# LABORATORY HEATING SYSTEM DESIGN

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The laboratory heating system is designed as a multiple input multiple output (MIMO) system. The system consists of two closed independent heating circuits, in which the water is the heat transfer medium. Both the circuits are equipped with a heater, cooler, pump and valves, by which the heat transfer within the circuit can be controlled. The heat can also be transferred between the circuits through a multi-plate heat exchanger. Monitoring of the heating system state is done via twelve thermometers and four flow-rate-meters. The whole system is controlled either by a PC equipped with data acquisition cards or by a modular industrial PLC Tecomat NS950 with analogue input-output modules.

Let us explain the function of the heating system, the photograph of which is in Fig. 1 and its scheme in Fig. 2, in more detail. Since both the circuits are independent, they both have a heat source as well as a cooler, rather than to name the circuits as a primary circuit and a secondary circuit, as it is common in the field of heating systems (the heat source is usually a part of the primary circuit), let us name the circuit as the left and the right circuit according to scheme in Fig. 2.

As can be seen in the scheme, the main subsystem units of the system are connected by pipe lines. Obviously, the lengths of the pipes determine the transport delays in the heat transfer throughout the system. Let us recall that to study the impact of the delay effect on the system dynamics is the main aim of our research. Therefore, in order to provide the possibility to enhance the delay effect, there have been placed seven delay units in the system, which consist of scrolled pipes, the lengths of which vary from 3 to 30 metres. Since the delay units are interchangeable and they can also be bypassed, the system provide a broad potentials in studying the effect of transportation phenomenon in real plants.

Let us first describe in detail the left circuit. The circulation of the medium in the circuit is forced by the Pump L which is controlled manually by determining its pipe-lift $U_{\mathrm{Lp}}$. The flow through the pump is measured by a flowmeter $Q_{\mathrm{L1}}$. The heat source is an accumulation-type Heater L. Notice that the inlet and the outlet water temperatures are measured as $\vartheta_{\mathrm{Lhi}}$ and $\vartheta_{\mathrm{Lho}}$, respectively. Even though the performance of the heater can be controlled by the signal $U_{\mathrm{Lh}}$, due to relatively large capacity of the heater, the control actions are fairly slow. Therefore, it is better to control the water temperate which goes to the exchanger, and which is measured as $\vartheta_{\mathrm{Lei}}$, by a mixing Valve L1, which is controlled by the signal $U_{\mathrm{Lv1}}$. In fact this signal, via a servo of the valve, controls the position of the valve seat determining the mixing ratio of the hot water from the heater and cooled water from the cooler (Cooler L). The temperature of the medium leaving the exchanger in the left circuit is measured as $\vartheta_{\mathrm{Leo}}$. The second mixing Valve L2 in the left circuit, which is controlled by the signal $U_{\mathrm{Lv2}}$, allows us to divide the water stream into two branches. One of the braches goes to the exchanger and the other accomplishes a bypass of the exchanger. The flow through the bypass branch pipe is measured by a flow-rate-meter as $Q_{\mathrm{L2}}$. In this way, by the signal $U_{\mathrm{Lv2}}$ we can control the amount of the heat transferred between the circuits. Consequently, the temperature of the water leaving the mixing valve and forced towards the Cooler L is also determined by the mixing ratio in the valve given by $U_{\mathrm{Lv2}}$. The temperatures in the inlet and outlet of the Cooler L are measured as $\vartheta_{\mathrm{Lci}}$ and $\vartheta_{\mathrm{Lco}}$, respectively. The cooling performance is controlled by signal $U_{\mathrm{Lc}}$. The water which leaves the cooler is forced by the pump towards the Heater L and the Valve L1.

