New LS-DYNA Features for Modeling Hot Stamping

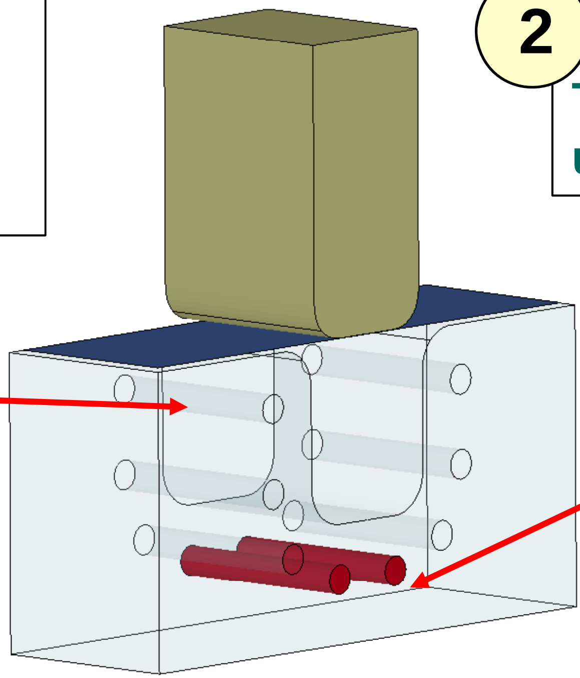
by: Art Shapiro, LSTC

1

MAT_UHS → Boron steel material model calculates phase fractions, Vickers hardness and yield stress distribution.

2

Thermostat feature used to model heaters



3

Flow Network Analyzer to model cooling fluid flow.

MAT_244 : Ultra High Strength Steel

MAT_244
MAT_UHS_STEEL

This material model is based on the Ph.D thesis by Paul Akerstrom (Lulea University) and implemented by Tobias Olsson (ERAB)

Input includes:

1. 15 constituent elements
2. Latent heat
3. Expansion coefficients
4. Phase hardening curves
5. Phase kinetic parameters
6. Cowper-Symonds parameters

Output includes:

1. Austenite phase fraction
2. Ferrite phase fraction
3. Pearlite phase fraction
4. Bainite phase fraction
5. Martensite phase fraction
6. Vickers hardness distribution
7. Yield stress distribution

MAT_244 : Ultra High Strength Steel

Phase change kinetics

austenite to ferrite

$$\frac{dX_f}{dt} = \frac{\exp\left(-\frac{Q_f}{RT}\right)}{C_f} 2^{(G-1)/2} (\Delta T)^3 X_f^{2(1-X_f)/3} (1-X_f)^{2X_f/3}$$

$C_f = 59.6Mn + 1.45Ni + 67.7Cr + 24.4Mo + K_fB$

austenite to pearlite

$$\frac{dX_p}{dt} = \frac{\exp\left(-\frac{Q_p}{RT}\right)}{C_p} 2^{(G-1)/2} (\Delta T)^3 DX_p^{2(1-X_p)/3} (1-X_p)^{2X_p/3}$$

$C_p = 1.79 + 5.42(Cr + Mo + 4MoNi) + K_pB$

Input parameters
- Q_f = activation energy
- Q_p = activation energy
- Q_b = activation energy
- G = grain size
- α = material constant
- K_f = boron factor
- K_p = boron factor

Reaction not shown:
- **bainite**
- **martensite**

MAT_244 : Ultra High Strength Steel

Mechanical Material Model

Since the material has 5 phases, the yield stress is represented by a mixture law

$$\sigma_y = x_1\sigma_1\left(\bar{\varepsilon}_1^{\,p}\right) + x_2\sigma_2\left(\bar{\varepsilon}_2^{\,p}\right) + x_3\sigma_3\left(\bar{\varepsilon}_3^{\,p}\right) + x_4\sigma_4\left(\bar{\varepsilon}_4^{\,p}\right) + x_5\sigma_5\left(\bar{\varepsilon}_5^{\,p}\right)$$

