BSRIA

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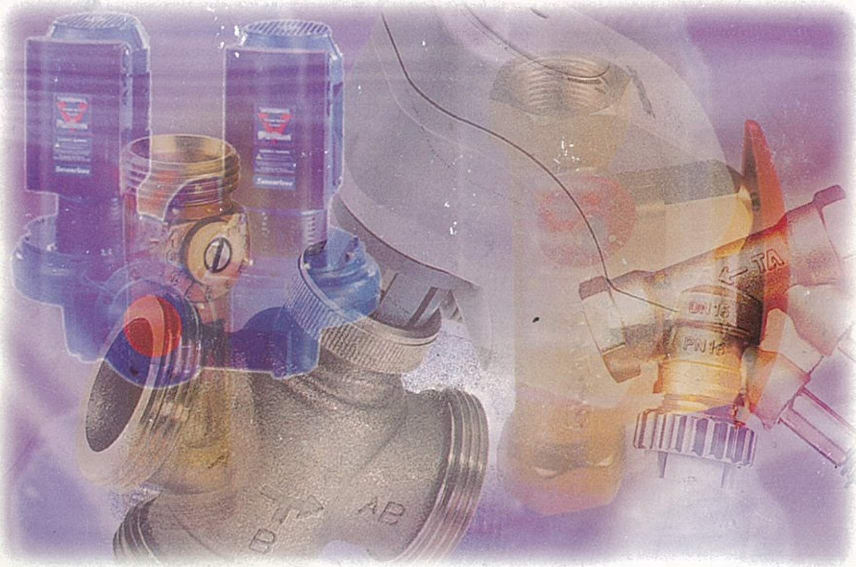
Variable-flow water systems

Design, installation and commissioning guidance

By Arnold Teekaram and Anu Palmer



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FIGURES

This section of the report gives examples of a number of variable flow systems for heating and chilled water circulation. The examples given are based on current practice involving the use of constant/variable speed pumps with the use of two-port regulating valves for controlling the system loads. The systems incorporate local self-acting differential pressure controllers and double-regulating valves to control sub-circuits and maximum volume at design load. Schematics are given for the primary circuit and secondary circuits. General guidance on commissioning of the various systems are given in Part C.

7.1 THE BODLE-ORCHARD CIRCUIT

Introduction

The Bodle-Orchard stepped variable-volume circuit was developed as an alternative to the use of variable volume/variable speed, single pump systems. The circuit is schematically illustrated in Figure 20.

The system has been used on every scheme engineered by Orchard Partners building services consulting engineers from 1974 to the present day and was originally applied on large hot water and chilled water systems.

The sequence control of the boilers and pumps is achieved by monitoring the common flow and common return temperatures of each constant flow, connected boilers and pumps combination. The sensed flow and return temperatures, obtained for each boiler and pump combination, are then used to connect or disconnect only those boilers and pumps required to match the system heating load.

The required stepped sequence control of the plant is achieved via a dedicated controller incorporating the necessary algorithms. The stepped sequence controller is in effect a heat meter. This accuracy is achieved by maintaining constant flow conditions during the steady-state operation of each combination of the boilers and pumps. When constant flow conditions are not maintained the heat meter indicates a false reading. This false reading is used to connect or disconnect boilers and pumps as required via the pre-programmed algorithms of the sequencer.

General Description

Figure 20 illustrates the general arrangement of the Bodle-Orchard circuit developed for variable flow systems, using stepped primary pumping only.

Figure 21 illustrates a development of the circuit. Figure 22 illustrates typical sub-circuits served by the arrangement in Figure 20 (and Figure 21 in more detail) for large directly connected systems. Figure 23 illustrates the mixing circuit used where a higher temperature primary feeds a lower temperature secondary circuit.

Figure 20: Bodle-Orchard circuit for variable volume heating system.

