Modelling of hydraulic system of CLIC prototype module type 0

Shoaib Azhar

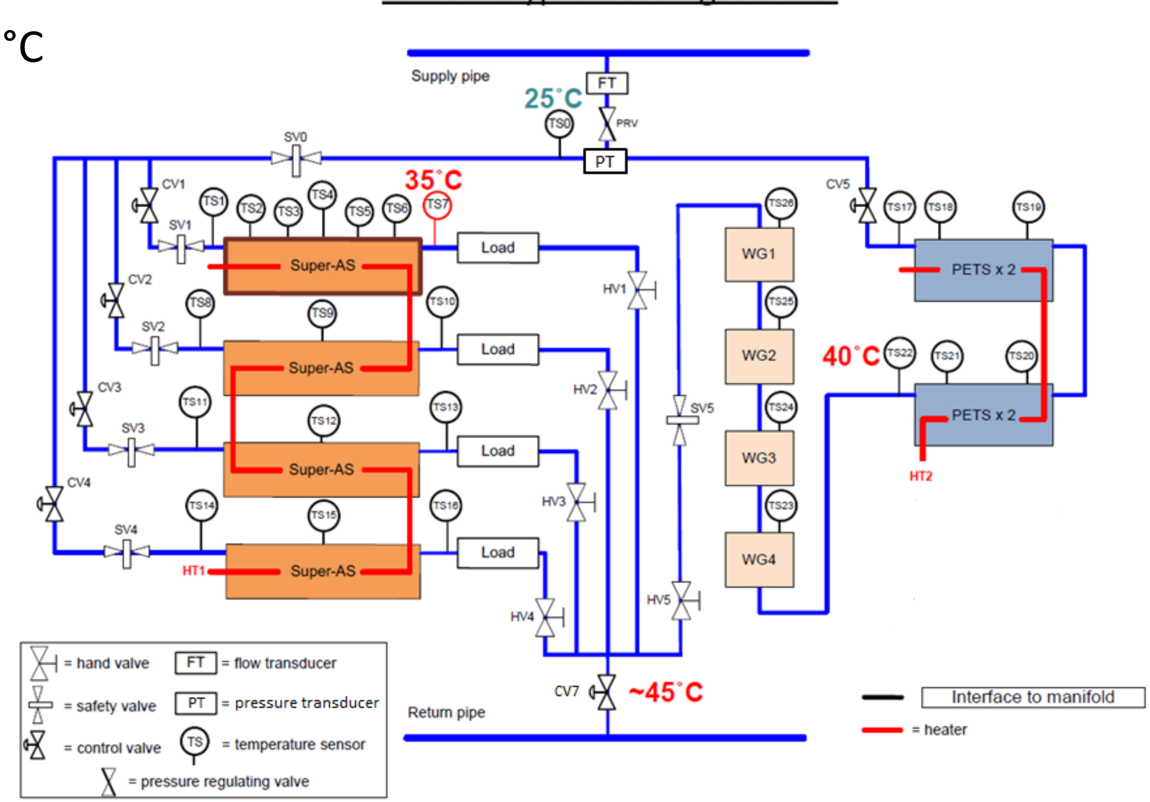
1. Introduction
2. Theoretical formulation
3. Numerical model