The circulation of the medium in the right circuit is forced by the Pump R which is controlled manually by determining its pipe-lift $U_{\mathrm{Rp}}$. The flow through the pump is measured by a flow-rate-meter $Q_{\mathrm{R1}}$. The heat source is a flow-type Heater R. Its inlet and the outlet water temperatures are measured as $\vartheta_{Rhi}$ and $\vartheta_{Rho}$, respectively. Unlike the dynamics of the Heater L, the dynamics of the Heater R is relatively fast and, therefore, the heater can serve well as an actuator controlling the water temperature entering the exchanger, which is measured as $\vartheta_{Rei}$. Alternatively as an actuator by which this temperature can be controlled can serve the mixing Valve R. In this valve, the hot water from the heater is mixed with cooled water from the Cooler R in a ratio determined by the position of the valve seat controlled via a servo by signal $U_{Rv}$. This mixing valve determines the flow passing through the heater measured as $Q_{R2}$. The temperature of the water leaving the exchanger in the right circuit is measured as $\vartheta_{Reo}$. The water is then forced towards the Cooler R. Its inlet and outlet water temperatures are measured as $\vartheta_{Rci}$ and $\vartheta_{Rco}$, respectively. The cooling performance is controlled by signal $U_{Rc}$. The water which leaves the cooler is forced by the pump towards the Heater R and the Valve R. All the signals $U$ except $U_{Lp}$ and $U_{Rp}$ are electronic signals generated either by PC equipped by data acquisition cards or PLC Tecomat NS950. All the temperatures $\vartheta$ are measured by thermometers Pt1000 and processed by PC or PLC.

Further, brief description of the parts of the heating system and some of their characteristics is provided:

- **Heaters**

For the left circuit, an accumulation-type heater SHU 5 S STIEBEL ELTRON 071754 was chosen. The performance of the heater is 2 kW and its capacity is 5 l. The heater is equipped with a thermostat which controls the outlet water temperature. The control unit of the heater was modified so that the performance of the heater could be controlled continuously.

For the right circuit, a flow-type heater was designed. The performance of the heater is 2 kW and its capacity is 1.5 l. The performance of the heater can be controlled continuously. For safety reasons, a thermostat guard is used to prevent the water temperature inside the heater get close to the boiling point, i.e. 100°C.

- **Pipe lines**

Due to very good isolation features and flexibility we chose five-layer aluminium plastic composite pipes Seacomppipe 16×2, with inner diameter 12 mm.

The computational water flow was determined by the ratio of the performance of the heaters $P$=2000 W and the design temperature increment on the heaters $\Delta\vartheta$ which was chosen $\Delta\vartheta$=20 K. Taking into consideration the following parameters, the specific thermal capacity of water $c$=4186 Jkg$^{-1}$K$^{-1}$, efficiency $\eta$=0.9, and water density $\rho$=1000kgm$^{-3}$, the design water flow-rate can be computed as follows

$$P\eta = Q\,\rho\, c\,\Delta\vartheta \rightarrow Q = \frac{P\eta}{\rho\, c\,\Delta\vartheta} = \frac{2000[W]0.9}{1000[kgm^{-3}]\ 4186[Jkg^{-1}K^{-1}]\ 20[K]} =$$

$$= 2.1500\ 10^{-5}[\mathrm{m^3 s^{-1}}] = 1.2900[\mathrm{l\,min^{-1}}] = 77.4[\mathrm{l\,hod^{-1}}]$$

On the basis of this value, the water flow-rate was chosen from 40 to 120 [l hod$^{-1}$].

- **Mixing control valves**

According to the water flow-rate and the pressure losses on the valves, from the catalogue of Landys & Staefa, we chose mixing valves VXG44.15-0.4 with $k_{vs}$=0.4 m$^3$s$^{-1}$. The pressure looses on the valve for the $Q_{max}$=120 l hod$^{-1}$ is 8 kPa.

For controlling the valves, servos SQS65 of Landys & Staefa were chosen.

- **Exchanger**

On the basis of the maximum performance of the heaters, a multi-plate heat exchanger Zilmet Z 1/8 with heat transfer up to 3 kW. In order to reduce the affectivity of the exchanger, the number of plates was reduced from 8 to 5.

- **Coolers**

In order to solve the problem with cooling the water, we used the water/air exchangers from the heating system of a car Škoda Felicia which had the characteristics which satisfied our requirements. For the ventilators in the coolers, control units were designed which allows us to control continuously the cooling performance.

- **Delay units**

The delay units are performed as scrolled pipelines. In Tab. 1 the delays on one meter of the pipes for the selected flow-rates are listed.

Tab. 1 Average velocity in the pipes and delays on one meter of the pipe

| Flow $Q$ [l $hod^{-1}$] | 40 | 60 | 80 | 100 | 120 |
|---|---|---|---|---|---|
| Delay on 1 m [s] | 10.2 | 6.8 | 5.1 | 4.1 | 3.4 |

The lengths of the pipes in the delay units are the following: 3.1, 5.6, 6.1, 9.4, 11.8, 20.2, 30 metres.

- **Pumps**

Due to the pressure losses in the circuits, determined predominantly by the losses in the mixing valves, pumps Wilo-Star-E 25/1-3 were chosen. The lift of this pump can be adjusted manually from 1 to 3 m.