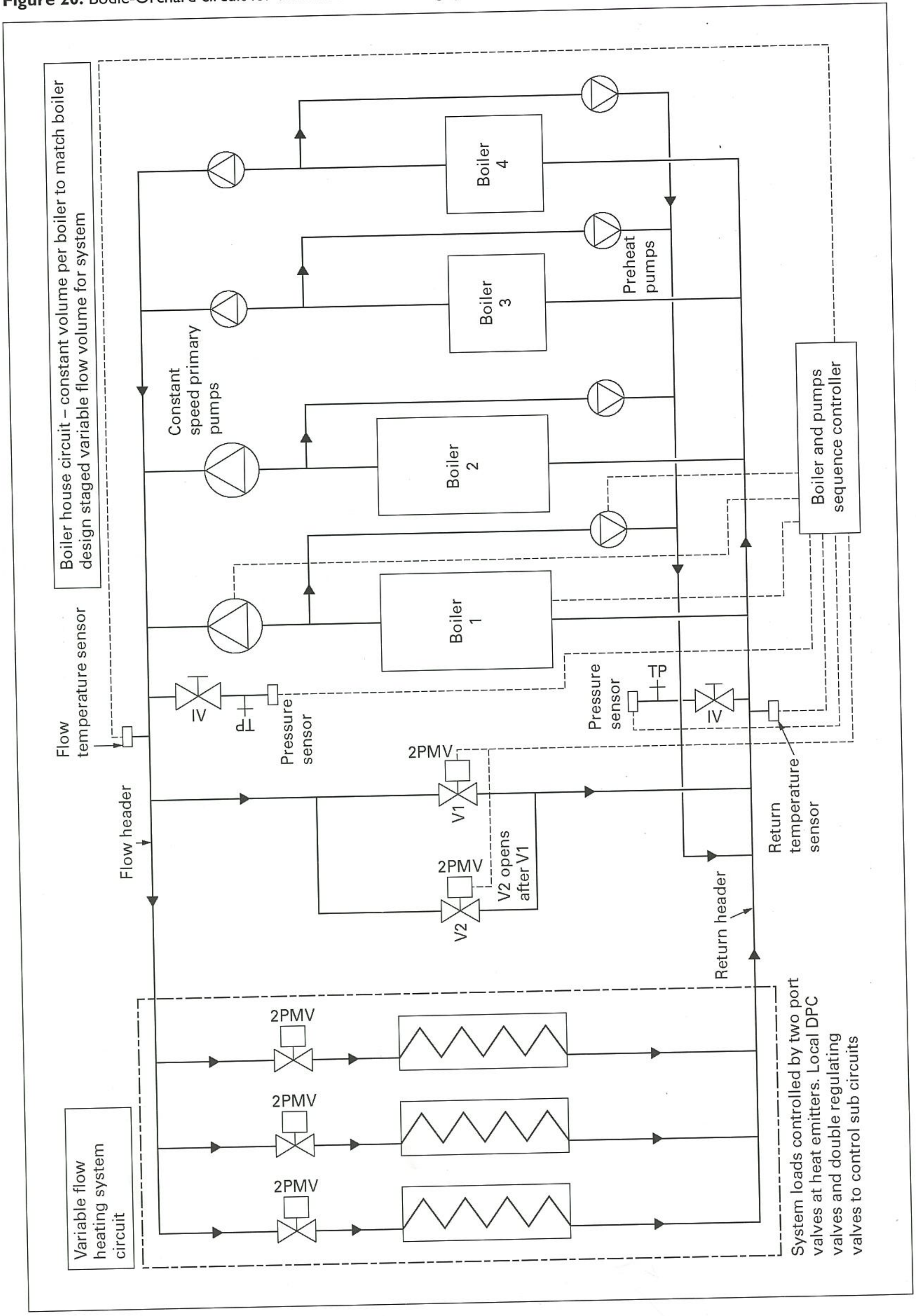


Figure 21: Bodle-Orchard circuit for primary/secondary variable-volume heating system.

