CLB 321: Laboratory

Heat Transfer

Experiment D: 18 September and 9 and 11 October 2019

Creating a correlation for the overall heat transfer coefficient

Authors:

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1. Introduction

The University of Pretoria has two heat exchanger test facilities, namely a plate and frame heat exchanger (or plate heat exchanger, PHE) test facility and a shell and tube (STHE) test facility that are used to demonstrate the principles of heat transfer and piping systems design with fluid movers.

The PHE facility comprises two plate heat exchangers which may be operated apart from one another or together by selecting the appropriate piping and valve configurations. Both exchangers are able to operate co- or counter-currently. A piping and instrumentation diagram of the PHE apparatus is provided in Appendix A. Figure A1 shows the overall configuration of the PHE facility while Figure A2 shows the configuration when the first heat exchanger (PF-01) is configured to operate counter-currently. A design drawing for the plate heat exchanger is provided in clickUP as well as the dimensions and materials of construction of both heat exchangers. Operating instructions for the heat exchanger test rigs are also available in clickUP.

Note that currently the radiator mentioned in the P&IDs is by-passed and that the temperature of the cold utility supply is being maintained by adding cold water to the supply tank and draining the excess water from the tank.

The STHE facility comprises two straight tube heat exchangers, one with a single pass tube-side construction and the other with a two pass tube-side construction. Both heat exchangers can be configured to operate co- or a counter-currently with respect to the first tube pass. The P&ID of the apparatus is also included in Appendix A, Figure A3. The configuration shown is for running either one of the heat exchangers counter-currently.

The main purpose of the assignment is to develop empirical equations to correlate the overall heat exchange coefficients of the STHE and the PFHE operating in counter current mode as functions of the cold and hot utility flow rates.

2. Proposed experiments

2.1 PHE facility

Objective 1

The first objective will be to obtain the pump curve of the two cold utility pumps, namely CPP-03 and CPP-04. These pumps are installed to operate in series which makes it possible to measure the pump curves simultaneously.

The output required from the test is a graph showing the differential pressure created by each pump in units of meter water as a function of the flow rate through the pump.

Objective 2

The second objective is to develop a semi-empirical equation describing the overall heat transfer coefficient as a function of hot and cold utility flows flowing counter-currently at rates varying between 4 and 20 Lit/min.

This can be done by measuring the overall heat transfer coefficient at a number of different hot utility flow rates while the cold utility flow rate is kept constant and also measuring the overall heat transfer coefficient at different cold utility flow rates while the hot utility flow rate is kept constant.

Note: Similar experiments are required for the STHE.

2.2 STHE facility

Objective 1

The first objective will be to determine the pressure drop over the tube side of the single pass STHE. The flow through the tube side is to be varied and the pressure drop over both tube side passes are to be measured and reported as a function of the volumetric flow rate.

Objective 2

As with the PHE facility, the second objective is to develop a semi-empirical equation describing the overall heat transfer coefficient as a function of the hot and cold utility flow rates when the heat exchanger utility streams are flowing counter-currently.

3. Heat exchanger design equations

The overall heat transfer rate of a heat exchanger is given by the following equation:

$$Q = UA\Delta T_{lm} \qquad (1)$$

with:

Q	The heat transfer rate, W
U	The overall heat transfer coefficient, W/m^2.°C
A	Overall heat transfer area, m^2
ΔT_{lm}	Log mean temperature difference, °C

The log mean temperature is derived from the inlet and outlet temperatures of the hot and cold streams:

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{ln\left({}^{\Delta T_1}/_{\Delta T_2}\right)} \qquad (2)$$

Where ΔT_1 is the temperature difference between the hot and cold streams on one side of the heat exchanger and ΔT_2 is the temperature difference between the hot and cold streams on the other side of the heat exchanger. This is further illustrated in Figure 1 for clarification.

Figure 1: Assignment of temperatures for calculating the LMTD.