LC1
LC2
LC3
LC4
LC5

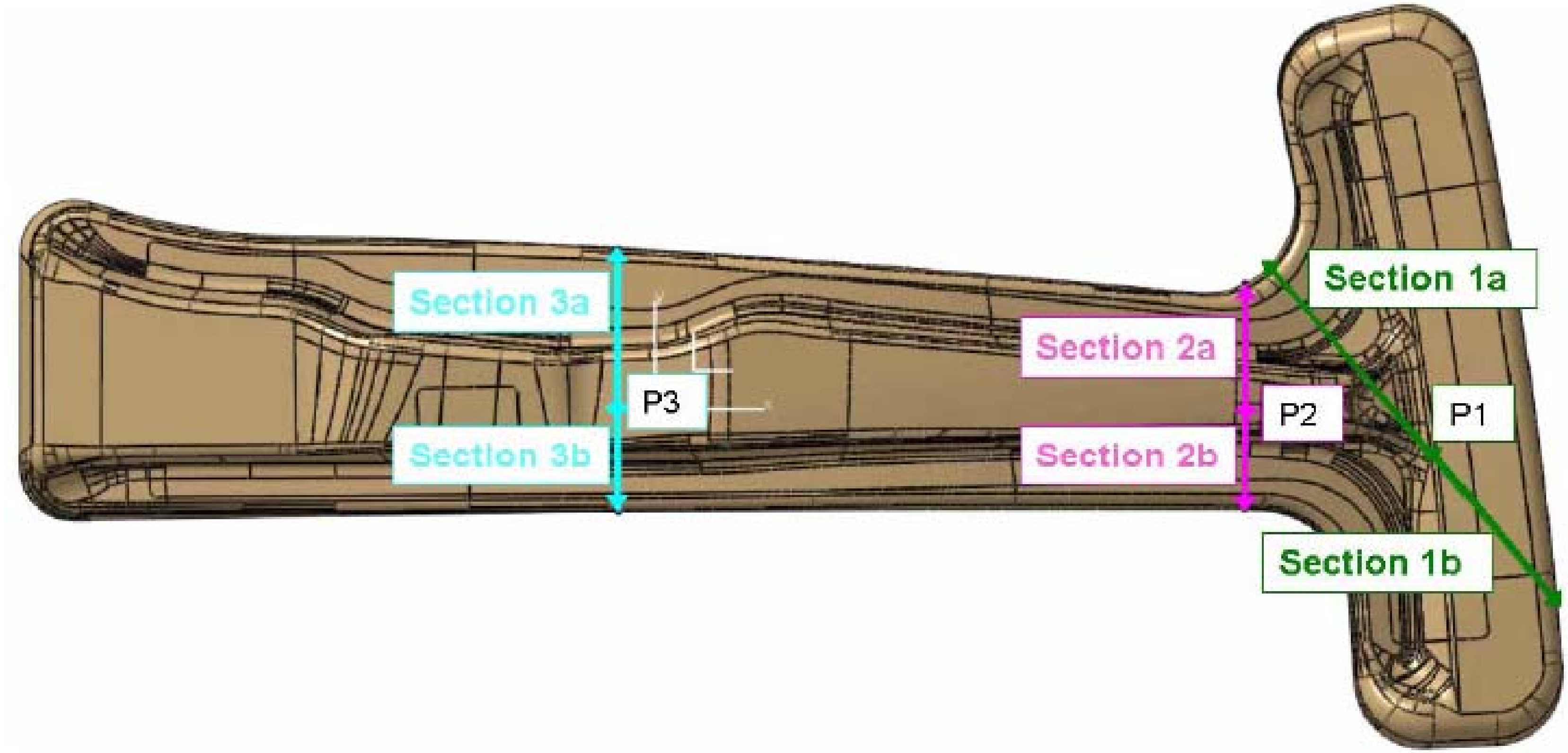
Where $\sigma_i\left(\bar{\varepsilon}_i^{\,p}\right)$ is the yield stress for phase i at the effective plastic strain for that phase.

References

1. T. Olsson, “An LS-DYNA Material Model for Simulations of Hot Stamping Processes of Ultra High Strength Steels”, ERAB, April 2009, tobias.olsson@erab.se
2. P. Akerstrom, Modeling and Simulation of Hot Stamping, Doctoral Thesis, Lulea University of Technology, Lulea, Sweden, 2006.