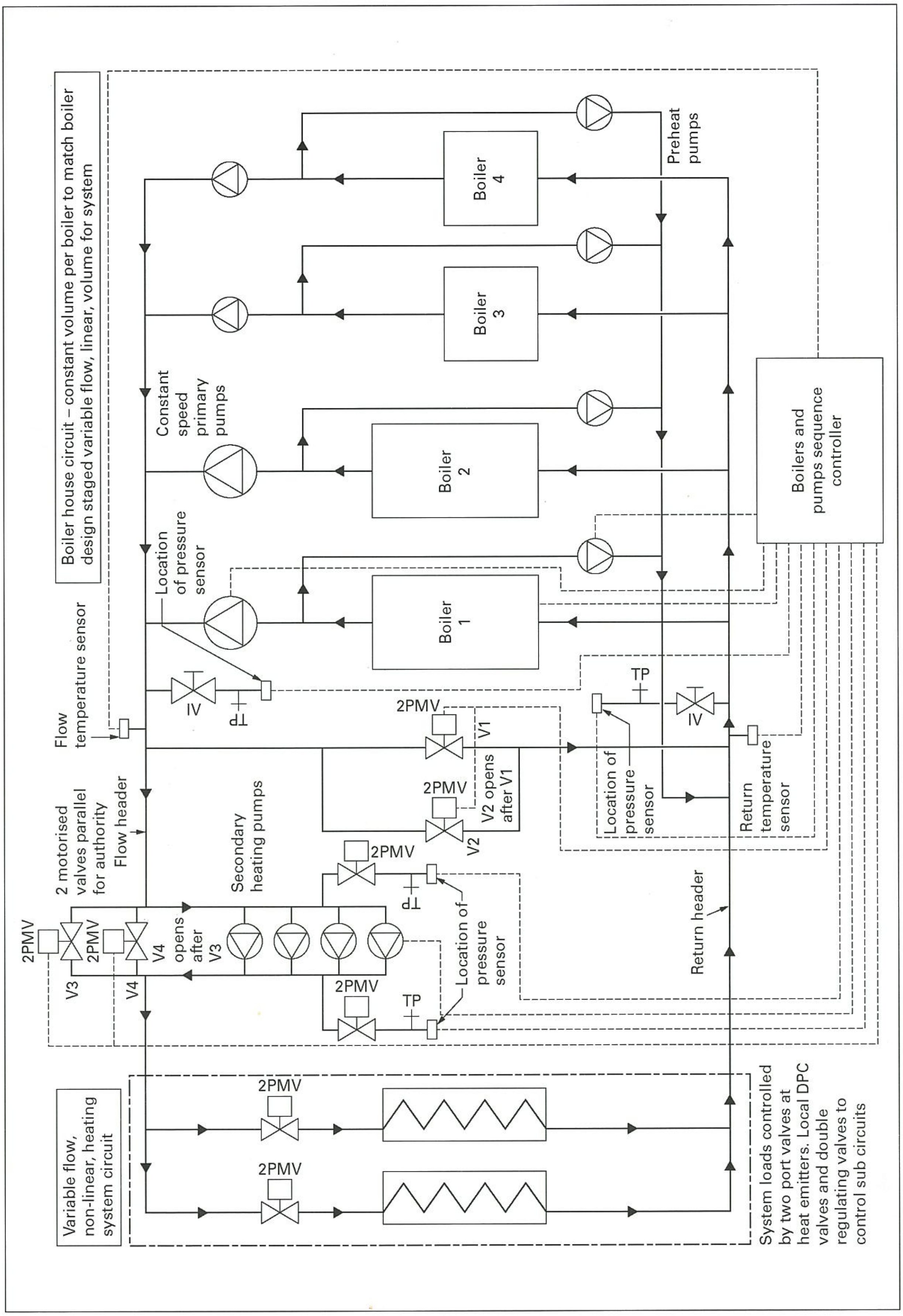


Figure 22: Schematic of sub-circuits.