The overall resistance for the transfer of heat from the hot side of a heat exchanger to the cold side of a heat exchanger is the sum of the resistances for heat transfer from the hot stream to the heat exchanger surface, the resistance for heat transfer from the surface of the heat exchanger to the material of construction of the heat exchanger caused by fouling, the resistance for heat transfer through the material of construction of the heat exchanger, the resistance for heat transfer cause by fouling at the cold sided of the heat exchange surface and finally the resistance to heat transfer from the surface of the heat exchange surface to the bulk of the cold stream.

For heat transfer through a plate the relationship is as follows:

$$\frac{1}{U} = \frac{1}{h_h} + R_h + \frac{t}{k} + R_c + \frac{1}{h_c} \qquad 3$$

Where U is the overall heat transfer coefficient, h_h is the film heat transfer coefficient on the hot side, R_h is the fouling factor on the hot side t is the thickness of the plate, R_c is the fouling factor on the cold side and finally h_c is the film heat transfer coefficient on the cold side of the heat exchanger.

For heat transfer through a tube the appropriate relationship is:

$$\frac{1}{UD_o} = \frac{1}{h_o D_o} + \frac{R_o}{D_o} + \frac{ln\left({D_o}/{D_i}\right)}{2\pi k} + \frac{R_i}{D_i} + \frac{1}{h_i D_i} \qquad 4$$

Where D is the diameter of the tube, h is the film heat transfer coefficient, R is the fouling factor and k is the thermal conductivity of the tube material. The subscripts i and o refer to the inside and outside of tube respectively.

From the on heat exchangers and past work, it is known that at hot and cold utility flow rates between 4 and 20 lit/min, the cold and hot side heat transfer coefficients of both plate and shell and tube heat exchangers can be correlated with an equation with the following form:

$$h_f = a\dot{V}^n \qquad 5$$

In Equation 5, h_f is the film heat transfer coefficient (either hot or cold side), $\dot{V}$ is the volumetric flow rate (either hot or cold) and n is an empirical coefficient. In the case of plate and frame heat exchangers, $n = 0.65$ whereas in the case of shell and tube heat exchangers, $n = 0.54$ for the shell side film heat transfer coefficient and $n = 0.8$ for the tube side film heat transfer coefficient.

The purpose is to develop a set of semi-empirical equations to estimate the overall heat transfer coefficients of the two heat exchangers and also to determine the accuracy with which the equations describe the measured results.

Tip: In order to determine the a-values for the different film heat transfer coefficients, measure the overall heat transfer coefficient while keeping either the hot or cold water flow rate constant and plot $\frac{1}{U}$ as a function of $\frac{1}{\dot{V}^n}$.

An alternative method is to calculate predicted heat transfer coefficients as functions of the measured parameters and the unknown parameters of the heat transfer equations and to then minimise the square of the difference between the predicted and measured values of the overall heat transfer coefficient by varying the unknown parameters of the heat transfer functions.

4. Outputs from experiments

Each group should prepare the following:

1. An oral presentation of no more than 20 min should be prepared for presentation with both groups present. An additional discussion with each group will also take place during the presentations. Arrange that at least two members of the group make the presentation together.
2. Secondly, a formal report with an introduction, theory, experimental apparatus, results, discussion and finally conclusions and recommendations should be completed in accordance with the Department's Guidelines and Rules for Writing Technical Reports and Papers.

Copies of the formal report and the presentation (both in pdf format) must be loaded onto clickUP before or on the day of the oral presentation.

5. Recommended Literature

Cengel, YA (2006) Heat and Mass Transfer: A Practical Approach, Third Edition, McCraw-Hill, New York.

Sinnott, RK (2005) Coulson and Richardson's Chemical Engineering Design Volume 6, Fourth Edition, Elsevier Butterworth-Heinemann, Oxford.

