J Fusion Energ (2016) 35:335–340
DOI 10.1007/s10894-015-0031-4

ORIGINAL RESEARCH

Thermal–Hydraulic Analysis of ITER Component Cooling Water System Loop 2B

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Abstract ITER cooling water system includes Tokamak cooling water system, component cooling water system (CCWS), chilled water system and the heat rejection system. The CCWS is further divided into CCWS-1, CCWS-2A, CCWS-2B, CCWS-2C, and CCWS-2D loops to provide independent chemical control and to prevent galvanic corrosion among the different clients' materials (e.g. Cu, Al). The CCWS-2B is responsible to remove heat load generated by coil power supply components and the neutral beam injectors and diagnostics system during all the phases: commissioning, testing and conditioning and plasma operation. A CCWS-2B thermal–hydraulic analysis model was developed, by using the AFT Fathom code, to conduct the steady state thermal–hydraulic analysis of the system. In this thermal–hydraulic analysis model, the critical path with the largest pressure loss was used to size the pump head has been identified and the pressure loss on the control valve were used to establish the required flow balance at each piping connection points. This paper presents the results of this thermal hydraulic analysis which was composed by required pump head of the CCWS-2B loop and the main thermal–hydraulic parameters for each client (i.e. flow rate, velocities, pressure drops and outlet temperatures).

Keywords Thermal–hydraulic model · Pump head · Pressure · ITER component cooling water system

Introduction

The Component Cooling Water System (CCWS) is a part of ITER Cooling Water System (CWS) whose purpose is the removal of heat load generated by the ITER machine and its supporting systems and transfer of this heat to the atmosphere through a Cooling Tower (CT) [1, 2]. The CCWS is furtherly divided into five loops: CCWS-1, CCWS-2A, CCWS-2B, CCWS-2C, CCWS-2D to meet different water chemistry requirements [3]. The CCWS-2B is designed to supply cooling water to the Tokamak coil power supply system and Neutral Beam Injectors system. The total flow rate of the loop is 1044.91 kg/s and the maximum total heat load to be removed by the CCWS-2B loop during the most demanding plasma operation cycle is 33.3 MW.

The simplified hydraulic model of the ITER component cooling water system loop 2B is shown in Fig. 1. The loop was composed by two pumps, two heat exchangers, control valve and 19 groups of client. In the diagram, the client group was labelled by building, client location and client type. C stands for converter system and B stands for the busbar system which are belong to the coil power supply system. N, CN, CS, S stand for north, center north, center south, south the location inside each building. For example, C/B-Building-32-CS means the client group for the converter and busbar system located in the building 32 center south trench. The total number of branches for the CCWS-