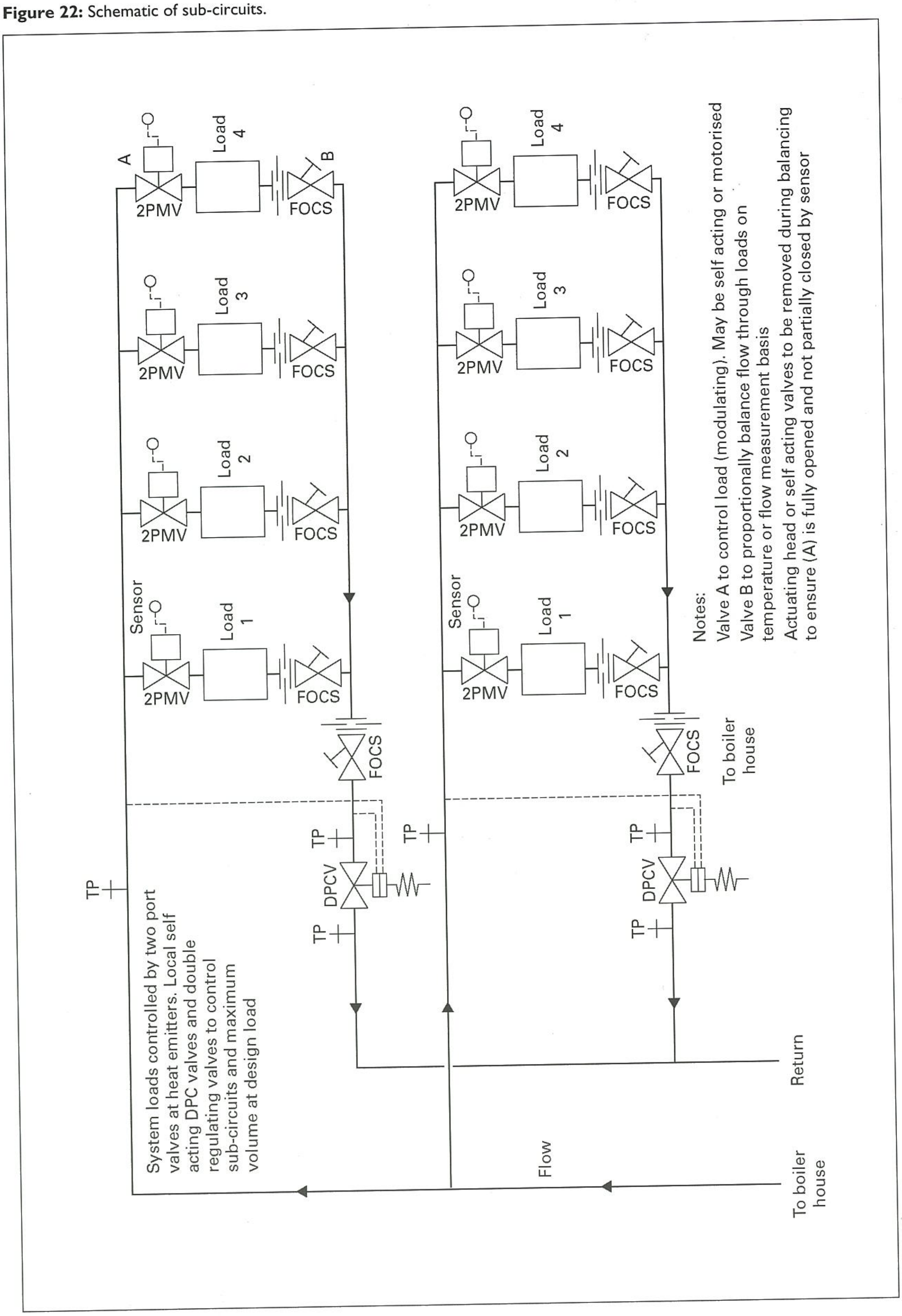
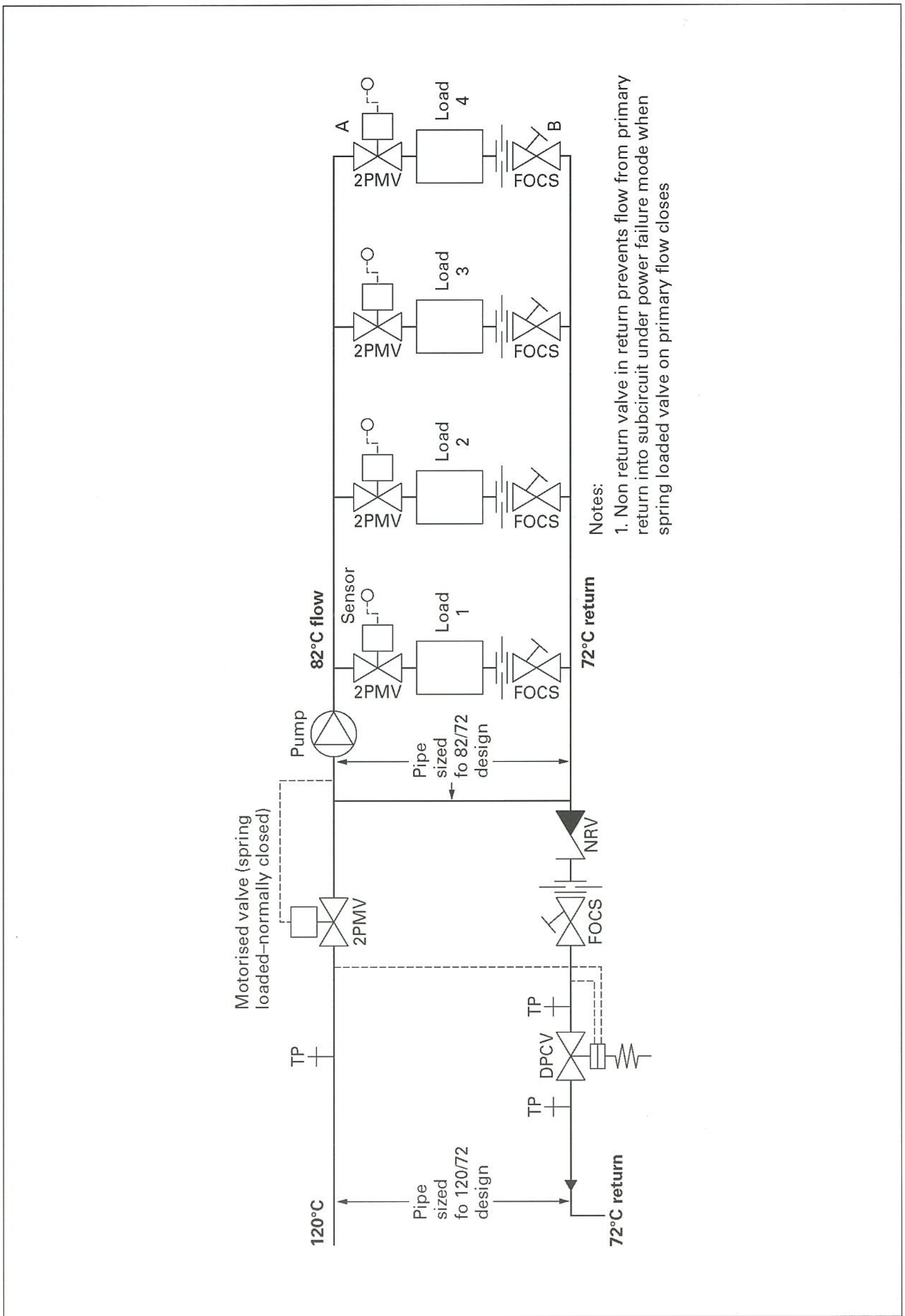