MAT_244 QA parameter study

Numisheet Benchmark BM03



MAT_244 QA parameter study

Numisheet Benchmark BM03 section 1a

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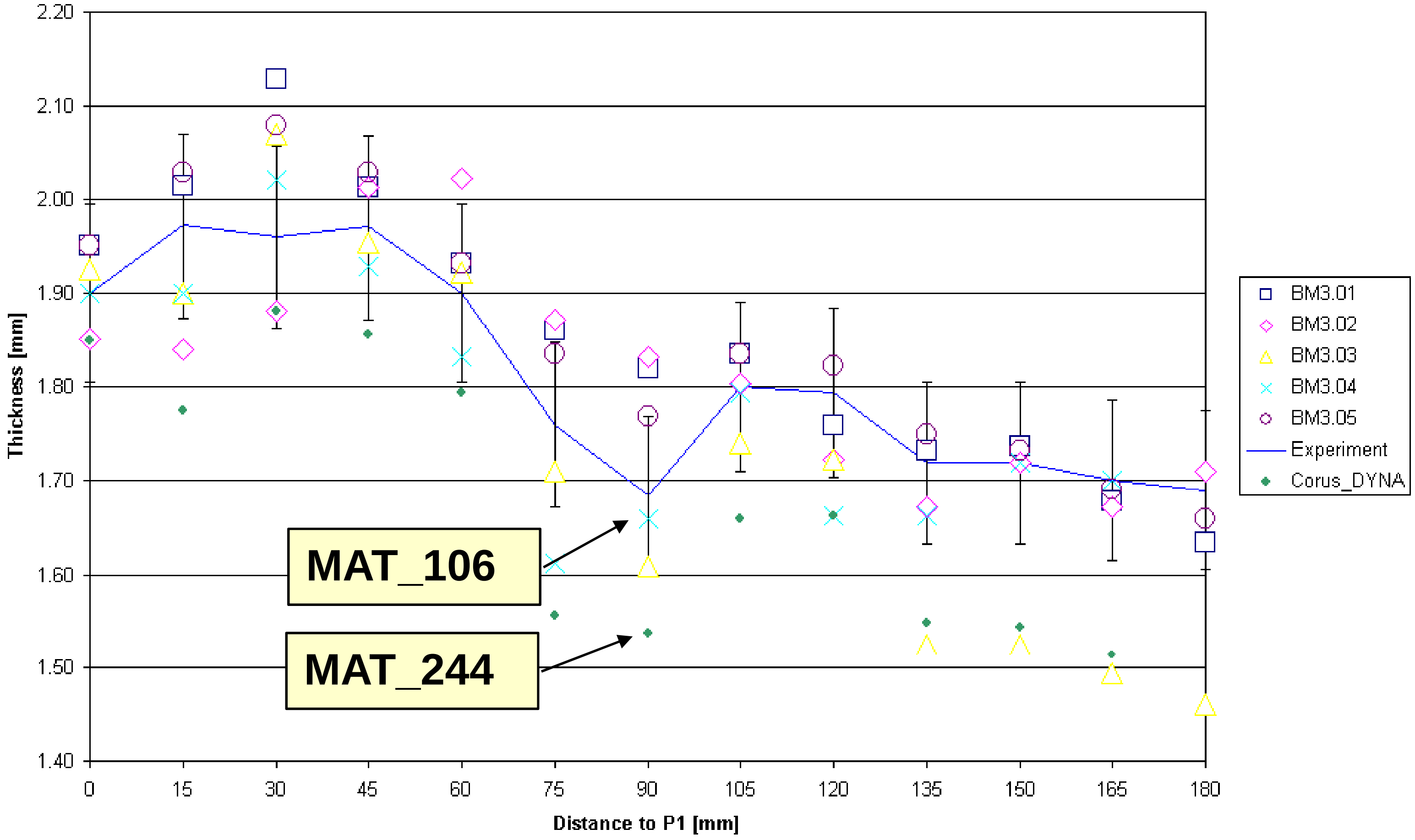
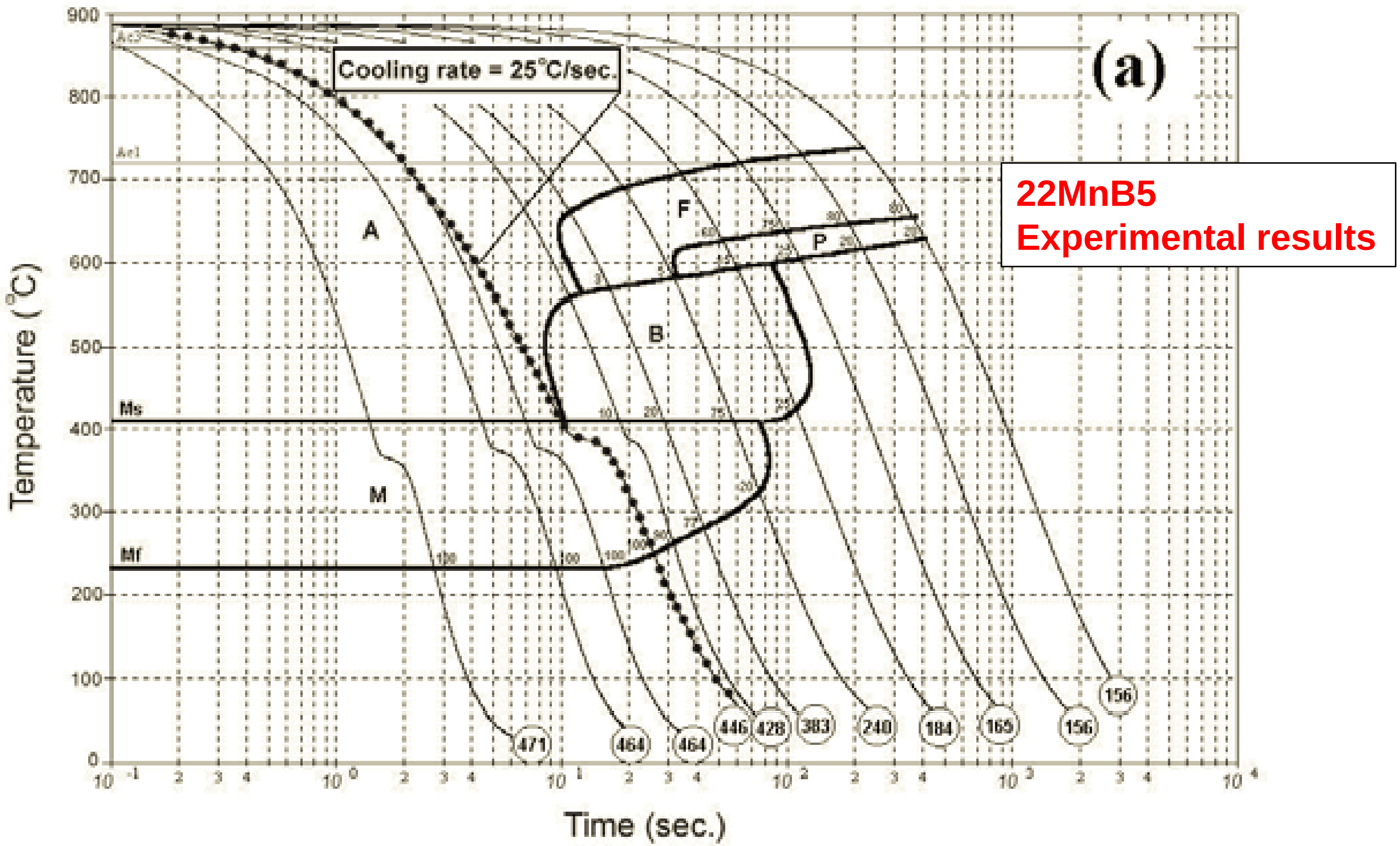