1. INTRODUCTION: cooling system

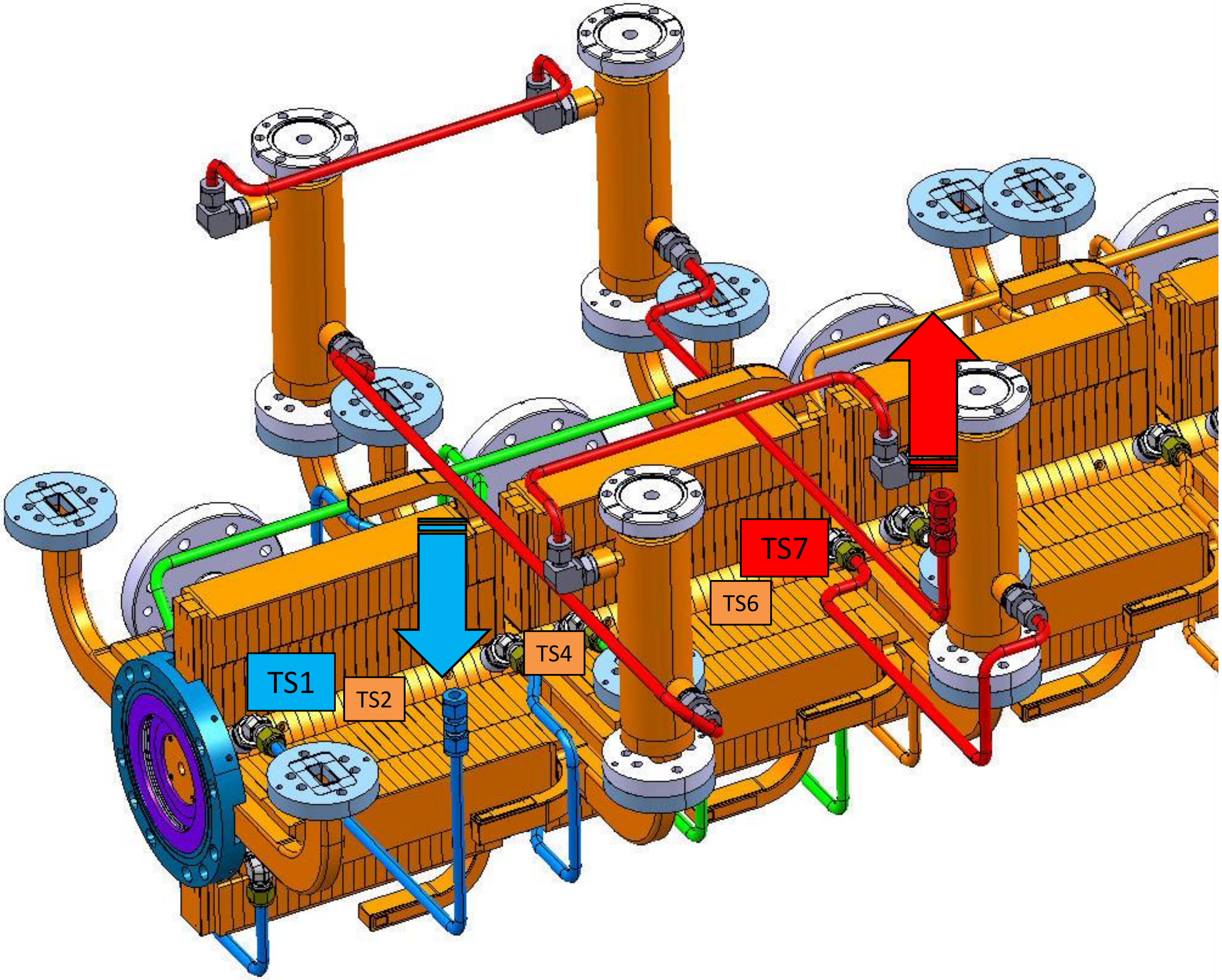
- Demineralized water
- Nominal volumetric flow rate: 0.36 m^3/h
- Water inlet temperature: 25 °C
- Water outlet temperature: ~45 °C
- Max. pressure allowed: 5 bar
- Inlet/outlet interface
- Water supply

