46

Hydronic systems overview

Hydronics, for the purpose of this chapter, will be defined as single-phase (liquid) energy transport systems, such as chilled or hot water systems. Over the past two decades, these systems have moved into the position of being the most commonly used heat transport and intermediate fluid energy transfer systems. If the reason for the shift to hydronics could be summed up in a single phrase, it would be *inherent ease of control.*

Although hydronic systems may lack some of the advantages of two-phase systems or all-air systems, their adaptability to multiple zones of load control with highly effective performance results has proved an overwhelming benefit. This benefit has had some backlash, in that the systems could be extremely forgiving of design or installation errors, such as oversizing of loads, sources, pumps, piping, etc., and the inherent control simplicity would correct for the deviations and still provide acceptable performance results.

Fundamentals re-evaluated

Like most new and rapidly growing technologies, the development of hydronic systems "happened" more than it was planned; i.e., much of the hardware development and system design evolution was to address prior problems. Three marketplace pressures are currently present that are forcing a re-evaluation of the fundamental concepts of hydronic systems. They are:

- Awareness of energy economics has resulted in a consideration of the inherent process energy waste resulting from both overdesign and designs that do not take into account auxiliary systems and false loading burdens.
- The spiraling costs of construction and interest rates on investment money have exerted pressures upon the engineering profession to develop systems that can be installed at a minimum construction cost while still satisfying the other performance and design parameters.
- The relatively simple concepts employed in earlier, smaller systems were not reevaluated as the hydronic systems grew in magnitude and complexity. As a result, hydronic systems of a complexity that is virtually impossible to understand have been installed spanning large campus complexes and large, densely populated areas.

The last of these was recognized prior to the energy and cost implications, and its presence or recognition formed the basis for reevaluating the concepts. There are two fundamental aspects to the analysis of a hydronic system that must be recognized if a systems analysis is to be performed: they are the *hydraulic analysis* and the *thermal analysis*. Although these are separate phenomena, they are intimately interdependent.

Hydronic system is hydraulic

The vast majority of problems revealed by the large complex systems was due to the lack of recognition of the hydraulic phenomena. Simply, a hydronic system is a hydraulic system containing a noncompressible fluid. As such, any change in pressure or flow rate in one part of the system, no matter how small or remote, will affect the pressure or flow rate in *all other parts of the system*. The only element of compressibility is the compression tank, which has a fundamental role in the hydraulic analysis. The compression tank contains the liquid of the system and a compressible gas (with either a free interface or separated by a diaphragm). Its salient hydraulic function is to establish the hydraulic constant pressure point in the system. Under operational dynamics, as valves change positions, pumps cycle on and off, and so on, the pressures at *all* other points will change, but at the point of the connection of the compression tank, it will be constant. This is analogous to the electrical concept of ground potential. Except for the ground in an electrical distribution and utilization system, all potentials are simply relative to one another, and an analysis of such a system is impossible to undertake without the ground reference. Similarly, in a hydronic system, any efforts at a hydraulic analysis cannot be undertaken effectively without establishing the ground, which in the analogy is the pressure at the compression tank.

Consider these basic rules

This establishes the first cardinal rule in the hydraulic systems analysis: *no hydronic system, no matter how large or complex, should have more than one compression tank connection*. Multiple tanks can be used if they are piped to function as one vessel and connected to the main piping at a single point.

The second basic component of the system that must be addressed in the hydraulic analysis is the load. The load is the component that transfers thermal energy between the system and the conditioned space or the psychrometric system that conditions the space. Considering the load control from the standpoint of the hydronic system, the load is controlled (reduced from design quantities) by reducing the log mean temperature difference between the hydronic fluid and the air. This is accomplished in most systems by either reducing the flow rate of the hydronic fluid or by reducing the temperature difference between the entering fluid and the entering air (reducing the EWT in heating systems or increasing the EWT in cooling systems). Although the heat transfer rate (or load control) is a thermal analysis phenomenon, if it is accomplished by either of those two means, it affects the hydraulic analysis.

Load control is important

The method of load control has been observed to be one of the most important and least understood design requirements of the hydronic system. The decision as to what method of load control to apply must be made with careful consideration of its impact on both the thermal and hydraulic characteristics of the system.