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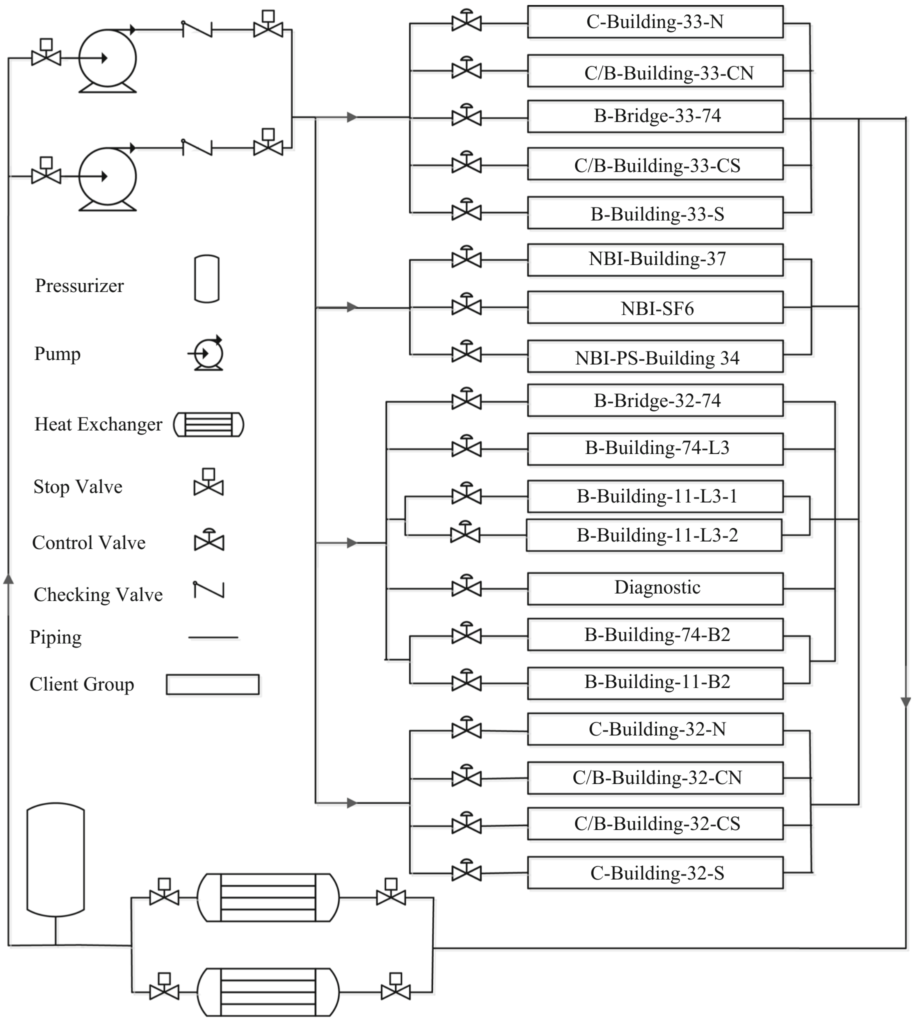

Fig. 1 Simplified CCWS-2B hydraulic model

2B clients which are located in six buildings with different elevation is 332 units (328 for power supply system components, 3 for Neutral Beam Injectors and 1 for Diagnostic system). Table 1 gives the number of branches for each client groups. The main challenge for the system is to supply cooling water to the clients which were located in different buildings at the different flow rate and pressure requirements [4].

A simplified hydraulic model of the CCWS-2B loop which has been analyzed was built based on the design of CCWS-2B cooling loop performed by India Domestic Agency team. This simplified hydraulic model only gives the hydraulic performance of the loop by client groups not by the detail clients itself. The thermal–hydraulic analysis model presented in this paper which was created based on the s piping and instrumentation diagram (P&ID) and process flow diagram (PFD) of the main loop can reflect hydraulic performance of all the 332 clients in the loop. In this way, the main purpose of this calculation is to determine system sizing parameters for the ITER component cooling system loop 2B [5, 6].

Thermal–Hydraulic Theory and Loss Model

To model the pressure losses in the pipes, it was used the equation Darcy–Weisbach Eq. 1:

$$\Delta P_p = f\frac{L}{D}\left(\frac{1}{2}\rho v^2\right) \tag{1}$$

where ΔP_f is the pressure loss of the pipe, f is pipe friction loss factor, L is the length of the pipe, D is the pipe diameter, ρ is the cooling water density, v is the velocity of the cooling water. The total pressure change between junctions is given by the momentum equation in the form of Bernoulli Eq. 2:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g z_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g z_2 + \Delta P_f \tag{2}$$

Table 1 The number of client for each client group

Client system	Client group	Client
Power supply system	C-Building-32-N	13
	C/B-Building-32-CN	31
	C/B-Building-32-CS	24
	C-Building-32-S	8
	C-Building-33-N	11
	C/B-Building-33-CN	33
	C/B-Building-33-CS	32
	C-Building-33-S	14
	B-Bridge-32-74	22
	B-Bridge-33-74	18
	B-Building-11-L3-1	12
	B-Building-11-L3-2	7
	B-Building-11-B2	47
	B-Building-74-L3	34
	B-Building-74-B2	22
Neutral beam injectors	NBI SF6	1
	NBI PS-Building 34	1
	NBI-Building-37	1
Diagnostic	Diagnostic	1
Total		332

where, g is the gravity coefficient.