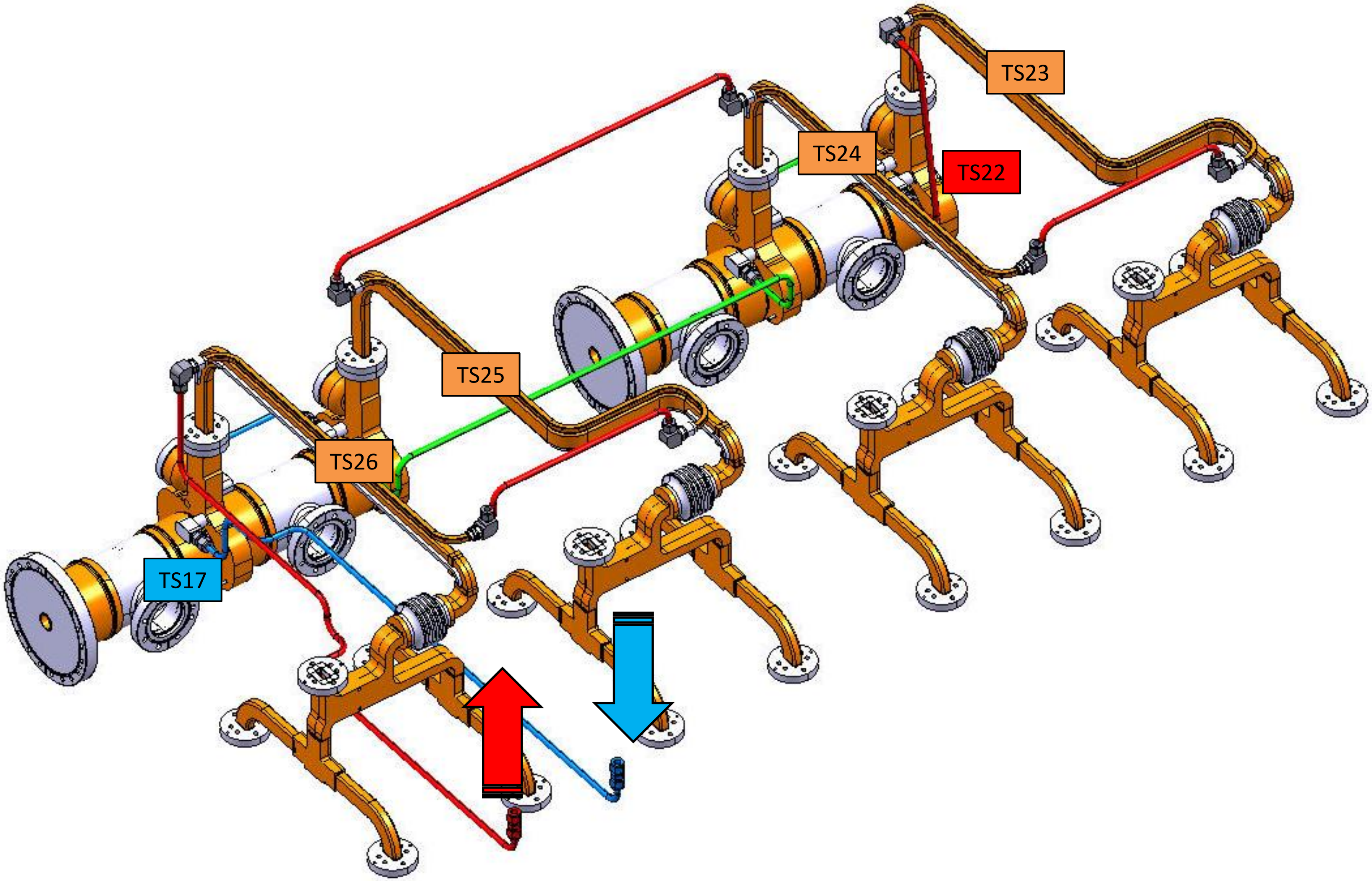
Updated 7-Dec-2011 Alexandre Samochkine @ cern.ch