Appendix A: P&IDs for the PHE and STHE test facilities

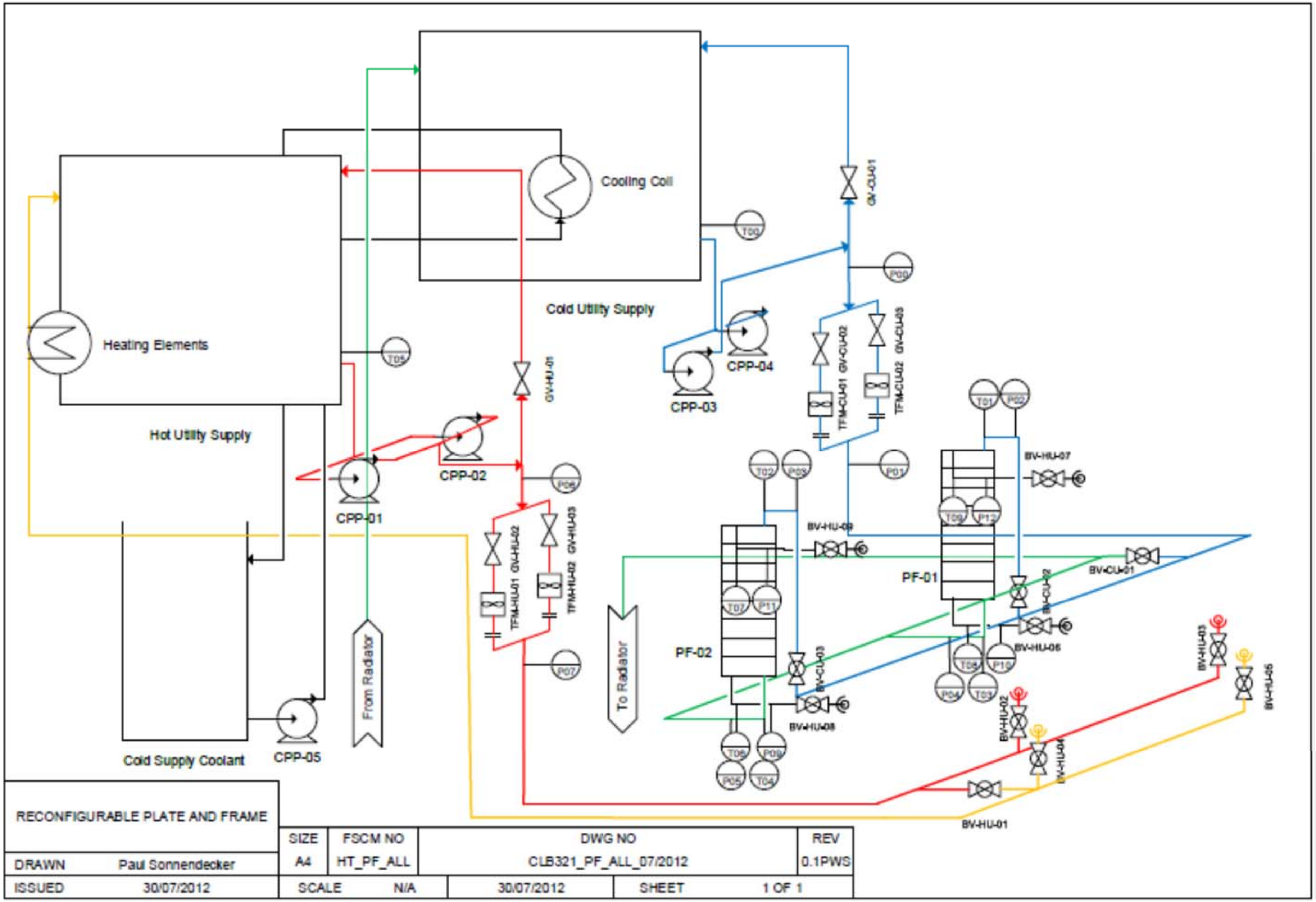

Figure A1: P&ID of the PHE apparatus (cold utility and hot utility piping systems shown in blue/green and orange/red respectively).