For the junctions in the model, pressure loss is indicated by the Eq. 3:

$$\Delta P_{loss} = k\frac{1}{2}\rho v^2 \quad (3)$$

where, k is the pressure loss factor of the component. There are many k factors for the junctions in the model, tees, bends, valves, and client components [7].

Thermal–Hydraulic Analysis Model

The thermal–hydraulic analysis model descripted in this paper is composed of two main heat exchangers, three pumps, control valves and 332 connections to clients which were divided into 19 sub-loops. Due to the whole model being too large to shows here, only an illustrative example for typical clients group C-Building-33-N model was given in the Fig. 2. Figure 2 represents the typical process flow diagram which has 11 connections and its corresponding Fathom model. A main control valve was applied at the main sub-loop header for the flow balance between the different client groups. Inside the client groups, sub-loop control valve was used to perform the flow regulation between various connections of the client in each group itself.

Analysis Model Input

With the model built, the main thermal–hydraulic parameters for the piping and fitting, heat exchanger, pump, client and control valve are then specified to perform the analysis.

Piping and Fittings

The piping length and size was based on the CCWS-2B P&ID drawings. The velocity of the cooling water flowing through the pipe is based on 2.5 m/s and the pipe schedule was chosen based on the temperature and pressure limits.

Heat Exchanger

There are two units of plate type heat exchanger in parallel in the loop. The main heat exchangers in the loop are specified with a specific pressure loss factor k which determines the pressure loss requirements for these two heat exchangers.

Pump

To calculate the pump head, a fixed flow rate was applied to the pump model. The flow rate of pump 1 was set as the constant flow rate 518.97 kg/s, and the pump 2 was set as the constant flow rate as 525.92 kg/s.

Clients

Two types of client are included in the model, one is in the busbar type and the other is in converter type. From the ITER project interface requirement sheet, pressure loss of the busbar in this calculation is set as 0.45 MPa and the converter is set as 0.3 MPa. The pressure drop data of client is entered into Fathom as a point from which Fathom extrapolates a quadratic resistance curve. Modeling the pressure drop in this fashion allows the system resistance to vary with variations in flow. Flow rate for each client is satisfied by the flow control of the sub-loop control valve for each client.

Control Valve

The main control valve at the main header of each building was modeled as pressure reducer valve. For the sub-loops, the control valves at the client level were modeled as flow control valves except for the sub-loop control valve for B2H16AL which is on the critical path, Constant pressure loss of 0.006 MPa was set for the control valve in the same flow path with the client B2H16AL.