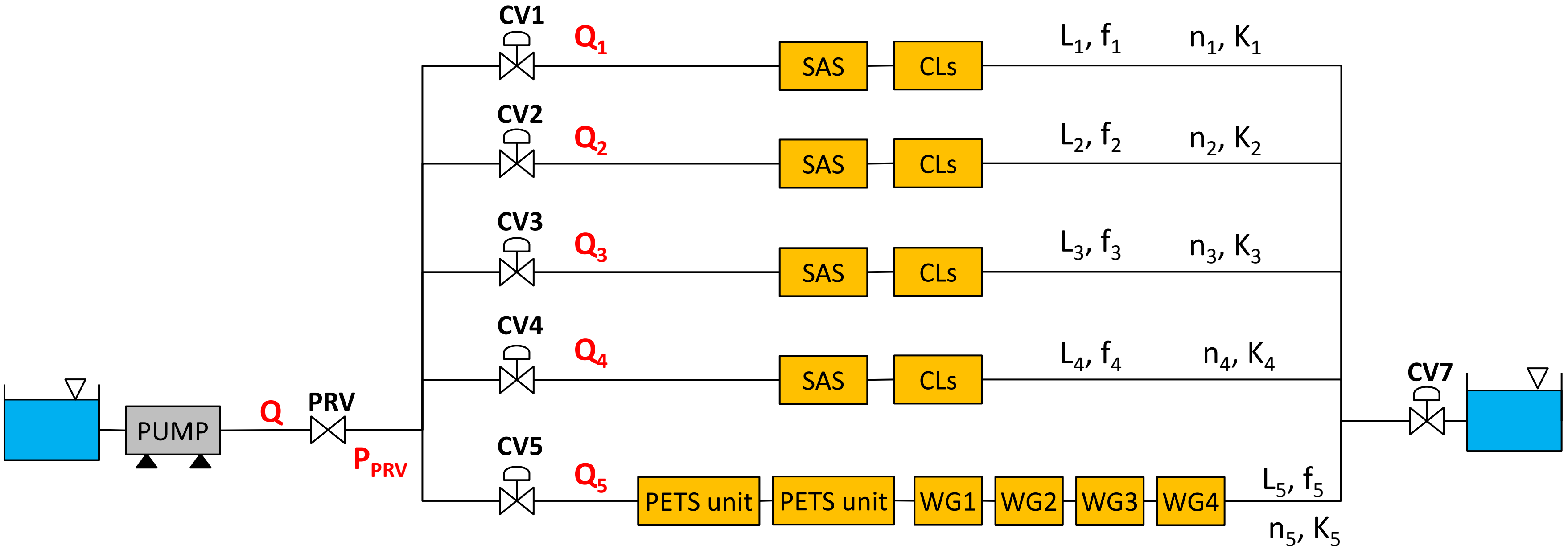
Module Type 0 cooling scheme



1. INTRODUCTION: SAS and CL cooling system




TS23
TS24
TS22
TS25
TS26
TS17



Q = total flow rate [m^3/h]

Q_1 ~ Q_4 = flow rate for SAS [m^3/h]

Q_5 = flow rate for PETS unit and wave guides [m^3/h]

P_{PRV} = set pressure for PRV [Pa]

CV = control valve

PUMP = water pump

f_i = pipe distributed energy loss (L_i = pipe length)

K_i = Pipe fitting coefficient (n_i = Number of fittings)

SAS = super accelerating structure

CL = compact load

WG = waveguide

1. Introduction

2. Theoretical formulation

3. Numerical model

The head loss in pipe flow is mainly because of 2 reasons

1-Distributed Pressure Drop (friction head)

2-Concentrated Pressure drop (Valves & pipe fittings)