Figure 23: Schematic of injection sub-circuit.



7.2 BOILER HOUSE CIRCUIT

The boiler house circuit (Figure 20) is designed as a constant volume system for each boiler/pump combination, with flow rates to match the boilers circulation requirements. The pumps and boilers are staged to operate together. The circuit and flow within the boiler house headers thus provides a stepped variable volume system. The flow rate in the flow and return header under these conditions matches the pumps and boilers nominated to run to meet the thermal load.

In the simplest form of the circuit, the pump serving each boiler matches the maximum system head requirement for the design load and also acts as the system pump. The flow rate for each pump is selected to match the boiler output and the design temperature drop for the system.

Preheat pumps are also provided to draw water from the mixed boiler return to warm the next boiler due on line as part of the sequence control, and to prevent a slug of cold water entering the system.

The bypass arrangement couples the boiler house circuit to the heating system where the loads are controlled by two-port valves at heat emitters. This two-way valve circuit is a fully modulating, variable-volume system that can operate from full design flow to no flow condition.

The bypass function maintains a constant differential pressure between the flow and return of the boiler house under steady-state operating conditions. It diverts flow not required by the system from the flow to the return header. The bypass capacity is matched to the flow rate from the largest boiler pump.

The boiler house bypass in the Bodle-Orchard circuit also automatically ensures that the design back-end temperatures for the boilers are maintained under all conditions. As the flow rate and return temperature from the heating system drop under reduced heating loads, the boiler house bypass opens to mix water at flow temperature with water returning at a lower temperature. The mixed return temperature in the return header can vary from the flow temperature. This can leave a single boiler under no load conditions. This condition is dictated by the system loads and the combination of boilers and pumps used in the system.

One advantage of the bypass arrangement is that the flow in the secondary circuit will not suffer from pressure rise caused by the pump in the event that a branch were to modulate shut.

Branches at the ends of the circuit controlled by differential pressure controllers inevitably see much greater changes in differential pressure than circuits close to the boiler house. The sequence controller controls the numbers of boiler operating at any one time. The controller uses flow and return temperature sensing, together with other information, to ensure that only those boilers required to meet the system heat load are operating.

The same conceptual principles are also applicable to chilled water systems.

Characteristics of a constant temperature variable-volume system
Under part load conditions the return water temperature from a constant supply temperature, all two-port valve, fully variable volume system falls as the heating demand and flow rate falls.

Figure 24 based on tests conducted for Orchard Partners by BSRIA over 20 years ago shows the link between the heat output from a radiator controlled by a two-way TRV, the flow rate and the return water temperature.

The algorithm derived from the tests is used in Figure 24. The curves are illustrative as the results depend on radiator type. There is considerable uncertainty about the actual behaviour of radiators at very low flow rates. Unless TRVs have the correct authority they cannot modulate the low flow rates.

Figure 24: Performance of a radiator as a function of the return temperature of the radiator.