From the thermal standpoint, the three methods of control are:

- constant flow and constant entering temperature and variable air side mass flow;
- constant entering or leaving fluid temperature and variable flow in the load circuit;
- constant load circuit flow and variable entering fluid temperature.

The first of these has historically been employed in smaller loads, such as unit heaters, with cycling of the fan or blowers, and in larger systems, with face and bypass control as for preheat coils or hot deck and cold deck coils of multizone or double duct systems. This method has no impact on the hydraulic system; i.e., the hydraulic system does not "know" whether the load at any given time is 100 percent or 10 percent of design. From an energy standpoint, the hydraulic system energy input is always at design quantity. Thermally, because of numerous phenomena, such as damper leakage, excess dehumidification, and so on, the wild flow-coil systems generally impose increased loads upon both chiller and boiler systems, relative to the reductions in space load. Thus, in the interest of energy economics, the use of wild flow systems is generally considered to be undesirable.

The second method, constant entering or leaving fluid temperature and variable flow in the load circuit, has historically been the most common control mode employed. In the simplest configuration, the on-off cycling of the circulator or pump is a form of this mode of control. As the load senses it, this is a frequency modulation or on-off control, and it has generally been limited to smaller heating-only systems. The understanding of the hydraulic impact of the on-off method is fundamentally simple if the constant pressure point has been properly established. If this has not been done, pump cycling can have catastrophic effects.

Valve control is one method

In larger systems, valve control is used to provide the variable load flow. Identical thermal response relating to the load is achieved with either a three-way or two-way throttling valve. The three-way valve is usually a mixing valve, installed at the outlet of the load device so that, as it mixes inlet flow streams, the flow from the bypass stream essentially accomplishes a reduction in the flow rate through the load. The same reduction in flow through the load can be accomplished with a throttling or two-way valve that is installed in the load circuit either upstream or downstream from the load device and responds to load reductions by simply throttling the flow. The selection of the type of valve is predicated upon a system feature other than load control. The differences are fundamentally hydraulic. When a three-way valve is employed, the total flow rate through the system, or at the least load circuit, is essentially constant. This, then, is theoretically a constant flow, variable temperature differential circuit as the hydraulic system sees it and as the thermal source system sees it. Being constant flow, the reduced load energy consumption by the hydraulic system is equal to the full load energy rate. From the standpoint of energy economics, this is an undesirable feature.

The two-way valve, on the other hand, has the feature of impacting the thermal source system with a reduced load characteristic of reduced flow and essentially constant temperature differential. It relates to the hydraulic system by reducing the flow rate and increasing pressure differentials across both the pump and the load circuits. Because of those pressure variations, application of two-way valves requires careful design attention to:

- location of the constant pressure point;
- maximum allowable pressure differential across the valves; and
- characteristic curves of the pumps.

The feature of variable flow reflected on the source generally improves the control stability and simplicity of the source system, but again imposes the requirement of careful design attention to the source apparatus configuration. Because of these crucial requirements of design in "two-way" valve systems, extensive use has been made of the three-way valve. However, from the standpoint of energy economics, this has been a costly alternative. The benefits of reduced energy consumption at reduced flow can no longer be overlooked, and future systems designers and manufacturers will be led to address the design concepts associated with the throttling valve load control systems.

Third control method cited

The third load control method, constant flow and variable entering fluid temperature, is also seen in numerous configurations. In its simplest form, this control method is achieved by varying the temperature of the fluid at the source system. It is commonly called reset control in heating water systems, used where the need for heat varies with outdoor temperature, such as in perimeter radiation or homogeneously loaded dual stream fan systems. This approach provides for stability of control in the case where it is compounded with fluid control, or pure simplicity where it is employed with wild flow circuits. The only hydraulic phenomenon interaction is that the wide range of average system temperatures must be considered in sizing the compression tank.

In larger systems with essentially nonhomogeneous load requirements, this type of control is accomplished by unique load-assigned pumping, commonly called secondary pumping.

Secondary pumping increasing

Secondary pumping is finding increasing use in large, complex systems for the fundamental reason that it provides a *modular* aspect to the design, seemingly simplifying the understanding of these extended systems. However, when improperly applied, secondary pumping can add a degree of complexity and control instability that is impossible to cope with. This is a result of a lack of proper understanding of the hydraulic phenomena.