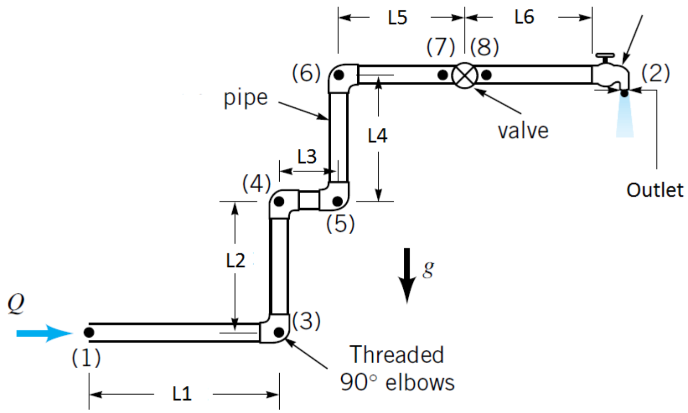
$$H_L = H_f + \Sigma H_c$$

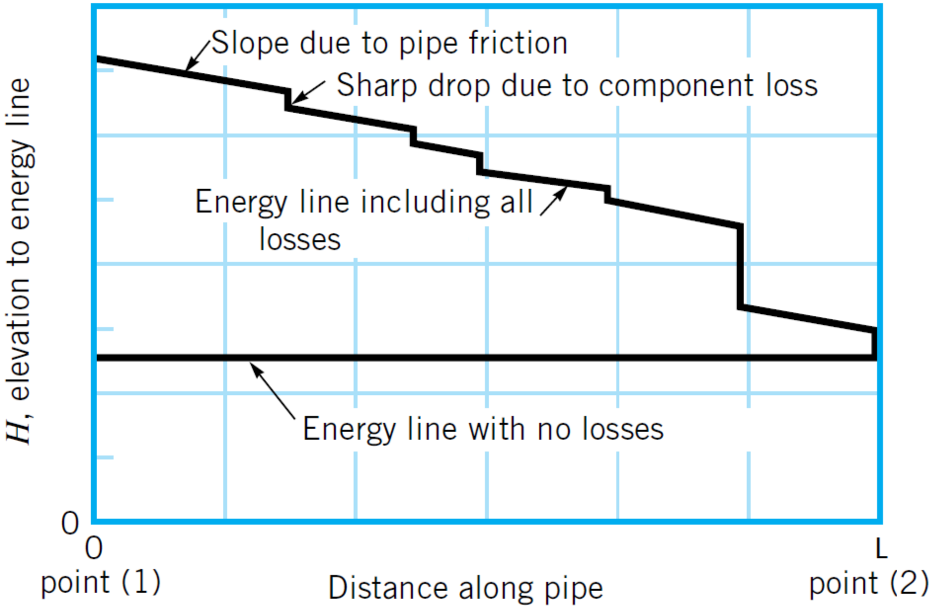
H_L = Total Head Loss

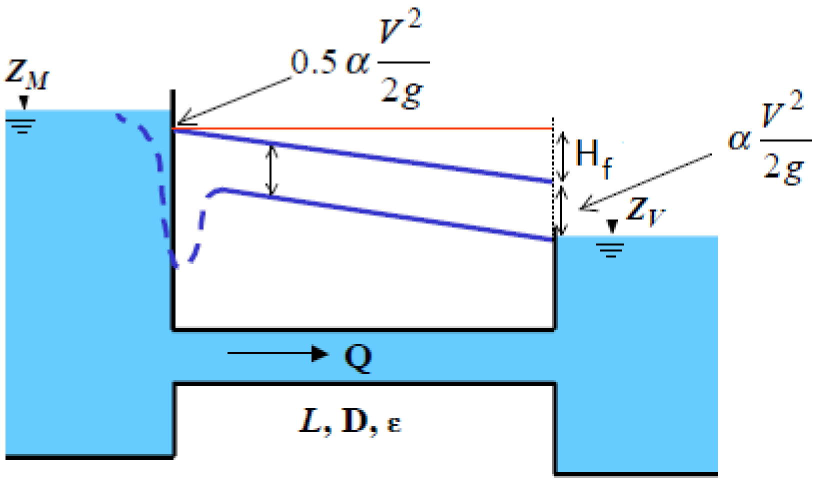
H_f = Head loss due to pipe friction

H_c = Head loss in component/fittings

L = L1+L2+L3+L4+L5+L6







- Darcy's Equation:

