

Modeling the System with PIPE-FLO

Before you design a new system, or make major modifications to an existing piping system it is a good idea to create a computerized hydraulic model of the HVAC piping system. Piping software can provide the information needed to properly select the pumps and control valves. In addition, the computer model provides a good understanding of the interaction of pumps, pipelines, and control valves. The information from the computerized model can also be used to perform an economic analysis of pumping costs for both types of control systems. Figure 1 below shows the model of an HVAC system modeled in PIPE-FLO software. This is the downloadable system we will be using for our analysis.

To perform this analysis, we will:

- Use PIPE-FLO to analyze the system under constant volume control.
- Use PIPE-FLO to analyze the system under variable demand control.
- Perform a pumping cost analysis to compare the two types of HVAC control.

HVAC System with Constant Volume Control

1. Start the PIPE-FLO program.
2. Open the HVAC Control system you downloaded from this article. NOTE: The system opens up under the Constant Volume lineup as indicated by the lineup drop-down list on the toolbar. Lineups are different operating scenarios for the system.
3. Click the calculate button to see how the system operates with constant volume control.

The differential pressure across the paths is displayed next to the FCV symbol. Since this is modeling a constant volume system, the FCVs show the flow going through both the bypass line and the air handler. Move your mouse over each pump and view the pump results in the fly-by viewer. Both secondary pumps are operating just over 660 gpm, and since this is a constant volume system both pumps will be running constantly at this flow rate year round.
HVAC System with Variable Demand Control

In a variable demand system the flow rates to the loads vary based on the required heating or cooling needs. The first requirement is to estimate the required flow rates. They are based on the heating or air conditioning loads, and may vary by the time of the year and time of day. In this analysis, it has been assumed that the average flow requirements in the winter months will be 30% of the maximum design flow, spring and fall is 45% of the maximum, and in the summer the design flow is 85% of the maximum. It is important to realize the maximum design load is based on the needs for the hottest or coldest day of the year.

A series of lineups has been created for this case study which includes Winter, Spring/Fall, and Summer operation. The lineups were quickly created using the System/Flow Adjustments menu item.

1. Click in the lineups drop-down list and select the Spring/Fall lineup. Note that the Spring/Fall lineup only has one secondary pump operating.
2. Double-click on the SP1 pump. Notice that it is set to run as a variable speed pump with 534 gpm output. This means that the pump speed will ramp down until the output is 534 gpm.
3. Click on the graph button in the pump dialog box. The graph window is displayed as shown below in Figure 2. Note that the pump's speed has dropped down to 800 rpm.

![Variable Speed Pump Graph Window](image)

Also notice the flow control for the C{03} air handler has been set to the fully open position. If we were controlling the flow rate through the pump as well as the flow rate through all of the paths, the system would be overcontrolled. Since the flow rate through the system is only 534 gpm, the head loss in the various pipelines is also much smaller than it was for the constant volume system. Since the head losses are smaller, the pump can run at a slower speed, which produces less head, and consumes less power.

Repeat the above steps for the Summer and Winter lineups. With a variable demand system only one secondary circulating pump is needed to meet the system pumping requirements, even with a system diversity factor of 85%. When you are finished, close the graph window and pump dialog boxes.

Pumping Cost Analysis (Version 2009 only)

Next we will determine the pumping costs for each of the two flow control methods. With PIPE-FLO's Operating Cost Calculator, you can set up your lineups to represent the different operating load scenarios which a piping system will undergo. Then you can define the amount of time the system will spend under each of those scenarios.

Constant Volume Pumping Costs

1. Click the Operating Cost button on the toolbar. This opens up the Operating Cost Calculator dialog box as shown below in Figure 3.
2. Specify an Analysis Period of 1 year.
3. Leave the Lineup as Constant Volume.
4. Change the Energy Cost to $0.08.
5. Click the Calculate button. This opens up the Operating Cost Calculator Results window as shown below in Figure 4. When you are finished reviewing the results, click the Close button to close the results window.
Notice that the operating costs for pumps SP1 and SP2 are $10,012 and $10,062. Together, the operating cost for the secondary pumps running at a constant volume and fixed speed is $20,074.

### Variable Demand Pumping Costs

1. If the Operating Cost Calculator dialog box is not displayed, reopen it by clicking the Operating Cost button.
2. Keep the Analysis Period as 1 year.
3. Change the Input Time to Percent.
4. Under Lineups, change the Constant Volume lineup to Summer.
5. Change the Energy Cost to $0.08.
6. Change the % of Time to 25.
7. Add a new lineup by clicking the Add button.
8. Change the second lineup to Winter.
9. Change the Energy Cost to $0.08.
10. Change the % of Time to 25.
11. Add a third lineup by clicking the Add button.
12. Change the third lineup to Spring/Fall.
13. Change the Energy Cost to $0.08.
14. Change the % of Time to 50. The Operating Cost Calculator dialog box should now look like Figure 5 below.

