

# A Review of Hydronic Balancing of Cooling Water Circuit

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**Abstract - Calculating head losses, water flows, pipe sizes and pressure drops is not an exact science. The design engineer can only use approximations. Without balancing, all loops that are closer to the pump will get too high pressure and also too much water. They will “steal” water from the loop located further away, which in turn will get too little flow. This paper reviews the need for balancing used to obtain proper flow rates across different parts of the cooling water circuit.**

**Keywords- head losses, need for balancing.**

## I. INTRODUCTION

Hydronic Balancing is the process of proper distribution of water in a building’s heating or cooling system by minor adjustments of fittings so that the system provides desired conditions at optimum energy efficiency and minimal operating cost.

To provide optimum power, output heating or cooling devices require a certain flow known as the calculated or design flow. Theoretically, plants can be designed that deliver design flow at each terminal unit (heating or cooling device). In practical situations this is not possible because pipes and valves are available in standard sizes and accurately predicting the real flow in a system is too complex. Some circuits (typically those closest to the pump) will be favored by higher than required flows at the expense of other circuits that will have underflows.

In small heating systems (e.g. domestic systems) balancing is quite easy because of the small number of terminal units and relatively simple flow network. Balancing can simply be achieved by pre-setting the flow through the radiators.

Larger buildings have a complex distribution system and require a more accurate balancing technique. Balancing valves allow the measurement of differential pressures which can be used to compute flow across that line. This paper reviews the various techniques involved in balancing of cooling water circuit.

## II. CONSEQUENCES OF IMBALANCED HYDRONIC SYSTEMS

Whenever a hydronic system is designed, the intent is to deliver the proper rate of heat transfer according to required specification. Without proper balancing hardware and adjustment, that goal is almost never achieved. The most obvious consequence of an improperly balanced system is lack of comfort and inappropriate ambient conditions. Wide variations in interior temperature often lead to problems beyond the lack of comfort. When some areas of a building cannot be warmed to the desired room air temperature, the following problems can develop

- Slow drying of wetted surfaces
- High velocities in piping components leading to noise and possible erosion
- Excessive use of energy by circulators due to overflow
- Circulators operating at low efficiency

- Circulators operating at high differential pressure, increasing potential for thrust damage of bushings or bearings.
- Circulators operating at high flow rates and low differential pressure which may lead to motor overloading.
- Possible “bleed through” flow in zones that are supposed to be off.

### III. THE PURPOSE OF BALANCING

Most hydronic heating professionals agree that balanced systems are desirable. However, opinions are widely varied on what constitutes a balanced system. The following are some of the common descriptions of a properly balanced system:

- The system is balanced if all circuits that operate simultaneously have the same temperature drop.
- The system is properly balanced if the ratio of the flow rate through a branch circuit divided by the total system flow rate is the same as the ratio of the required heat output from that branch divided by the total system heat output. The system is properly balanced if all branch circuits are identically constructed (e.g., same type, size and length of tubing, same fittings and valves, same heat emitter).
- The system is balanced if constructed with a reverse return piping layout.

While some of these definitions of proper balancing are related, none of them is totally correct or complete. It follows that any attempt at balancing a system is pointless without a proper definition and “end goal” for the balancing process. A properly balanced hydronic system is one that consistently delivers the proper rate of heat transfer to each space served by the system.

### IV. FUNDAMENTAL CONCEPTS UNDERLYING BALANCING

Balancing hydronic systems requires simultaneous changes in the hydraulic operating conditions (e.g., flow rates, head losses, pressure drops), as well as the thermal operating conditions (e.g., fluid temperatures, room air temperatures) of the system. These operating conditions will always interact as the system continually seeks both hydraulic equilibrium and thermal equilibrium. The operating conditions will also be determined, in part, by the characteristics of the heat emitters and circulator used in the system.

Considering that there are often hundreds, if not thousands, of piping and heat emitter components in a system and that nearly all of them have some influence on flow rates and heat transfer rates, it is readily apparent that a theoretical approach to balancing can be complicated.

This section discusses several of the fundamentals that collectively determine the balanced (or unbalanced) condition of every hydronic system. All these fundamentals can be dealt mathematically. However, in many cases this is not necessary. Instead, it is sufficient to have a clear understanding of how and why certain conditions exist or develop with a system.

Such an understanding can guide the balancing process in the field, and help the balancing technician avoid mistakes or incorrect adjustments that delay or prevent a properly balanced condition from being attained.