By: Sander van der Hoorn, Corus, The Netherlands

MAT_244 QA parameter study

M. Naderi, Thesis 11/2007, Dept. Ferrous Metallurgy, RWTH Aachen University, Germany



MAT_244 QA parameter study

Using data set 2

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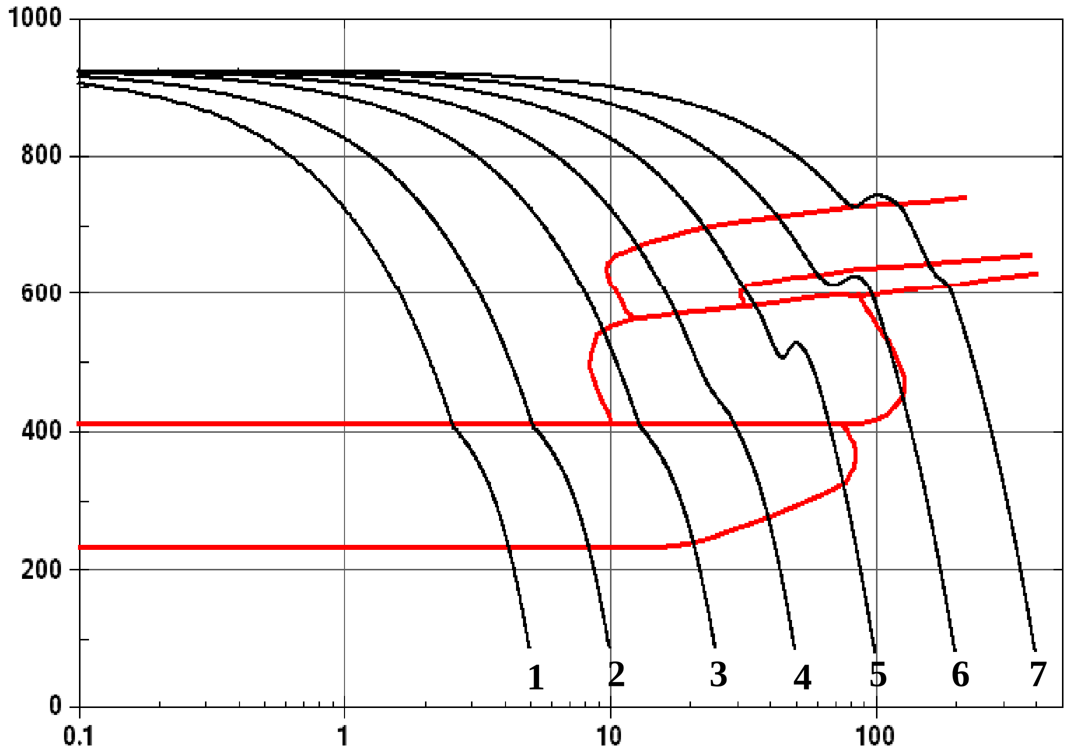
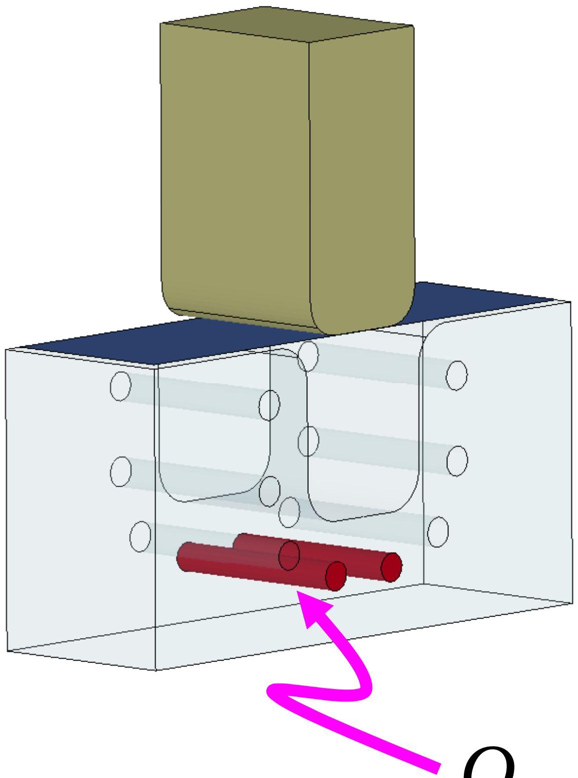
CCT Diagram for 22MnB5 overlaid with LS-DYNA calculated cooling curves and Vickers hardness using MAT_UHS_STEEL



	Rate C/sec	Vickers Hardness	Exp. Naderi
1	200	478	-----
2	100	472	471
3	40	459	428
4	20	376	383
5	10	273	240
6	5	174	175
7	2.5	172	165

Thermostat feature adjusts the heating rate of a part to keep a remote sensor temperature at a specified set point.



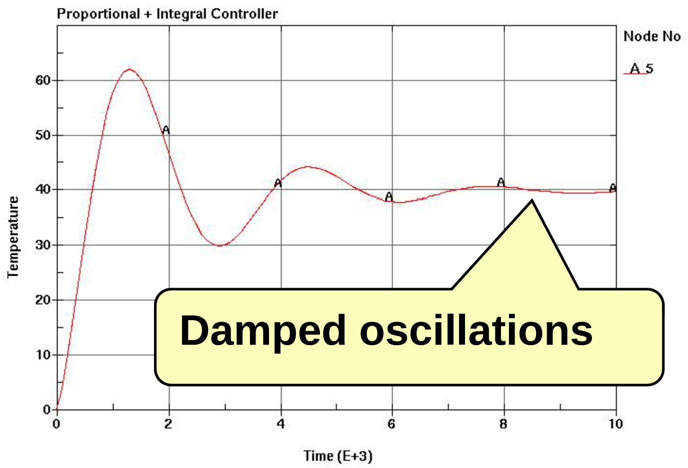
***LOAD_HEAT_CONTROLLER**

Q_{cont}	controlled heating rate
Q_0	part volumetric heating rate
G_p	proportional gain
G_i	integral gain
T_{set}	set point temperature
T	sensor temperature (at a node)

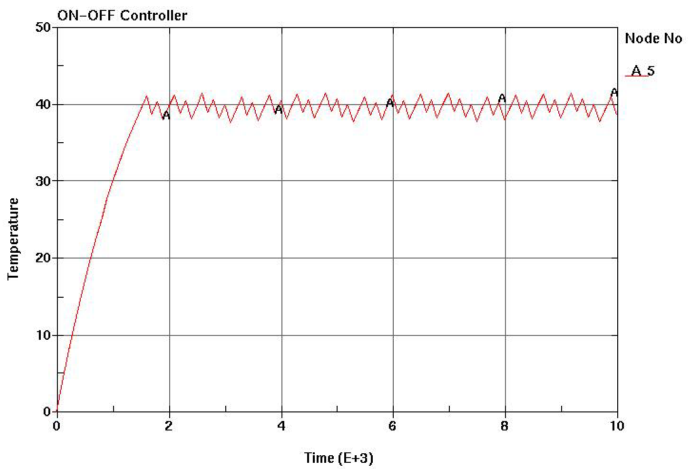
$$Q_{cont} = Q_0 + \underbrace{G_p\left(T_{set} - T\right)}_{\text{proportional}} + \underbrace{G_i \int_{t=0}^{t} \left(T_{set} - T\right) dt}_{\text{integral}}$$

Thermostat controller

Set point T_{set}= 40



Proportional + Integral Control
The heating rate is adjusted to keep the sensor temperature at the set point.