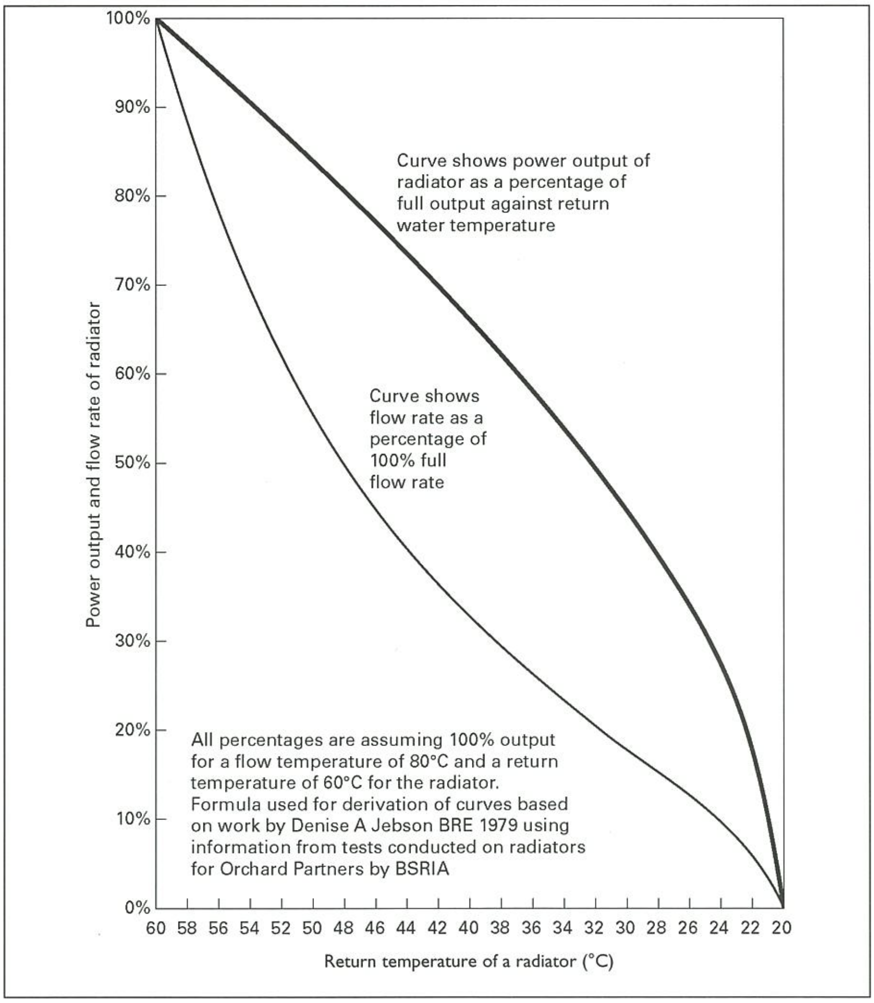


Figure 20 shows how flow rates drop faster than the heat-load a key factor in the control regime. Changes in flow rate are transmitted virtually instantly to the boiler house in the Bodle-Orchard circuit signalling a requirement for an increase or decrease in load. The system by detecting change in flow rate thus responds faster to load change requirements than systems that wait for a return temperature drop to be seen by the boiler house.

7.3 SUB-CIRCUITS AND BRANCHES

Typical sub-circuits (Figure 22) use differential pressure control valves to regulate pressure across sub-circuits and give maximum volume control.

Position of self-acting differential pressure control valves and differential pressure sensors in sub-circuits
Differential pressure control valves can also be installed in either the flow or return. For many applications the location makes little difference.

In heating system applications the return temperature is lower than the flow temperature, and there is therefore less likelihood of cavitations occurring if the controller is installed in the return. If cavitation does occur it will be to a lesser extent.

There is also an impact on the maximum pressure seen in a system down stream of a differential pressure controller depending on its location. Lower pressures will occur in the sub-circuit if any differential pressure controller, pressure-reducing function is in the flow rather than in the return.

This is an undesirable feature, especially in a large system where the index connections of the system could be some considerable distance from the boiler house where there is a need to maintain a minimum static pressure at the highest points in the sub-circuits of the system. Therefore all sub-circuit differential pressure controllers, of the Bodle-Orchard circuit, are located in the return mains to overcome this potential problem. Where a low-rise existing building is served and there is a problem with the maximum pressure created by a combination of the static pressure and the pump head, then consideration can be given to the installation of a differential pressure controller in the flow to reduce the effect of the pump head added to the static head.

Sensing for sub-circuits is normally local to the differential pressure controller in the flow and return of the circuit the differential pressure controller controls.