$$H_f = f \frac{L}{D}\frac{V^2}{2g}$$

f → Re,ε   Moody's Diagram

- For Laminar flow (Re < 2000) :

$$f = \frac{64}{Re} \qquad Re = \frac{\rho v D}{\mu}$$

Re = Reynolds Number

ε/D = Relative Roughness

- For Turbulent flow:

$$f = \frac{0.316}{Re^{0.25}}$$ Blasius Equation (smooth pipe)

$$\frac{1}{\sqrt{f}} = -2\,log_{10}\left[\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right]$$ Colebrook Equation

$$\frac{1}{\sqrt{f}} = -1.8\,log_{10}\left[\left(\frac{\varepsilon/D}{3.7}\right)^{1.11} + \frac{6.9}{Re}\right]$$ Haaland Equation (Approximation)

Concentrated Loss (Minor Loss)

- Bends
- Tees
- Valves
- Expansion
- Contraction
- ....

Depends upon

- Velocity ‘v’
- Fitting loss coefficient ‘K’

They may be small as compared to distributed pressure drop.

But for short pipes with multiple fittings, minor losses are not minor

$$H_c = K\frac{V^2}{2g}$$

‘K’ depends on type and shape of fittings.

In TM0 cooling system for AS lines there are more than 70 bends in 9 m span of diameter 6 mm.

1. Introduction

2. Theoretical formulation

3. Numerical model

1-Required Inputs

Regulating Pressure (PRV)	Control Valve Voltages (v1~v7)	Assumed Flow rates (Q1, Q2, Q3, Q4, Q5)

↓

2-Available Constants and Parameters

Fluid Properties (Density, Viscosity)	Valve Characteristics (kvs1~kvs7)	Pipe Diameters & Lengths (D & L)	Fitting's loss coefficient (kb, ke, kt)

↓

3-Calculated Values

Valve Opening	Reynolds Number	Pipe frictional coefficient

↓

4-Final Results

Flow Rates	Pressure Drops across Valves	Distributed Pressure Drop	Concentrated Pressure Drop

Inputs

Regulating Pressure (Pa) $PRV := 140000$

CV Voltage (Volts)

$v1 := 8$ $v2 := 8$ $v3 := 8$ $v4 := 8$

$v5 := 8$ $v7 := 8$

Fluid Properties

Fluid Density (Kg/m³) $\rho := 1000$

Fluid Viscosity (Pa-s) $\mu := 0.001002$

Assumed Flowrates

$Q1 := 0.071$ $Q2 := 0.071$ $Q3 := 0.071$ $Q4 := 0.071$

$Q5 := 0.032$

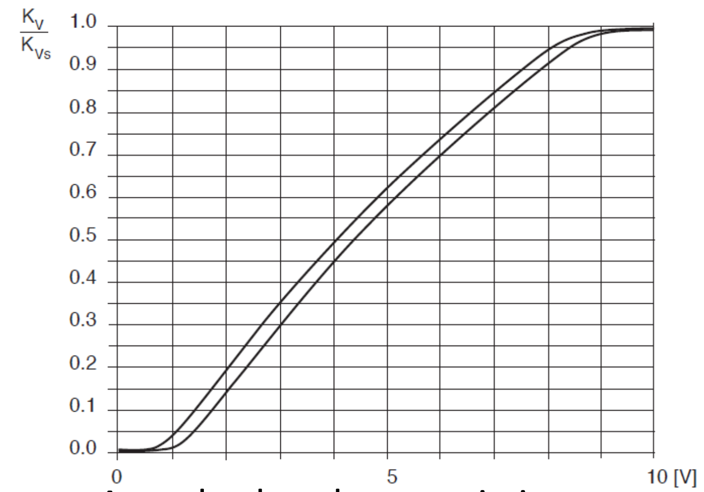
$Q := Q1 + Q2 + Q3 + Q4 + Q5$ $Q = 0.316$

- **Pressure:**
  Pressure of the Regulating Pressure Valve
  Range: $4x10^5$ Pa (4 bar) Max.