### V. REVERSE RETURN PIPING

When two identical devices are piped in reverse return the total flow will divide equally between them without use of control valves. Examples of devices, commonly piped this way include two identical boilers or two identical solar collectors.

However, when more than two identical devices are piped in reverse return, the flow rates do not necessarily divide equally across all devices.

The only way to create the same flow rate in each line would be to size the supply and return mains for exactly the same head loss per unit of length along their entire length. In theory this is possible, provided tubing could be obtained in virtually any diameter. In reality this is not the case. Finite selections of tubing sizes keeping cost criteria in mind, and differences in lengths between the mains segments will usually result in variation of flow rate through more than two identical devices piped in reverse return.

The degree of flow rate variation between flow lines in a reverse return system depends on the magnitude of the head loss through the lines versus the head loss along the mains. The following principle applies to reverse return systems with identical lines. The higher the ratio of the head loss through the line divided by the head loss through the mains, the closer the reverse return system will be to “self-balancing” (e.g., equal flow rates in all flow lines).

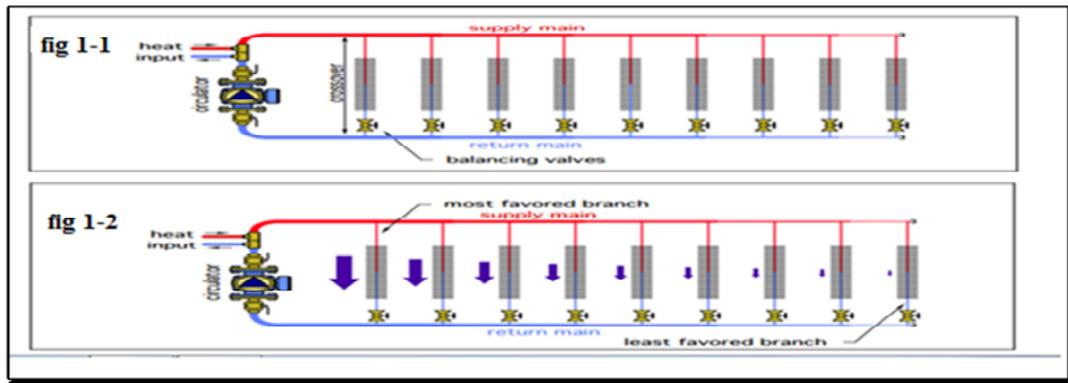
The reverse return configuration will help in balancing the system, but it does not guarantee self-balancing of the system. In such cases, a balancing device should be installed in each flow line to allow for flow rate adjustments.

Following principles apply to reverse return piping systems:

Simple, symmetrical reverse return piping of identical devices that have more hydraulic resistance than the main segments between them; this will produce small but acceptable variations in flow rate from one device to another. However, complex systems containing variety of pipe sizes, and heat exchangers, should contain control valves across each line, even when piping is done in reverse return manner.

VI. BALANCING BASICS

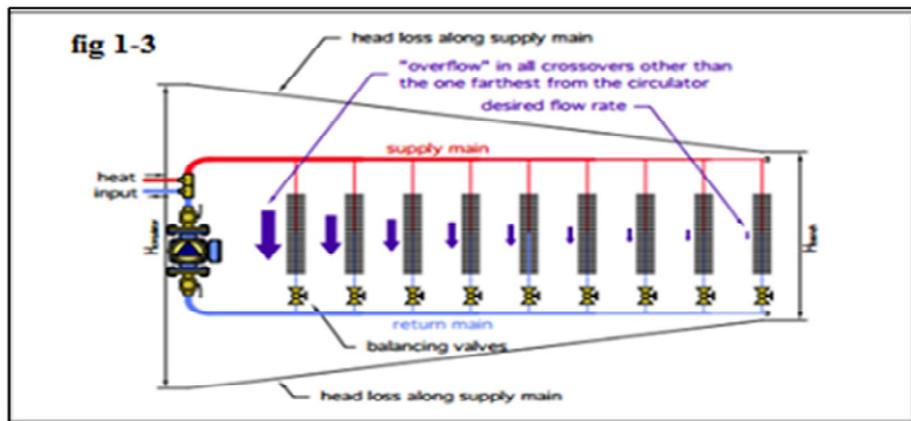
Consider the hydronic system shown in figure 1-1.