Mixing sub-circuit
A typical mixing sub-circuit is shown in Figure 23. Analysis of pressures around this circuit will demonstrate to engineers how this simple system works. The circuit can feed further sub-circuits and branches as Figure 22.

Boiler house with boiler pumps and system pumps
An alternative arrangement to the circuit in Figure 20 is shown in Figure 21. This uses separate secondary pumps to match the maximum head for the constant temperature fully-variable heating system.

The boiler house circuit is essentially the same as in Figure 20. The pumps in the heating system, as with the boiler house arrangement, are of the constant-flow type but are staged to provide the required flow when the system load changes. Two motorised bypass valves are installed across the secondary pumps. They maintain constant differential pressure between the flow and return header at all load conditions. The advantages of this circuit over that in Figure 20 is that even larger savings in pumping energy can be achieved. The pumps for the boiler house circuit in Figure 20 have to match the head/volume required to deal with the stepped variable-volume systems around the boiler house in addition to the head/volume required to deal with the fully variable heating system. This in effect provides a stepped constant-volume pumping system.

The circulated volume required by the boiler house is heat-load related, constant-volume and linear in nature. The circulated volume required by the heating system is variable-volume and non-linear as illustrated in Figure 24. Therefore the heating system pumps could be operated at considerably lower volumes than the boiler pumps for most of the heating season. The pumping energy savings are attributable to this difference in the volumes for the same heating demand.

With the arrangement in Figure 21, the secondary pumps are only sized to match the maximum heating system head, and the boiler pumps are sized to match the head required for the boiler house circuit.

Control of the boiler house bypass in Bodle-Orchard circuit

The function of the heating system bypass in this circuit is to maintain a constant differential pressure to the system fed by the boiler house and also to provide constant volume boiler flow under steady-state operating conditions.

In the system shown in Figure 20, as the heating demand decreases or increases, the two-port valves in the secondary sub-circuits modulate accordingly towards the closed or open position. This effectively alters the flow rate in the pipe and thus the pressure drop in the piping system. Consequently, there will be an increase in the pressure differential in the sub-circuits of the heating system, under part-load operation, due to reduced flow. Detection of this change in pressure differential across the secondary sub-circuits activates self-acting differential pressure control valves to maintain constant pressure differentials to meet the limited characteristics of the self-acting heating control valves of the system. The secondary sub-circuit differential pressure control valves also act as volume limiters for each sub-circuit because they maintain a constant differential at the sub-circuit.

In the case of the bypass in the boiler house, the change in pressure that is detected arises both from the impact of pressure changes due to changes of flow in the piping. This change in pressure is used to modulate the boiler bypass control valves to maintain the system supply pressure differential within close limits. It is important to note that the bypass valves V1 and V2 in the boiler house circuit are not self-acting differential pressure control valves. Self-acting differential pressure control valves are not suitable for this application in the boiler house as they are not sufficiently sensitive to react to relatively minor changes in head resulting from the pump curve characteristic. The use of self-acting differential pressure control valves further down the piping system is entirely satisfactory as the changes in pressure as the volume changes are a function, not only of the pump head, but the much larger effect of system resistance.

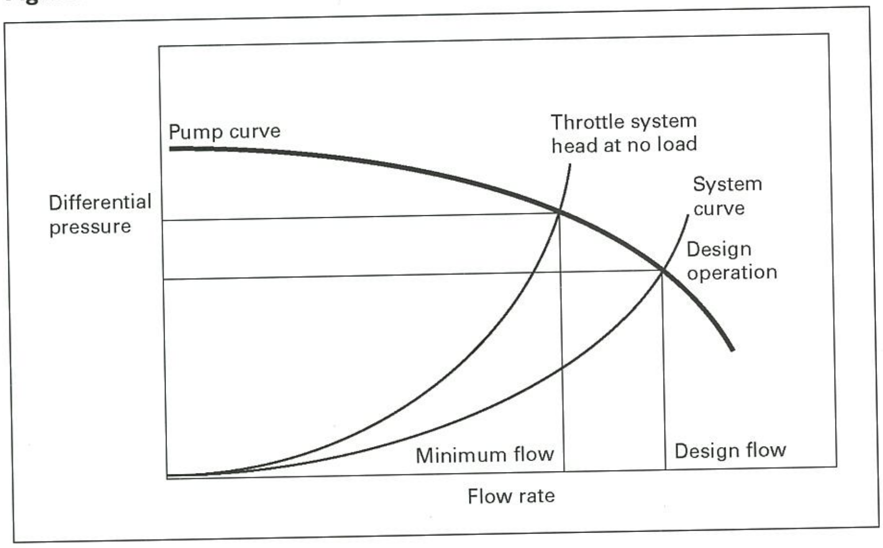
To maintain flow, differential pressure control can be used in various forms to maintain minimum flows in the circuits. In this mode of operation, the pressure differential across the flow and return rises and actuates the differential pressure controller to allow minimum flow to occur while ensuring adequate pressure to meet demands from the system.