On – Off Control can also be activated.

There are 2 methods available to model tool cooling

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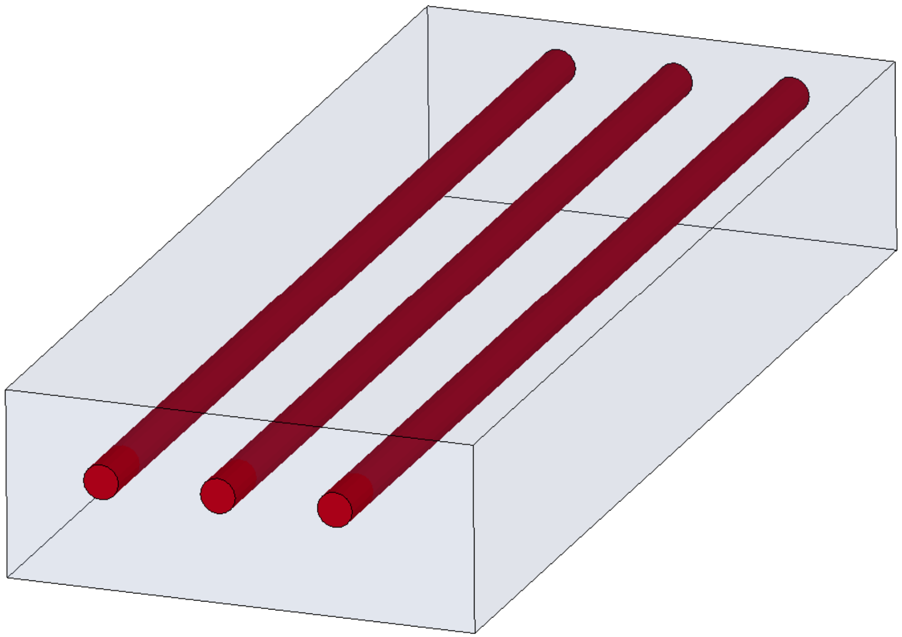
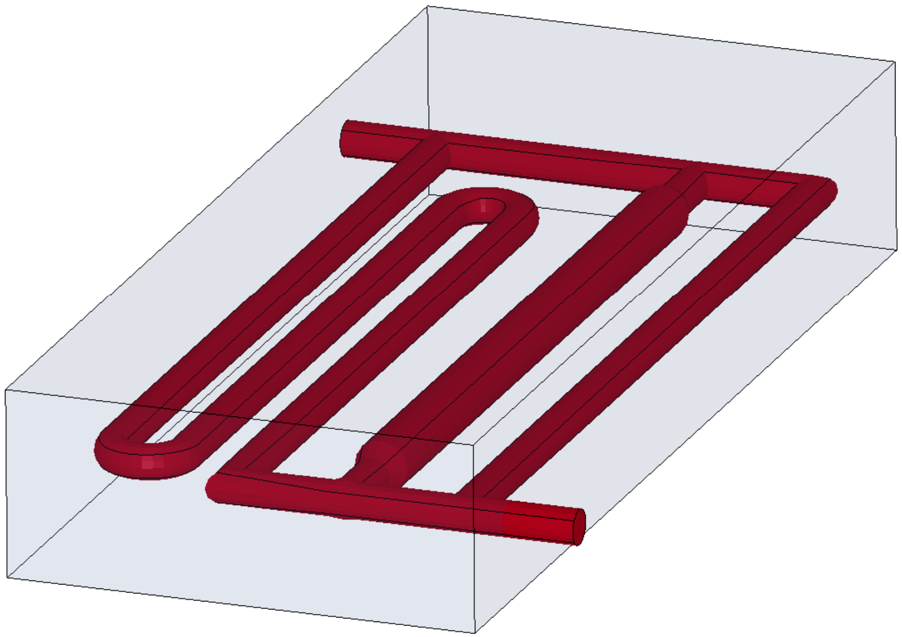
1 BULKFLOW