- **Control Valve Voltages (v1~v7):**
  to control the opening of the valve
  Range: 0 ~ 10 volts

- **Assumed Flow rates:**
  As it is iterative solution,
  so
  Initial assumption for flow rates of lines 1, 2, 3, 4 and 5
  Q1, Q2, Q3, Q4 and Q5 in m^3/h

#	BURKERT REFERENCE	k_{Vs} [m³/h]
CV1	Type 1 (2835, n. 175996)	0.12
CV2		
CV3		
CV4		
CV5	Type 2 (2833, n. 175869)	0.04
CV7	Type 4 (2835, n. 176006)	0.45

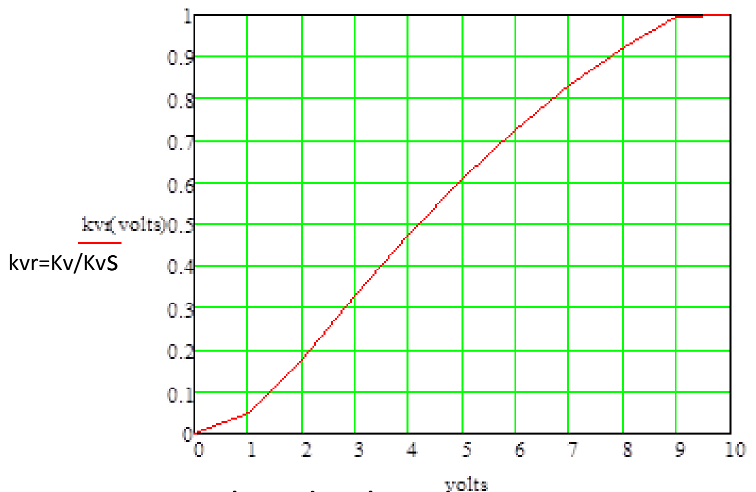


Actual valve characteristic curve

k_{Vs} value: Flow rate value for water, measured at +20 °C and 1 bar pressure differential over a fully opened valve

$$[0 - 10\ volt] \rightarrow k_V \rightarrow \Delta p = \rho \cdot \left(\frac{Q}{k_V}\right)^2$$

$$kvr(x) := B_0 x^5 + B_1 x^4 + B_2 x^3 + B_3 x^2 + B_4 x + B_5$$



Interpolated valve characteristic curve

Δp = pressure drop across control valve for a certain opening position [bar]

ρ = water density [kg/dm³]

- Following set of implicit equations are solved in Mathcad to calculate flow rates

$$Q = Q1 + Q2 + Q3 + Q4 + Q5$$

$$PRV = (m1 + a1)\cdot Q1^2 + Pf1\cdot Q1 + (a7 + m0)\cdot Q^2$$

$$PRV = (m2 + a2)\cdot Q2^2 + Pf2\cdot Q2 + (a7 + m0)\cdot Q^2$$

$$PRV = (m3 + a3)\cdot Q3^2 + Pf3\cdot Q3 + (a7 + m0)\cdot Q^2$$

$$PRV = (m4 + a4)\cdot Q4^2 + Pf4\cdot Q4 + (a7 + m0)\cdot Q^2$$

$$PRV = (m5 + a5)\cdot Q5^2 + Pf5\cdot Q5 + (a7 + m0)\cdot Q^2$$

$ai.Qi^2$ =
Control Valve Pressure Drops

Pfi.Qi =
Distributed Pressure Losses
(Frictional Losses)

$mi.Qi^2$ =
Concentrated Pressure Losses
(bends, entrance/exit, tees, etc.)