In its simplest form, the cardinal rule of design for all secondary pumping systems is that the primary circuit must have no dynamic

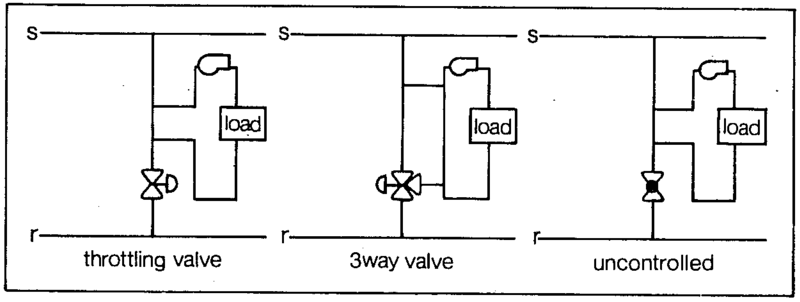

Fig. 46-1. Three basic secondary pumping connections.

hydraulic effect upon the secondary circuit and the secondary circuit must have no dynamic hydraulic effect on the primary circuit. This is a simplified statement of the "common pipe" concept originally published by G. F. Carlson.[1] Although there are numerous configurations of the secondary pumping connections, they can virtually all be reduced hydraulically to one of the three diagrams shown in Fig. 46-1. A cursory study of the three diagrams will reveal some rather interesting features:

- The primary circuit is hydraulically unaffected by either the operation of the secondary pump or the hydraulic control aspects (not shown) of the secondary circuit load.
- Dynamic hydraulic effects on the primary are contributed *only* by the positioning of the control valves or balancing valve. In this regard, as the primary system sees it hydraulically, a pumped secondary circuit connection is no different from a simple valve-controlled nonpumped load.
- Like the simple valve-controlled load, the use of a throttling valve has no significance so far as the load circuit is concerned—either accomplishes exactly the same thing.
- The choice of a throttling or a three-way valve is purely a consideration of the source system thermal dynamics and the primary system hydraulic dynamics.

To amplify this last point; from the consideration of the source system, the three-way valve will provide an essentially constant flow rate to the source with a decreasing temperature differential at reduced load while having a minimal hydraulic effect on the primary system, whereas the throttling valve will provide the source system with a reducing flow rate of essentially constant temperature differential. Given the two alternatives, as stated above, the constant flow variable temperature range alternative imposes a control burden upon the source, particularly if it is a chilled water system, and a significant energy burden upon the primary pumping system.

Three-way valve is choice

In spite of these evident disadvantages, the three-way valve has been the overwhelming choice of systems designers—for both large and small systems—for decades. The reasons: simplicity of understanding the hydraulic impact and assurance of adequate flow rates through the source apparatus. *It is time to re-evaluate this logic*—which brings the discussion to the source systems.

In small systems with a single-source device (chiller, boiler, or heat exchanger), the advantages to be gained by the use of throttling valves may be difficult to justify in terms of the complexity introduced to address the hydraulic effects, and there is no control advantage. However, as system sizes and module numbers increase (two or more), the throttling valve operation option cannot be ignored.

Consider chilled water system

Consider, for example, a chilled water system. If there is one single humidity critical load, the primary supply chilled water temperature must be held at a given design temperature,

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[1] Carlson, G. F., "Hydraulic Systems: Analysis and Evaluation, Part 1," *ASHRAE Journal*, October 1968.

with control span variation only. However, if the multiple chiller units are piped in parallel and one or more units are cycled off as the load reduces, noncooled return water through the down unit will mix with cooled water from the operating unit, raising the temperature of the supply water. This phenomenon has been found to be one of the major problems in the larger chilled water systems.

Again, the recognition of the hydraulic and thermal phenomena inevitably leads to rather simplistic answers to the complex problems. In this case, the concept of circuiting a primary loop around the chillers, with no hydraulic impact of the source upon the distribution system and a separate module-assigned source pump, provides a reasonably valid alternative for virtually all multiple-unit systems. This alternative achieves a degree of simplicity that is readily understood, allows numerous alternatives for the designer for methods of interconnecting the load subsystems, depending on other system dynamics, and allows the design of small or large systems that consume minimum process energy while improving performance.