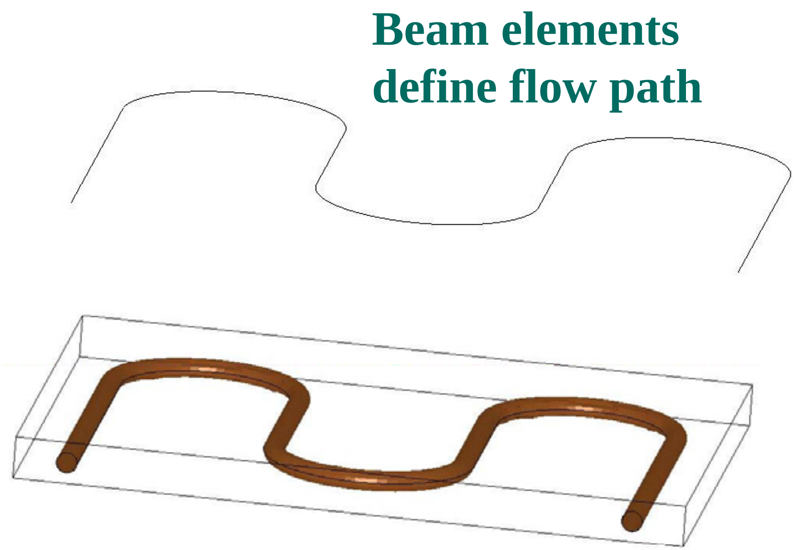
2 Network Analyzer

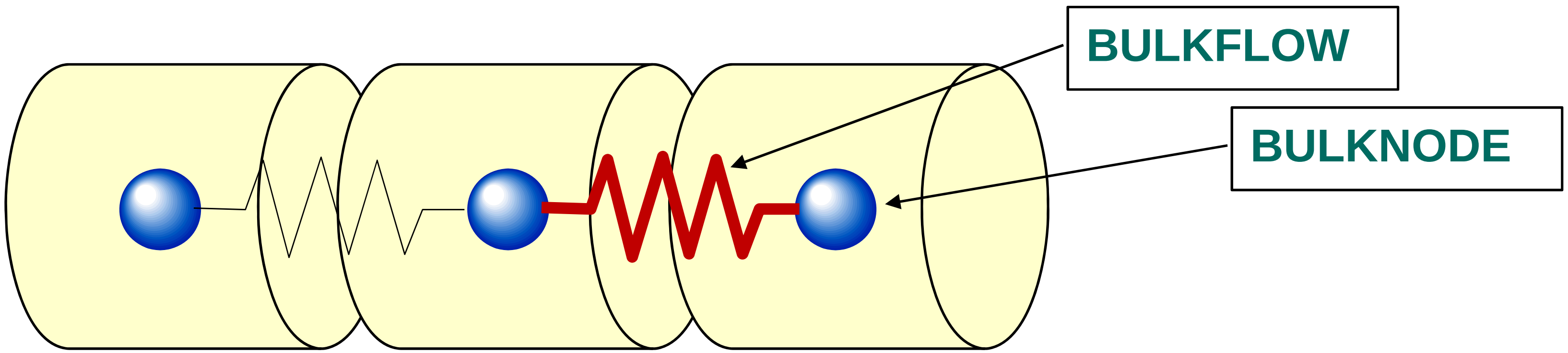




BULKNODE and BULKFLOW

BULK FLOW is a lumped parameter approach to model fluid flow in a pipe. The flow path is defined with a contiguous set of beam elements. The beam node points are called **BULK NODES** and have special attributes in addition to their (x,y,z) location. Each **BULKNODE** represents a homogeneous slug of fluid. Using the **BULKFLOW** keyword we define a mass flow rate for the beams. We then solve the advection-diffusion equation.





Application – die cooling

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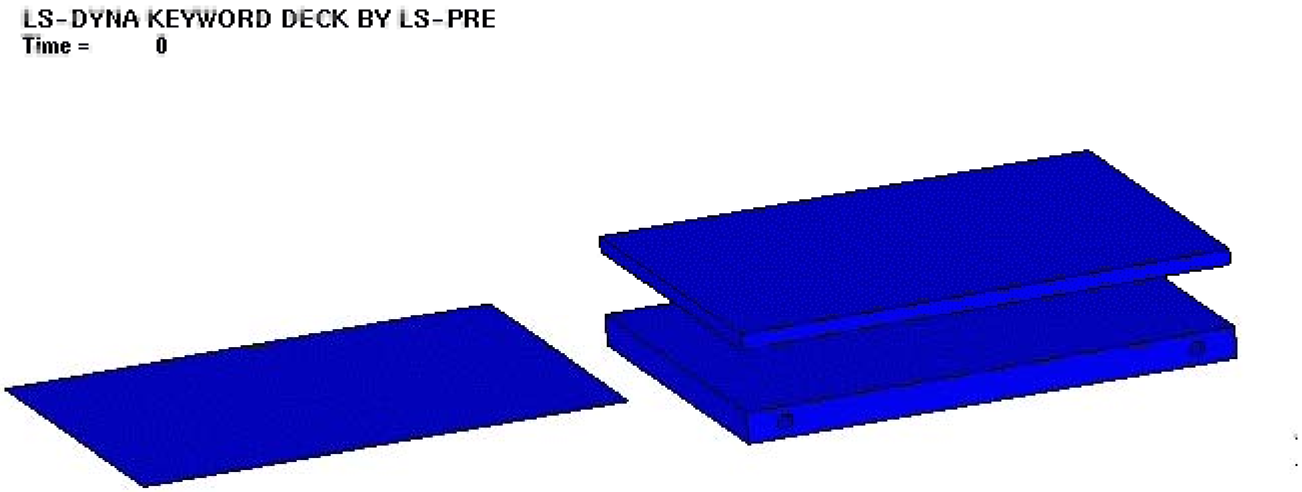
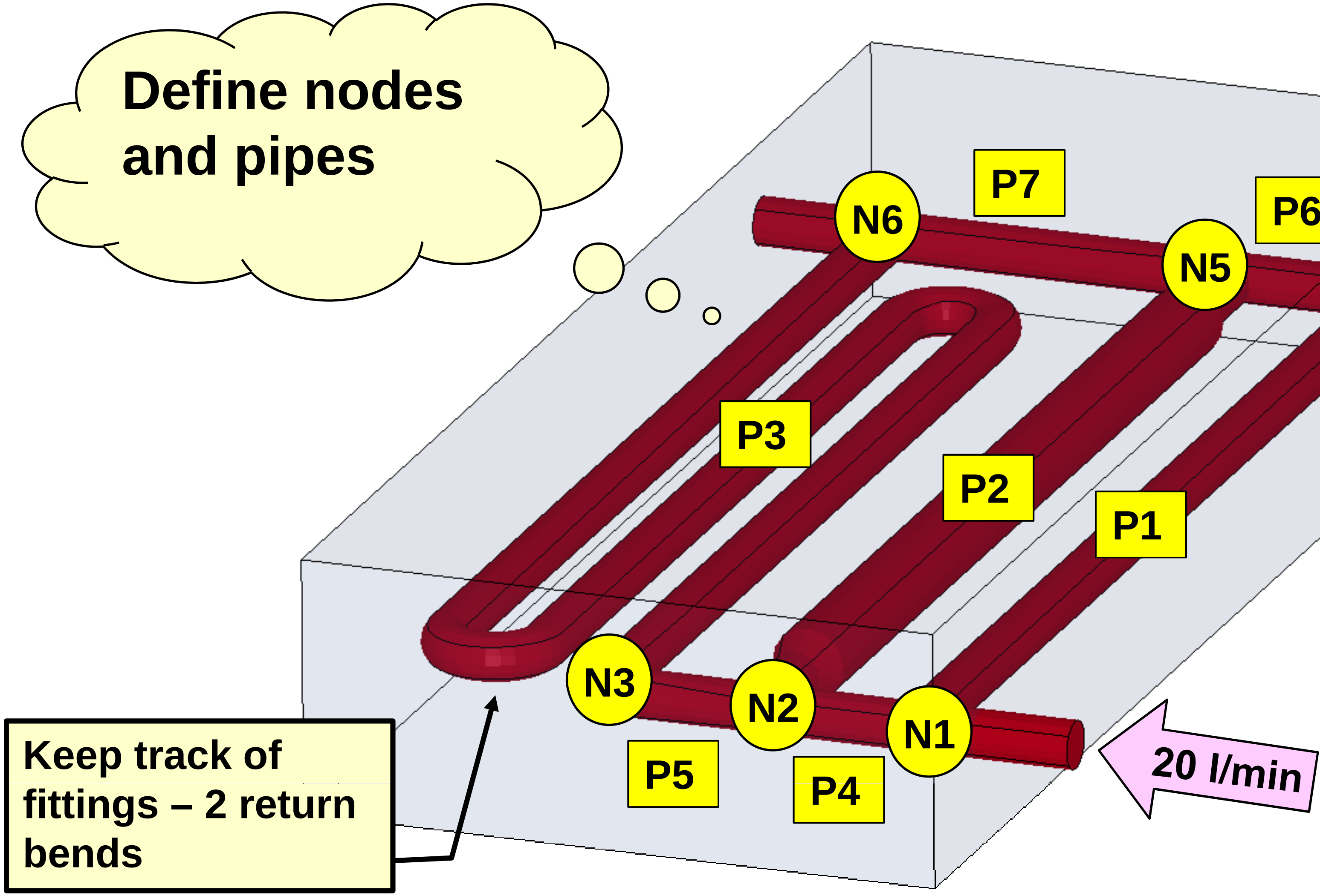