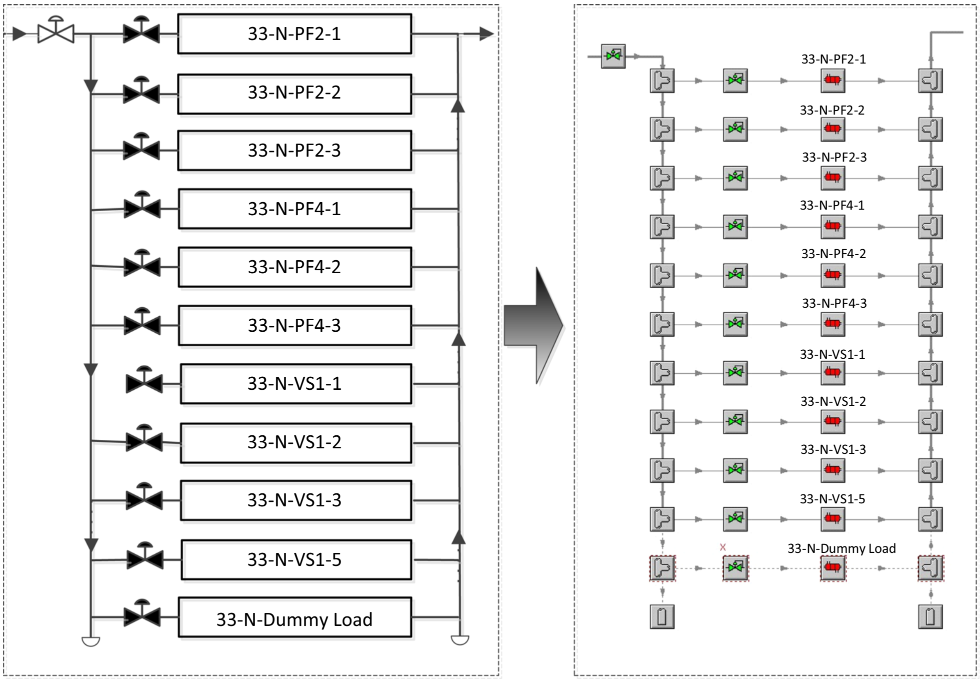

Fig. 2 Process flow diagram and hydraulic model for Clients group C-Building-33-N

Analysis Results

Steady state thermal–hydraulic analysis was performed by using AFT Fathom 7.0. The main results from this thermal–hydraulic analysis are the pump head and client inlet pressure which indicate the system performance in normal operation.

Pump Results

Pump thermal–hydraulic analysis result is shown in Table 2. In normal operation scenario, the mass flow rate of the cooling water flowing through the two pumps is 518.969 and 525.921 kg/s respectively.

The pump head which compensates for the pressure loss of piping and fittings, the main heat exchanger, the control valves of the loop is 0.9026 MPa for pump 1 and 0.9030 MPa for the pump 2 and the critical path is the flow path of client B2H16AL which is located in the client group B-Building-74-B2. The minimum net positive suction head available (NSPHA) is 26.29 m which must be larger than the net positive suction head requirement (NSPHR) of pump selected for this loop.

Client Inlet Pressure

When the client flow rate is fixed at each control point, the pressure at client inlet is the main thermal–hydraulic parameter to indicate the system operation. The inlet pressure for the client was given in Figs. 3, 4 and 5. In these figures the vertical axis gives the pressure value, and the horizontal axis gives the connections number in each group. The connections are numbered by the sequence of their location in the process flow diagram (PFD) of CCWS-2B.

The Fig. 3 shows the cooling water inlet pressure for all the converter connections in the building 32&33. The maximum inlet pressure of the converter client in building 32 is 0.719 MPa and the minimum inlet pressure is 0.6849 MPa. In the Building 33 the inlet pressure range is between 0.7127 and 0.6855 MPa.

The clients' inlet pressure result for the busbar system in building 32 and building 33 is indicated in the Fig. 4 and the inlet pressure for the busbar clients is between 0.8378

Table 2 Pump thermal–hydraulic analysis result

Name	Vol. flow (m^3/h)	Mass flow (kg/s)	dP (MPa)	dH (m)	Overall power (kW)	NPSHA (m)
Pump 1	1900	518.969	0.9026	92.9	472.5	26.29
Pump 2	1926	525.921	0.9030	92.93	479	26.42