It consists of nine flow lines connected across common supply- and return mains. Circulation is created by a fixed-speed circulator (pump). This piping arrangement is called a parallel direct return system. Assume that all crossovers have identical piping components, and thus should (ideally) all operate at the same flow rate and head loss.

The vertical piping near the circulator, and the closely spaced tees where heat is added, can be considered to have insignificant head loss. Assume that when this system is first turned on, all the balancing valves are fully open. Because of the head loss along the supply main and return main, the differential pressure exerted across each crossover will be different.

The “most favoured crossover” nearest the circulator will have the highest differential pressure and thus the highest flow rate. The “least favoured crossover” at the far right side of the system will have the lowest differential pressure and thus the lowest flow rate. This undesirable but none-the-less present condition, shown in figure 1-2, is what proper balancing is meant to correct. Figure 1-5, is a graphic representation of how head energy is added to the system by the circulator and is dissipated as flow passes along the supply and return mains and through the crossovers.



The vertical line to the left of the circulator represents the head required to push flow along the supply header, through the least favoured crossover at the design flow rate, and back through the return main.

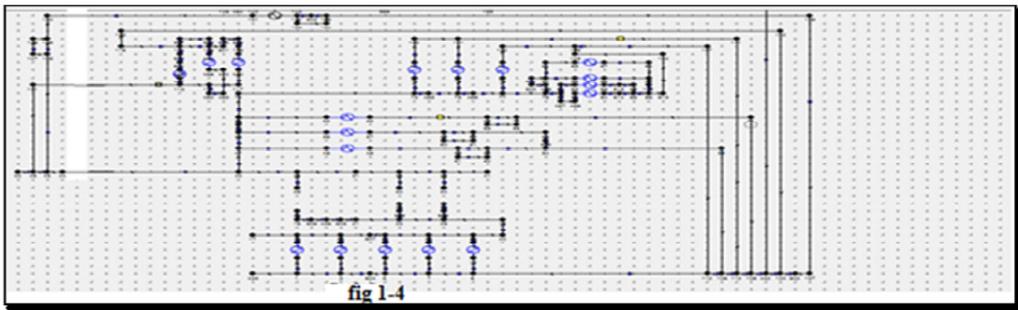
The sloping lines above and below the piping system represents head loss as flow moves through the supply and return header. These lines get closer to each other as they progress from left to right. This implies that each line has less head available to it than the crossover to its left, due to head dissipation in each segment of the mains. Less available head means lower differential pressure across the line, and thus lower flow rate.

The head available to the “least favoured flow line” at the far right of the system determines the flow rate through the line. In this system, the circulator is assumed to be sized so that it can provide the necessary head to drive flow through the least favoured line, accounting for the head loss along the full length of the supply and return mains.

This initial unbalanced conditions leads to “overflow” in all lines other than the least favoured line, as indicated by the flow arrows. Such overflow increases the power demand of the circulator, and thus increases the operating cost. Overflow may also result in undesired flow noise or erosion corrosion of fittings which adds to the cost.

To achieve required flow in each line, there must be equal head loss across each line. This requires the control valve in each line to overcome the difference between the head available between the supply and return header, and the head dissipated by the other piping components in the line. The head that each balancing valve must dissipate is indicated by the vertical height of the yellow shaded area at each line location. In this system, which assumes identical equipment line piping and mains piping that is sized for a constant head loss per unit of length, the required head loss of each control valve is proportionally less than that of the control valve to its left. The control valve on the most favoured line (at left) needs to dissipate the greatest head, while the control valve on the least favoured line(at right) needs to dissipate zero head. The latter case assumes that the circulator is sized to provide exactly the head required by flow along the full length of the headers and through the least favoured line. If the circulator supplies excess head, the control valve in the least favoured circuit will also have to be partially closed to absorb some excess head.

VII. BALANCING USING COMPENSATED METHOD



Consider the above layout which consists of three input and output nodes which are left open for analysis. The requirement of flow across equipments is shown in the table below.

SR NO.	EQUIPMENT	FLOW REQ. m <sup>3</sup> /hr
1	HX-1	37.5
2	HX-2	37.5
3	HX-3	28
4	HX-4	97.5
5	HX-5	97.5
6	HX-6	290
7	HX-7	2.5
8	HX-8	1.5
9	HX-9	1.5
10	HX-10	0.5
11	HX-11	1222
12	HX-12	4600
13	HX-13	5
14	HX-14	7.5
15	HX-15	7.5

fig 1-5

Assumption is made that pumps will be connected at the input nodes which provide a head of 30 meters to overcome the friction loss within the closed loop. For balancing the above circuit “compensating method” is used in which balancing resistance to be added across each line will be computed to achieve balancing of the circuit. This method assumes that required flow is already known which is similar to our case.