Pipe Network Analyzer

Think about the pipes in your house. The starting point is the valve on the pipe entering your house. We will call this NODE 1. Node 1 is special and has a boundary condition specified. The BC is the pressure you would read on a pressure gauge at this location. The water enters your house and passes through several pipe junctions before it exits through your garden hose. Every junction is represented by a NODE. The last node also needs a BC specified. This BC is the mass flow rate. The pipe network code will calculate the pressure at the intermediate junction nodes and the flow rate through the pipes.

Given an entering flow rate, calculate the flow in each pipe and the convection heat transfer coefficient



Pipe Network

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input							output	
Pipe	**N1**	**N2**	**Length [m]**	**Dia. [mm]**	**Rough [mm]**	**Ftg. [L_e/D]**	**Q [l/min]**	**h [W/m²C]**
1	1	4	1	10	0.05		5.7	5600
2	2	5	1	20	0.05		9.7	2400
3	3	6	3	10	0.05	100	4.5	4600
4	1	2	0.2	10	0.05		14.2	11000
5	2	3	0.2	10	0.05		4.5	4600
6	4	5	0.2	10	0.05		5.7	5600
7	5	6	0.4	10	0.05		15.5	12000

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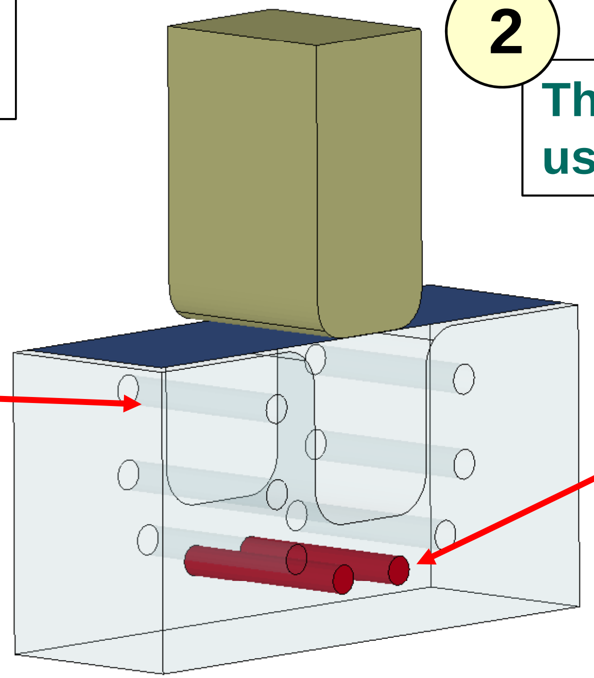
1

MAT_UHS → request user feedback to refine data and improve model.

2

Thermostat feature used to model heaters



3

Flow Network Analyzer → request user feedback on usefulness before GUI implementation in LSPP.

Pipe Network

Solution algorithm

Solve:

Bernoulli equation

$$\left(\frac{V_1^2 - V_2^2}{2g}\right) + \left(\frac{P_1 - P_2}{\rho g}\right) + (z_1 - z_2) = H_f$$

Friction equation

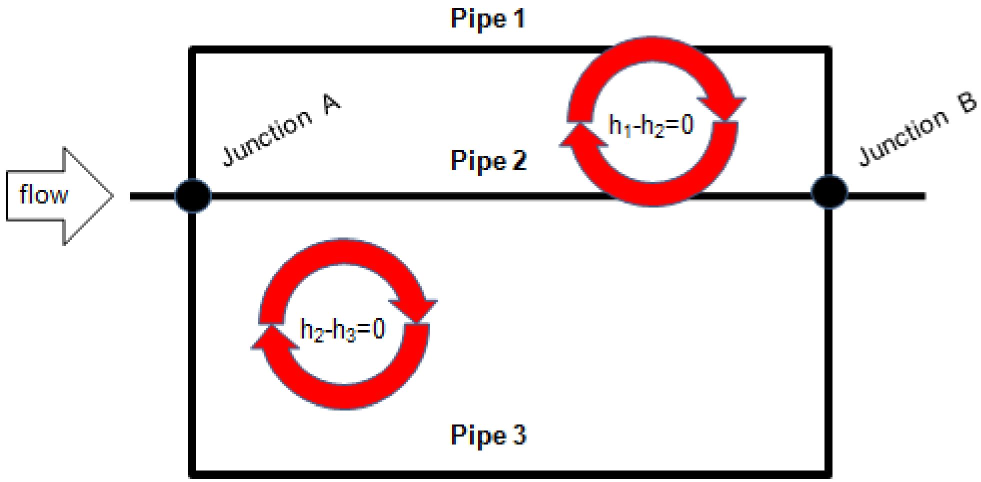
$$H_f = f\,\frac{L}{D}\frac{V^2}{2g} + H_{fitting}$$