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**Figure 5: Operating Cost Calculator dialog box w/multiple lineups**

<table>
<thead>
<tr>
<th>Lineup</th>
<th>Energy Cost ($)</th>
<th>% of Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>.08</td>
<td>25</td>
</tr>
<tr>
<td>Winter</td>
<td>.08</td>
<td>25</td>
</tr>
<tr>
<td>Spring/Fall</td>
<td>.08</td>
<td>50</td>
</tr>
</tbody>
</table>
15. Click the Calculate button. This opens up the Operating Cost Calculator Results window as shown below in Figure 6.

**Figure 6: Operating Cost Calculator Results - Variable Demand**

The first important note here is that the system is capable of meeting the demands year-round using only one secondary pump. The operating costs for this secondary pump are $3080 in the summer, $140 in the winter, and $560 in the combined spring and fall seasons for a total of $3780 for the year.

This annual operating cost for the secondary pumps is significantly less than the cost associated with the constant demand system. It is important to note that the reduction in pumping cost can only be brought about by installing a variable frequency drive (VFD). It is also important to factor the cost of the VFD in your life cycle pumping cost calculations.

This concludes the PIPE-FLO example. The information below provides some additional detail on how constant volume and adjustable demand systems operate.

**Constant Volume System**
The constant volume system is the more traditional method in which the system is balanced, such that a constant volume of fluid is flowing to each air handler regardless of the load. The piping to the air handler consists of a three-way valve that directs flow to the air handler or to a bypass line (see Figure 7 below). In a constant volume system the combined flow in the bypass line and to the air handler is constant, regardless of the flow rate to the air handler. A three-way valve directs the fluid through the bypass line, unless there is a demand on the air handler. When a demand is placed on the air handler, the three-way valve is repositioned to send some fluid to the air handler and less fluid through the bypass line. When there is no longer a demand by the air handler, the three-way valve redirects the flow through the bypass line.

The major advantage of the constant volume design is that once the system is balanced, by setting the design flow rate to each load, the control system is very stable. The three-way valve is able to direct the flow to the air handler without affecting the total flow rate through the system.

The major disadvantage to the constant volume system is the flow rates to each air handler are the same year round regardless of the system's heating or cooling load. In other words, in an HVAC chilled water system the flow rate through the secondary loop is the same for the coldest day of the winter as it is for the hottest day of the summer. Therefore, constant volume systems typically have a higher operating cost because the flow rate through the secondary system is the same regardless of the system load.

**Variable Demand System**

Now that energy costs are higher, variable demand systems are becoming more popular. On a variable demand system the three-way valve and bypass line are replaced with a pressure reducer and control valve in series to regulate flow to the air handler (see Figure 8 below). As the control valves in the other loads regulate the flow rate through the various paths, the differential pressures across the control valve can vary considerably. The wide variation of differential pressure across the control valves due to changes in system loads could cause problems with the control valve. To overcome this problem, a pressure regulator is placed upstream of the flow control valve to absorb some of the excess differential pressure between the supply header and return header. The job of the pressure regulator is to reduce the pressure drop across the control valve. A smaller valve actuator can then be used so that a finer control can be achieved.
Using a variable demand system saves on the operating cost, because the flow rate through the system varies to meet the needs of the system demands rather than maintaining a constant system flow rate.

Greater pumping cost savings can be achieved on a variable demand system by adding a Variable Frequency Drive (VFD) on the pump. As mentioned previously, a pressure regulator is typically placed upstream of the control valve to limit the maximum differential pressure across the control valve. That is because as the flow rates in the other paths decrease, the pump moves back on its pump curve and provides a greater differential pressure across the pump. This results in a greater differential pressure across the supply and return headers. The job of the pressure regulator is to absorb some of the excess differential pressure so that the control valve can operate properly.

By installing a variable speed drive and controlling the pump's speed based on the differential pressure across the various control valves, the pump produces less head for the same flow rate. This results in a lower differential pressure across the pressure regulator. Since the pump head is less, the pump consumes less energy, resulting in further savings in pumping cost.

It is important to remember that there needs to be a minimum differential pressure across each control valve for the valve to operate properly. The purpose of the variable speed drive is to slow down the pump to provide only sufficient head needed for the control valves to operate properly. There is usually one control valve in the system that has the lowest differential pressure, and this is referred to as the most hydraulically remote control valve. A differential pressure sensor can be installed across the most hydraulically remote control valve to control the pump speed.

One additional point to remember; based on the various load combinations to the air handlers, the most hydraulically remote control valve in the system can change. Therefore, additional differential pressure sensors may be needed, resulting in additional instrumentation. Since there may be many loads in a large HVAC system, it can become cost prohibitive to insert differential pressure instrumentation on each control valve in the system. It is more cost effective to install the differential pressure controls only on the valves in the system that have the possibility of the lowest pressure drop. This requires a good understanding of the HVAC piping system.

Attachments:

* HVAC Control.pipe