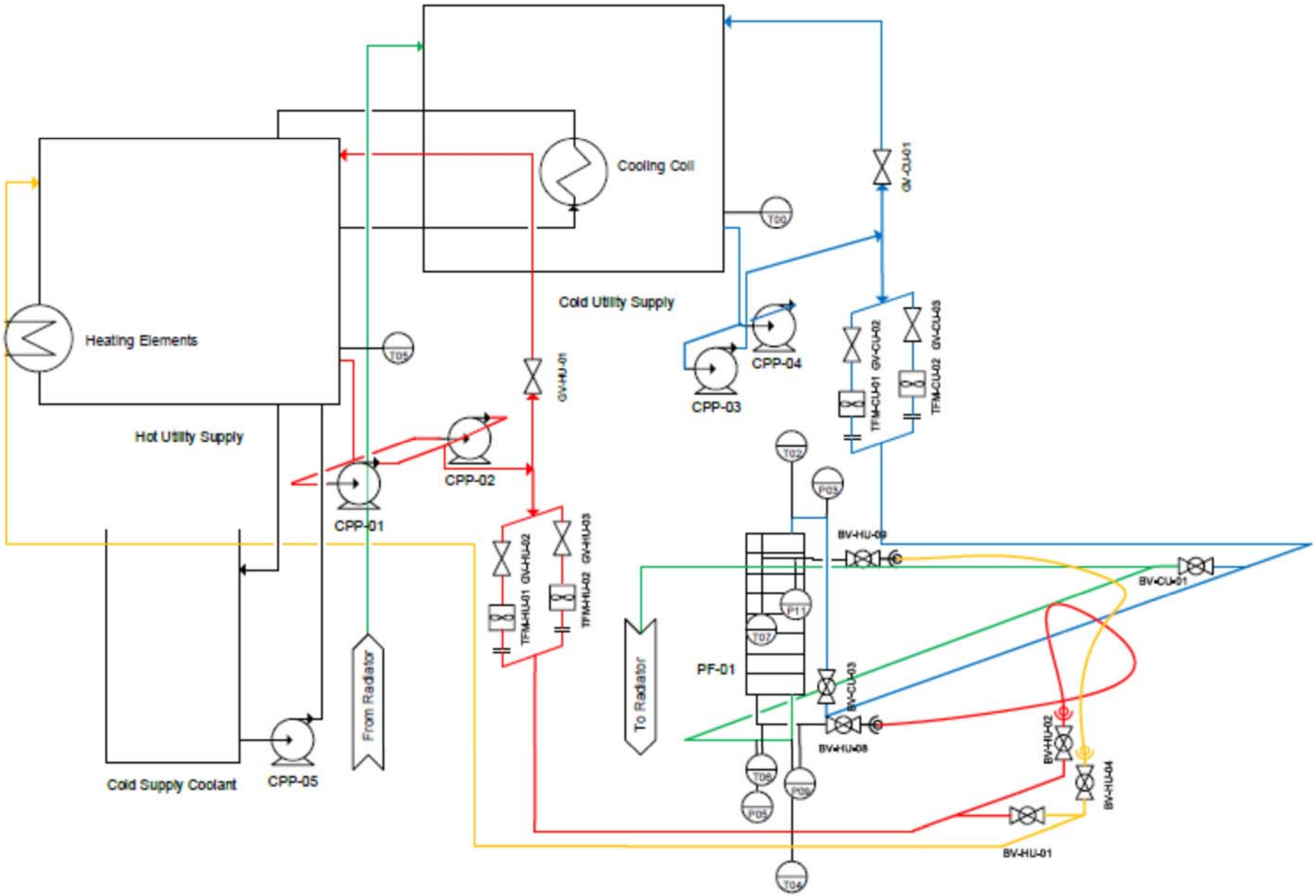

Figure A2: P&ID for the PHE PF-01 operated with a counter-current configuration.