The following procedure can be used to adjust the control valves (i.e. add resistance) in the branches:

STEP-1: select the most critical path (i.e. path with highest head loss). In our case HX-12 has the highest head loss and thus is the least favoured path.

STEP-2: determine the resistance across each line in the initial unbalanced condition to obtain equivalent resistance across pump. This helps to obtain flow delivered by the pump.  
Resistance is calculated by using:

$$H=K*Q^2$$

H=head loss across line in unbalanced condition

Q=flow required across each line

K=resistance in each line

SR NO.	EQUIPMENT	FLOW REQ. m <sup>3</sup> /hr	PD ACROSS R3 mwc	R3	ACTUAL FLOW m <sup>3</sup> /hr
1	HX-1	37.5	17.32993	22280.745	100.4005405
2	HX-2	37.5	17.32178813	22178.9398	96.56367859
3	HX-3	28	16.38717292	24075.212	156.700657
4	HX-4	97.5	15.63588382	8649.03	153.0664523
5	HX-5	97.5	15.54505699	8586.6972	153.1741877
6	HX-6	290	12.79478515	1531.366	329.0633384
7	HX-7	2.5	9.311491	27798082.4	2.083553688
8	HX-8	1.5	9.311491	37870000	1.78510786
9	HX-9	1.5	3.39309	41317609	1.031650516
10	HX-10	0.5	3.39309	59007859	0.863267243
11	HX-11	1222	16.89652885	74.6121	1713.154834
12	HX-12	4600	16.72961681	9.460641	4787.240172
13	HX-13	5	13.87931681	3821877.42	6.860379941
14	HX-14	7.5	13.79180513	4312462.5	6.437991383
15	HX-15	7.5	13.79180513	2803543.8	7.984714351

fig 1-6

The flow curve obtained is shown below. The resistance obtained is 9.310336968 and flow obtained from curve is 6472.8 m<sup>3</sup>/hr at head of 30 meters.

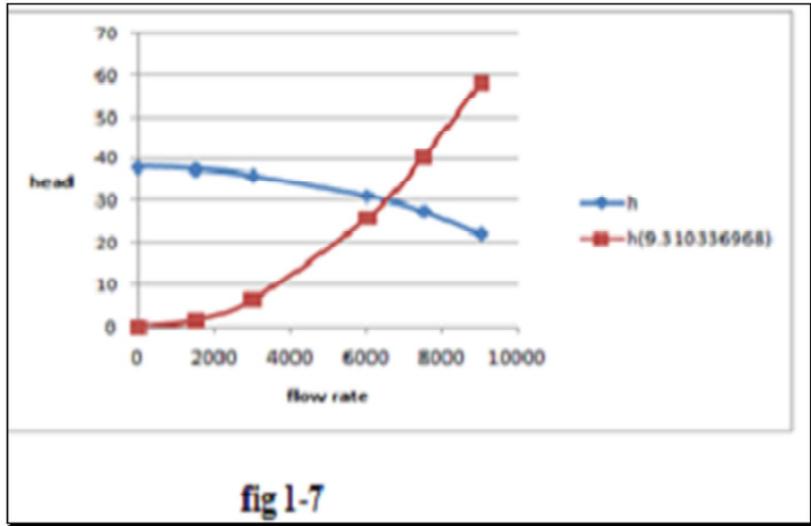


fig 1-7

STEP-3: The obtained flow is redistributed to the circuit by maintaining the head of 30 meters in the critical path and other lines are balanced with respect to this line. The resistance to be added is computed to dissipate the extra head and obtain the desired flow in the line.