Figure 25 illustrates the situation of change of pressure as seen close to a pump with a differential pressure controller activated to bypass pump flow to maintain minimum pump flow. Such systems result in a range of flow rate through the boilers.

The Bodle-Orchard circuit differs in that the bypass is large enough to ensure that the system pressure differential, under steady-state operating conditions, will remain constant and not be allowed to rise as shown in Figure 25. Constant volume flow in the boilers/pumps combination, operating at that time, will also be maintained due to the above.

For best authority and control, two parallel valves operating in sequence, digitally controlled, have been found to be most effective. They also offer standby should one valve fail.

Figure 25: Control of minimum flow through boilers.



Control of constant boiler flow rate

In the case of the Bodle-Orchard circuit control occurs naturally, and a virtually constant flow through the boilers is achieved due to the arrangement of one pump per boiler and the staged sequencing of the boiler with its pump to match the system heating load. This system operates in such a way as to keep the boiler pump combinations operating at their full design conditions under steady-state heating conditions.

The maintenance of stepped constant-flow rates through the boilers, under steady-state heating conditions, is essential for the correct sequence of operation of the Bodle-Orchard circuit. The actual boiler flow rate for each boiler capacity step will vary from the design value, when there is an increase or decrease in the connected load of the heating system.

This increase/decrease in system flow rate will occur when the two-port valves, at the heat emitters in the system circuit outside the boiler house, open/close further, to meet an increase/decrease in heat demand. The increase in flow rate will occur because of the reduced pressure drop of the sub-circuits of the heating system. The decrease in flow rate will occur because of the increase in pressure within the sub-circuits of the heating system.

There will be an increase in boiler/system flow, (on an increase in the heating load) greater than the connected boiler combined heating capacity, and a decrease in system flow on a decrease in heating load below the connected boiler combined heating capacity. This has a beneficial effect in accelerating the action of the boiler plant sequencer.

Increased flow through a boiler combination already at full output will lead to a rapid drop in the boiler combination output temperature for the same system design return-temperature.

The effect of decreased system flow on a boiler combination, already at full output, will lead to a rapid rise in return temperature due to the injection of constant temperature boiler flow water, via the boiler differential pressure controller, into the common boiler return header.

These flow and return temperature changes are used in the programmed algorithms of the plant sequencer.

Further development and discussion

Figure 20 illustrates the stepped boiler/pump arrangements which cover the requirements of the heating variable volume system and the boilers stepped constant volume system, when using a single pump per boiler which also serves as the system pump.

As stated previously, boilers require a constant-volume pumping system and the heating requires a variable-volume pumping system.

Analysis of the volume requirements of the above two elements indicated that, under part load conditions, the volume requirement of the variable flow heating system are some 55% of the boiler constant volume requirements. If the volume requirements of each system could be satisfied separately, there would be pumping energy savings due to the reduced volume requirement of the variable volume heating system.

Therefore to match the differing volume requirements the pumping arrangement of the common, stepped, constant-volume boiler/variable volume system pumping system, was replaced with:

- A separate stepped constant volume pumping arrangement for the boilers.
- A separate stepped variable volume pumping arrangement for the heating system.

Figure 21 illustrates the boiler and pump arrangements which cover the requirements of the heating variable volume system and the boilers stepped constant volume system. The arrangements of Figure 21, which are now the current configuration of the Bodle-Orchard circuit, will offer a 44% reduction in pumping energy costs over a conventional full flow system.

The arrangements of Figure 20 will offer some 35% reduction in pumping energy costs over a conventional full flow system.

Use of variable-speed pumps with the circuit

It is possible that some further benefits could be obtained by the use of variable-speed pumps for the system pumps instead of the arrangements shown in Figure 21. This will depend on a further analysis which has not been carried out using current costs and operating characteristics of today's variable speed pumps. Several years ago the technology and extra cost for variable speed pumps and their control did not justify their use compared to the simpler fixed speed pump option. Further developments on the fundamental concepts behind the circuits are likely to be possible as the cost of sensing and controlling systems improves.