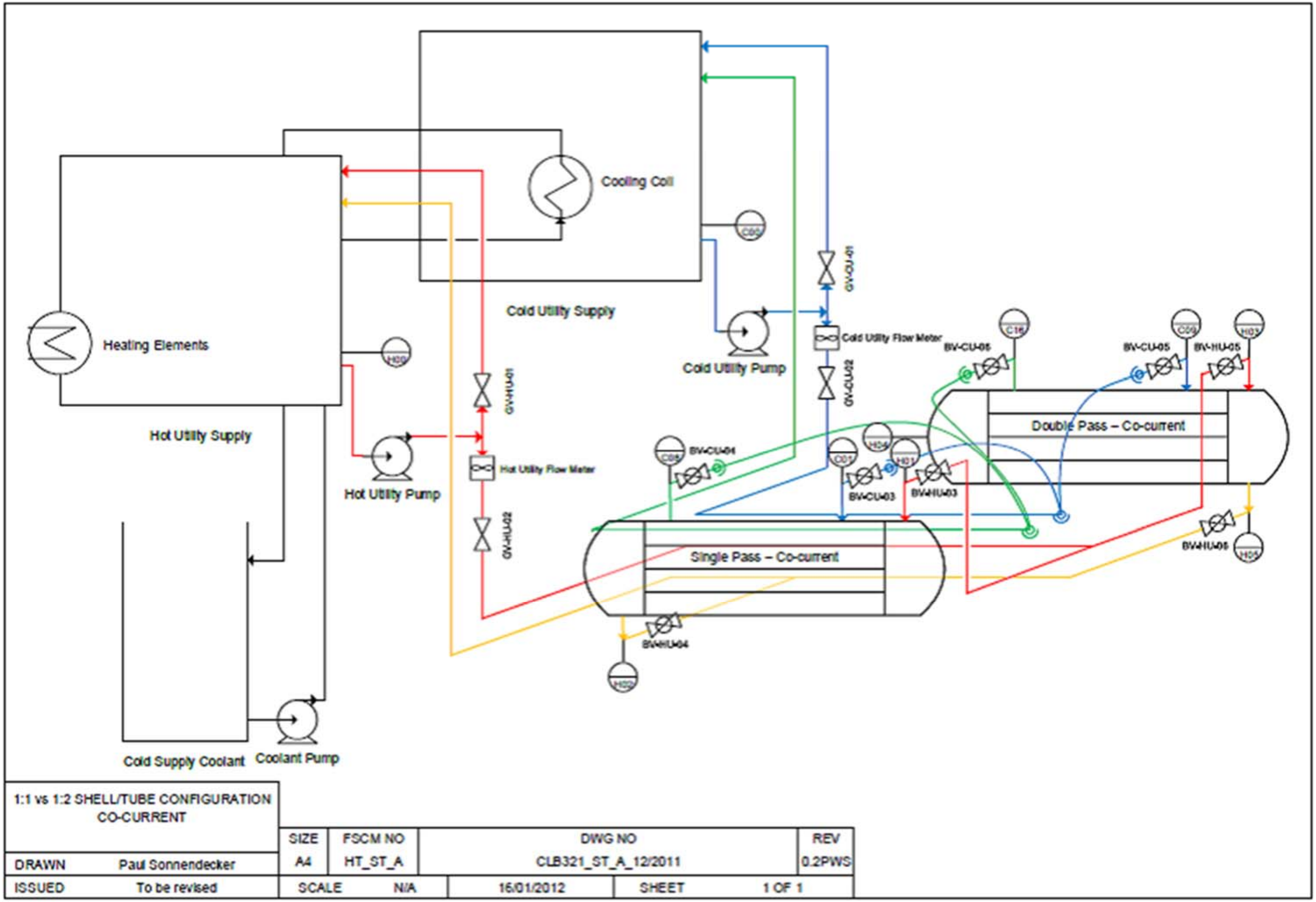

Figure A3: P&ID of the STHE apparatus (cold utility and hot utility piping systems shown in blue/green and orange/red respectively).