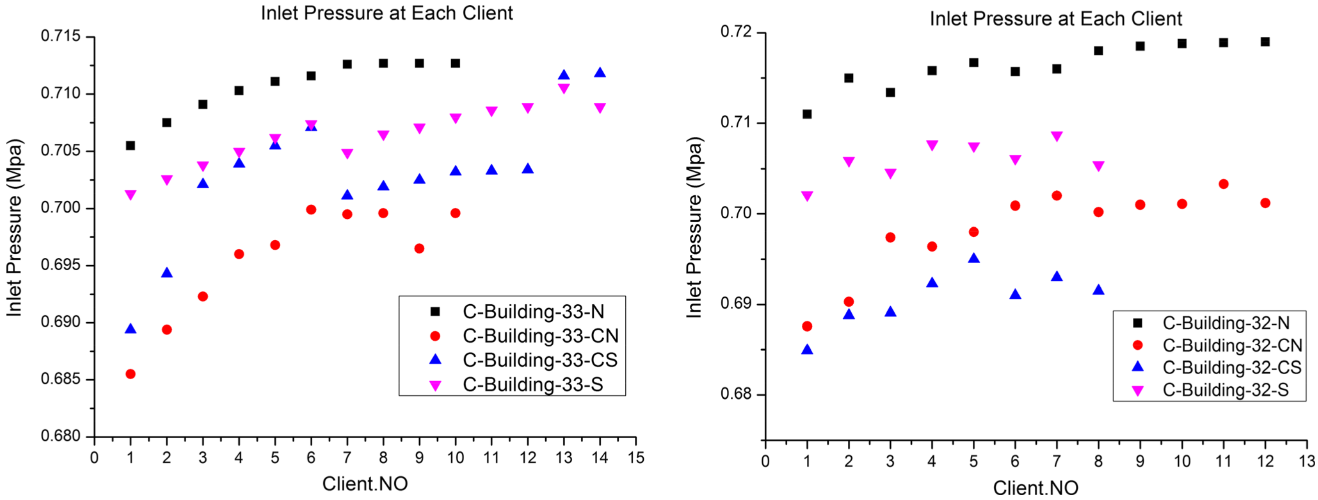

Fig. 3 Cooling water inlet pressure of the converter in building 32&33

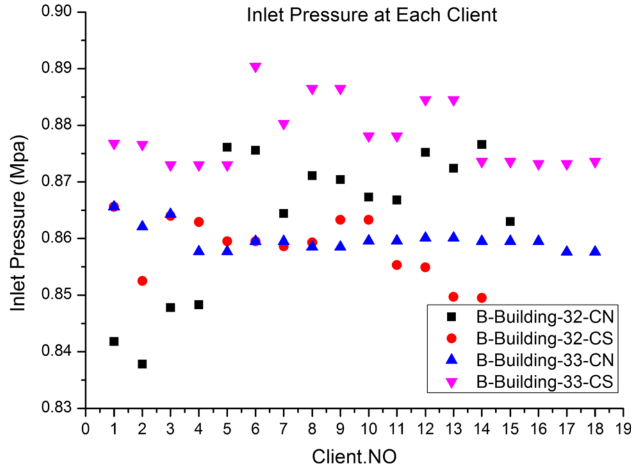

Fig. 4 Cooling water inlet pressure of the busbar in building 32&33

and 0.8904 MPa. Sharing the same main header with the converter client in the center south and north trench, pressure inlet for the busbar is about 0.15 MPa more than the inlet pressure for the converter which accounts for the difference pressure drop of two types of client.

The Fig. 5 illustrates the inlet pressure for the busbar clients located in the building Bridge 32-74, Bridge 33-74, Building 74-L3, Building 11-L3, Building 11-B2, and Building 74-B2. The maximum inlet pressure for bridge and building 74-L3, 11-L3 is 0.784 MPa and the minimum inlet pressure is 0.6831 MPa. Total number of the clients in building 11-B2 is so large that the result for it is shown in two parts in terms of B-Building-11-B2-1 and B-Building-11-B2-2. Range of the client inlet pressure in Building 11-B2 and Building 74-B2 is between 0.9811 and 1.0056 MPa.