- **PLC**

A modular PLC Tecomat NS950 mini was chosen. It consists of the main unit and four analogue input output modules.

- **PC**

PC used to monitor and control the system was equipped with data acquisition cards Advantech PCI-1713 and ICP DAS PIO-DA16. The processing of the measured signals is done using Matlab Simuling with Real Time Toolbox.

Fig. 1 A photograph of the laboratory heating system

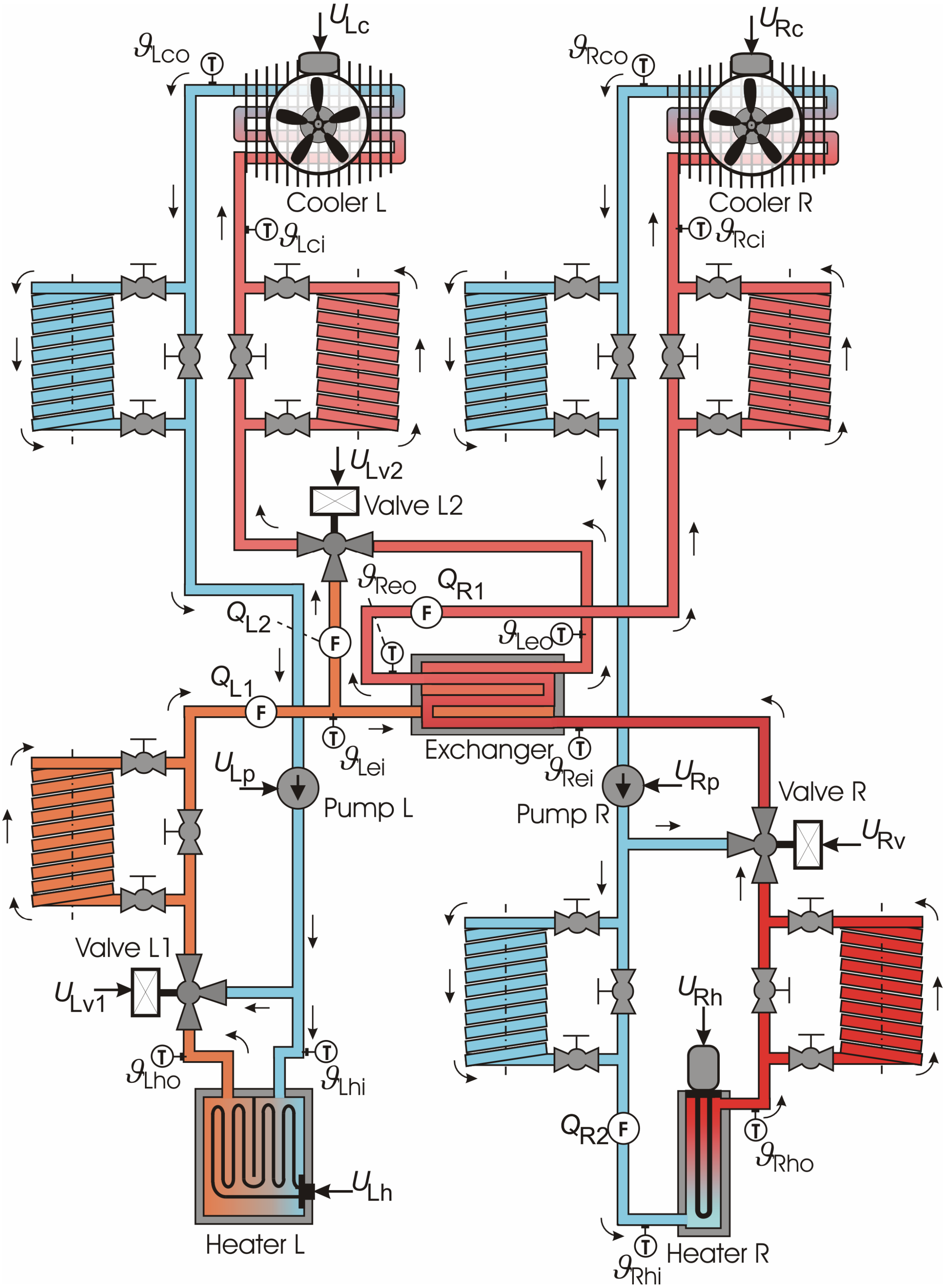


Fig. 2 Scheme of the laboratory heating system