To maintain the head loss across line, the same and to obtain the required flow resistance added is calculated as given below:

$$H = K_{added} * Q_r^2 + K_{actual} * Q_r^2$$

Also,

$$H = K_{actual} * Q_{act}^2$$

Therefore,

$$K_{actual} * Q_{act}^2 = K_{added} * Q_r^2 + K_{actual} * Q_r^2$$

Thus,

$$K_{added} = \frac{K_{actual} * (Q_{act}^2 - Q_r^2)}{Q_r^2}$$

K<sub>added</sub> =resistance to be added

K<sub>actual</sub> =resistance of unbalanced line

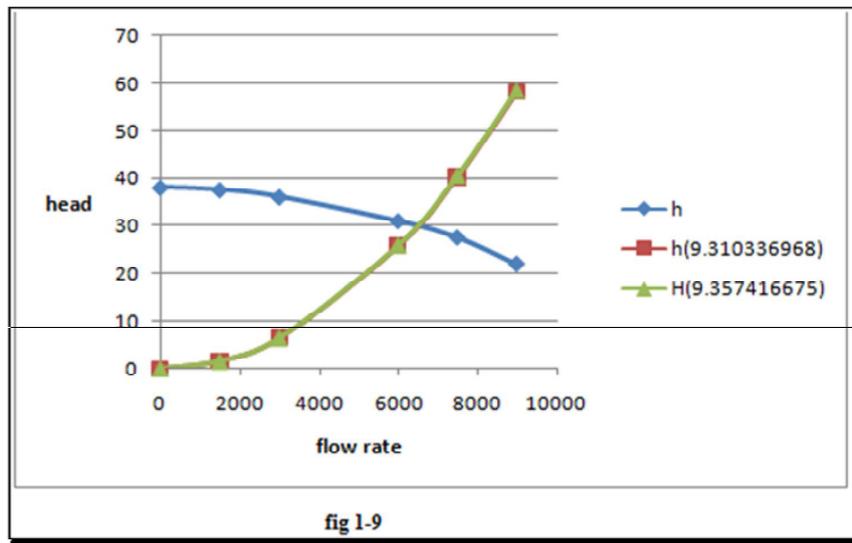
Q<sub>act</sub> = actual flow without balancing

Q<sub>r</sub> = required flow in the line

SR NO.	EQUIPMENT	FLOW REQ. m <sup>3</sup> /hr	PD ACROSS R3 mwc	R3	FLOW m <sup>3</sup> /hr	ACTUAL FLOW m <sup>3</sup> /hr	RESISTANCE ADDED (RA)	PD ACROSS RA mwc	FLOW AFTER BALANCING
1	HX-1	37.5	17.32993	22280.745	6472.8	100.4005405	137431.8899	14.91231444	37.48365924
2	HX-2	37.5	17.32178813	22178.9398	6435.316341	96.56367859	135562.3874	14.70946044	37.7127591
3	HX-3	28	16.38717292	24075.212	6397.603582	156.700657	262240.9713	15.86395999	27.71380521
4	HX-4	97.5	15.63588382	8649.03	6369.889776	153.0664523	12667.58321	9.291760252	99.95761792
5	HX-5	97.5	15.54505699	8586.6972	6269.932159	153.1741877	12606.09055	9.246654964	100.0821756
6	HX-6	290	12.79478515	1531.366	6169.849983	329.0633384	440.3392978	2.857448684	295.1836417
7	HX-7	2.5	9.311491	27798082.4	5874.666341	2.083553688	-8489774.662	-4.094220034	2.025005537
8	HX-8	1.5	9.311491	37870000	5872.641336	1.78510786	15764188.16	2.736838222	1.457849789
9	HX-9	1.5	3.39309	41317609	5871.183486	1.031650516	-21773410.6	-3.780106007	0.639517995
10	HX-10	0.5	3.39309	59007859	5870.543968	0.863267243	116889926.6	2.254821115	0.535137556
11	HX-11	1222	16.89652885	74.6121	5870.00883	1713.154834	66.112748	7.617678147	1251.07577
12	HX-12	4600	16.72961681	9.460641	4618.93306	4787.240172	0.785853984	1.283076412	4600
13	HX-13	5	13.87931681	3821877.42	18.93306032	6.860379941	3373160.414	6.506868083	5
14	HX-14	7.5	13.79180513	4312462.5	13.93306032	6.437991383	-1134830.598	-4.925480026	6.437991383
15	HX-15	7.5	13.79180513	2803543.8	7.495068934	7.984714351	374088.102	1.623646276	7.5

fig 1-8

STEP-4: After adding resistances in the line again equivalent resistance is calculated to check for the modified curve.



After adding the extra resistance equivalent resistance obtained is 9.357416675. Thus full circuit is balanced and 30 meter head is maintained.

#### VIII. CONCLUSION

- 1) For head loss up to 10 meters throttling of control valve will be done to add extra balancing resistance.
- 2) For head above 10 meters orifice will be added to obtain extra resistance.

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