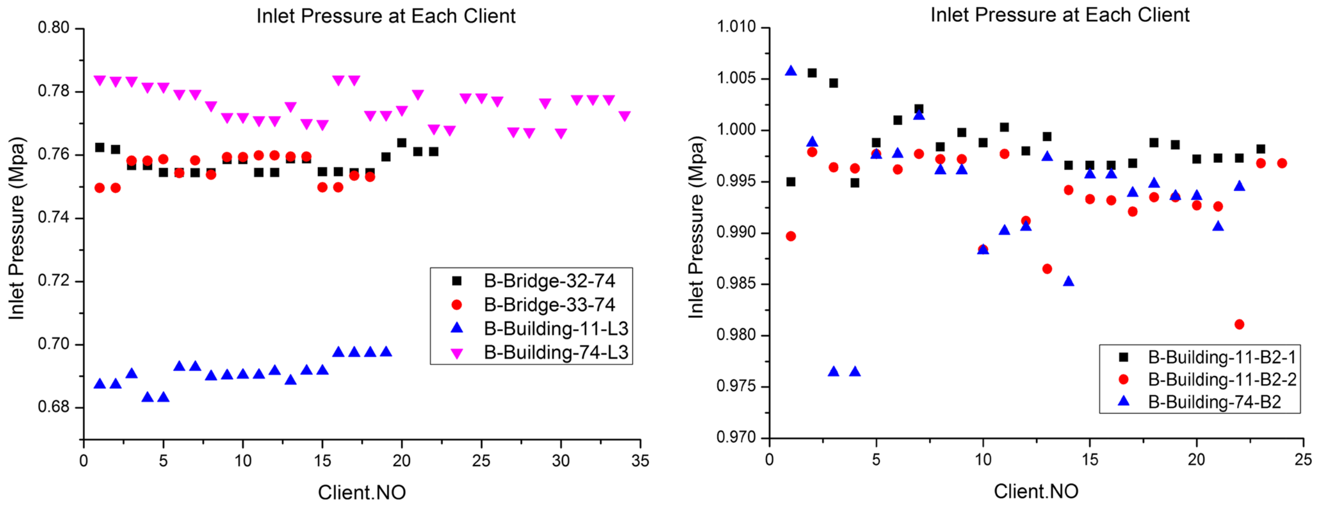

Fig. 5 Cooling water inlet pressure of the busbar in bridge and building 74L3, 11L3, 11B2 and 74B2

Discussion

Different piping size and control valve pressure loss factors caused different cooling water inlet pressure under the same cooling water pressure in the main header. Comparing the Figs. 3, 4 and 5, we can find client inlet pressure of the converter is lower than the busbar's pressure drop. This is because the larger pressure loss of the busbar and the excess pressure is consumed by the sub-loop control valve for the converter. In the Fig. 5, there is a larger difference between the client group B-building-74-L3 and B-building-11-L3, this phenomenon was caused by elevation difference between these two client groups.

This thermal–hydraulic analysis indicated that the highest client cooling water inlet pressure is 1.0056 MPa and it is located in the client group B-Building-11-B2. Client in the group B-Building-11-L3 has the lowest cooling water inlet pressure in the total loop, and the exact value is 0.6831 MPa. Clients in the group B-Building-11-B2 have the lowest elevation of -11.6 m and the clients in the group B-Building-11-L3 have the highest elevation of 19.24 m. There is 30.84 m differential between the elevation of the two client groups which accounts for the biggest inlet pressure differential is 0.3225 MPa between the different client groups [1].

Conclusion

The thermal–hydraulic analysis alternative model which includes 332 connections to client was developed and introduced in this paper. By using this model, 2 sets of Thermal–Hydraulic calculation were performed. When the pressure loss of the busbar was increased from 0.3 to 0.45 MPa, the pump head requirement increased from 0.74 to 0.9030 MPa. Due to the elevations difference and piping length and size, the client inlet pressure varies by building. The highest cooling water inlet pressure is 1.0056 MPa and it is located in the client group B-Building-11-B2. Client in the group B-Building-11-L3 has the lowest cooling water inlet pressure in the total loop, and the value is 0.6831 MPa. These results will give a reference for the Component CCWS-2B client design and main pump, control valve, piping sizing in future.

Acknowledgments This paper was elaborated with the collaborative effort of ITER Organization, Institute for Plasma Research India and Chinese Academy of Sciences (ASIPP). The authors acknowledge the contribution of ITER Organization Cooling Water Section and the ITER India Cooling Water System project team.

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