Gnielinski equation

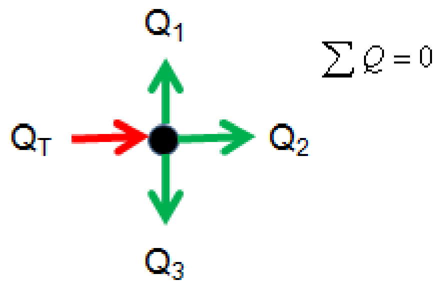
$$h = \left(\frac{k}{D}\right)\left[\frac{(f/8)(\mathrm{Re}-1000)\mathrm{Pr}}{1+12.7(f/8)^{0.5}\left(\mathrm{Pr}^{2/3}-1\right)}\right]$$

Subject to:

Pressure drop around each circuit =0.



Flow at each junction = 0.



How do you determine a pipe flow friction factor

http://www.mathworks.com/matlabcentral/fx_files/7747/1/moody.png

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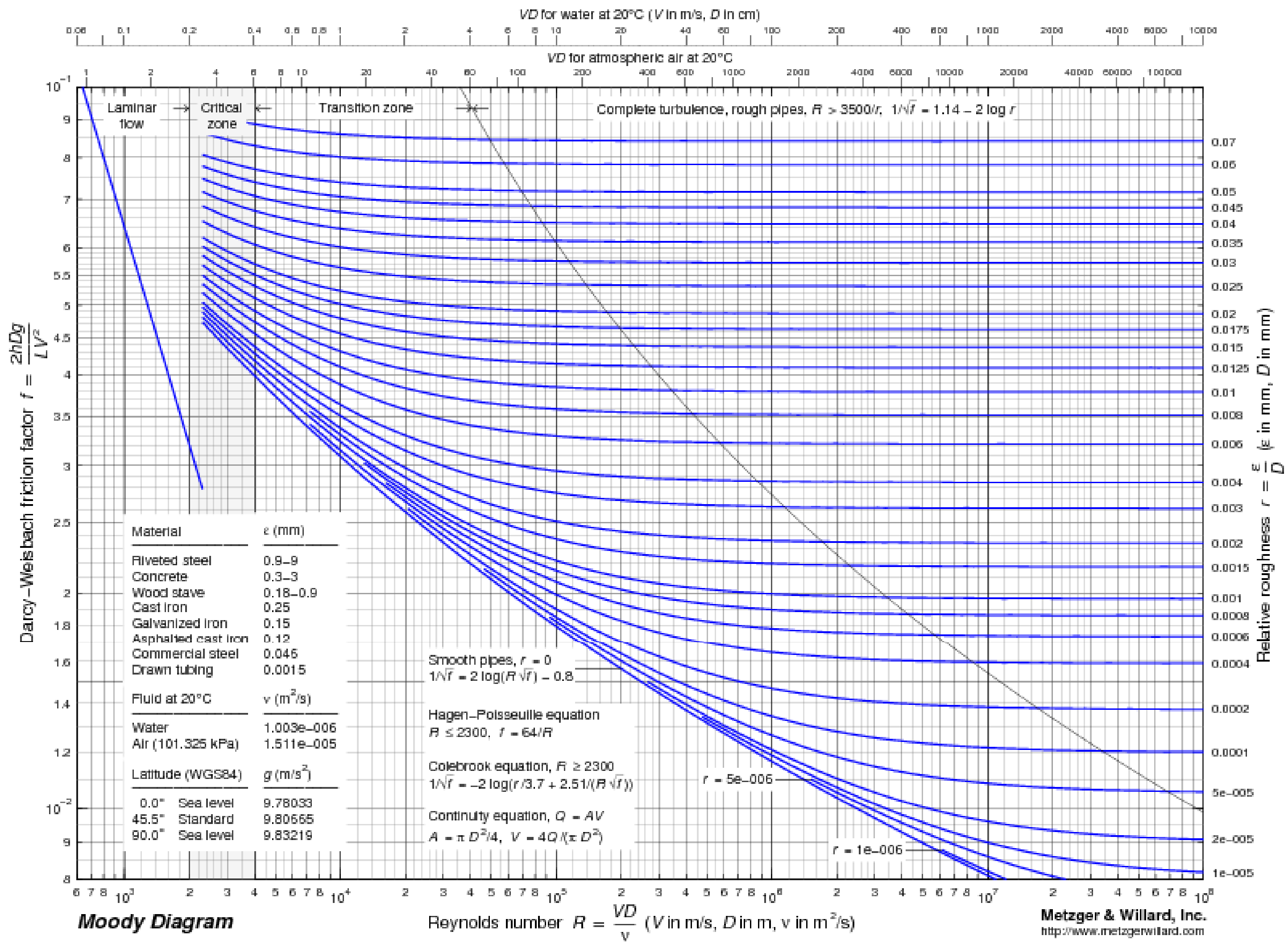

Pipe Network

Pipe type	Roughness, e [mm]
Cast iron	0.25
Galvanized iron	0.15
Steel or wrought iron	0.046
Drawn tubing	0.0015

Fitting type	Equivalent length L_e/D
Globe valve	350
Gate valve	13
Check valve	30
90º std. elbow	30
90º long radius	20
90º street elbow	50
45º elbow	16
Tee flow through run	20
Tee flow through branch	60
Return bend	50