Qi = flow rate in m^3/h in line ‘i’

ai = coefficient for Control Valve → (k_s, v)

mi = coefficient for pipe fittings →(K, v)

Pfi = coefficient for friction loss →(L, D, v, Re, ρ, μ)

- On the basis of the operating condition of the control valves (i.e. input voltage), the pressure to be set at PRV depends on the requested flow rate inside the cooling system.

Inputs		Results										
V	P_{PRV}	Q	$Q_{1\sim4}$	$\Delta P_{CV1\sim4}$	$\Delta P_{f1\sim4}$	$\Delta P_{c1\sim4}$	Q_5	ΔP_{CV5}	ΔP_{f5}	ΔP_{c5}	ΔP_{CV7}	ΔP_{c7}
(volts)	*[bar]*	*[m³/h]*	*[m³/h]*	*[bar]*	*[bar]*	*[bar]*	*[m³/h]*	*[bar]*	*[bar]*	*[bar]*	*[bar]*	*[bar]*
4	4.1	0.311	0.071	1.563	0.158	0.188	0.026	1.867	0.028	0.018	2.117	0.074
6	2.0	0.312	0.071	0.665	0.157	0.187	0.028	0.961	0.032	0.022	0.916	0.075
8	1.4	0.315	0.071	0.409	0.157	0.187	0.031	0.698	0.037	0.026	0.572	0.076
10	1.27	0.317	0.071	0.352	0.157	0.187	0.032	0.640	0.039	0.028	0.496	0.077

- For each control valve, a desired voltage input can be considered into the simulation. The corresponding flow rates inside each branch of the circuit are calculated consequently.

ΔP_{cv} = Pressure Drop across control valve [bar]

ΔP_f = Total Distributed Pressure Drop due to pipe friction

ΔP_c = Total Pressure Drop in component/fittings

V = control valve set voltage

- Keeping the pressure at the PRV constant, the flow rate can be changed modifying the position (i.e. input voltage) of the control valves.

Input		Results										
V	P_{PRV}	Q	$Q_{1\sim4}$	$\Delta P_{CV1\sim4}$	$\Delta P_{f1\sim4}$	$\Delta P_{m1\sim4}$	Q_5	ΔP_{CV5}	ΔP_{f5}	ΔP_{m5}	ΔP_{CV7}	ΔP_{m0}
(volts)	*[bar]*	*[m³/h]*	*[m³/h]*	*[bar]*	*[bar]*	*[bar]*	*[m³/h]*	*[bar]*	*[bar]*	*[bar]*	*[bar]*	*[bar]*
3	4.1	0.219	0.05	1.644	0.085	0.094	0.018	1.825	0.015	0.009	2.214	0.037
4		**0.311**	**0.071**	**1.563**	**0.158**	**0.188**	**0.026**	**1.867**	**0.028**	**0.018**	**2.117**	**0.074**
5		0.388	0.089	1.480	0.231	0.292	0.033	1.906	0.042	0.031	2.017	0.116
7	1.4	0.289	0.066	0.432	0.136	0.159	0.028	0.690	0.031	0.021	0.600	0.065
8		**0.315**	**0.071**	**0.409**	**0.157**	**0.187**	**0.031**	**0.698**	**0.037**	**0.026**	**0.572**	**0.076**
9		0.332	0.075	0.392	0.171	0.206	0.033	0.704	0.042	0.030	0.552	0.085

- The higher the pressure at the PRV, the higher the ΔQ for a given ΔV

CONCLUSIONS

- By giving the desired set pressure for pressure regulating valve and input voltages for each control valve, we can get the values of flow rates in different lines as well as pressure drop distribution along the path.

- Hence we can adjust the input parameters to get the desired flow in any line according to requirement.

- Parameters of safety valve and surface roughness of pipes & flow path can be included for better results in the model.

- From results we can observe that:

    - When the control valves are partially closed (4 volt), for each AS line the total pressure drop in the pipes is 20% of the pressure drop across control valve.

    - When the control valves are fully open (10 volt), for each AS line the total pressure drop in the pipes is almost the same as pressure drop across the control valve.