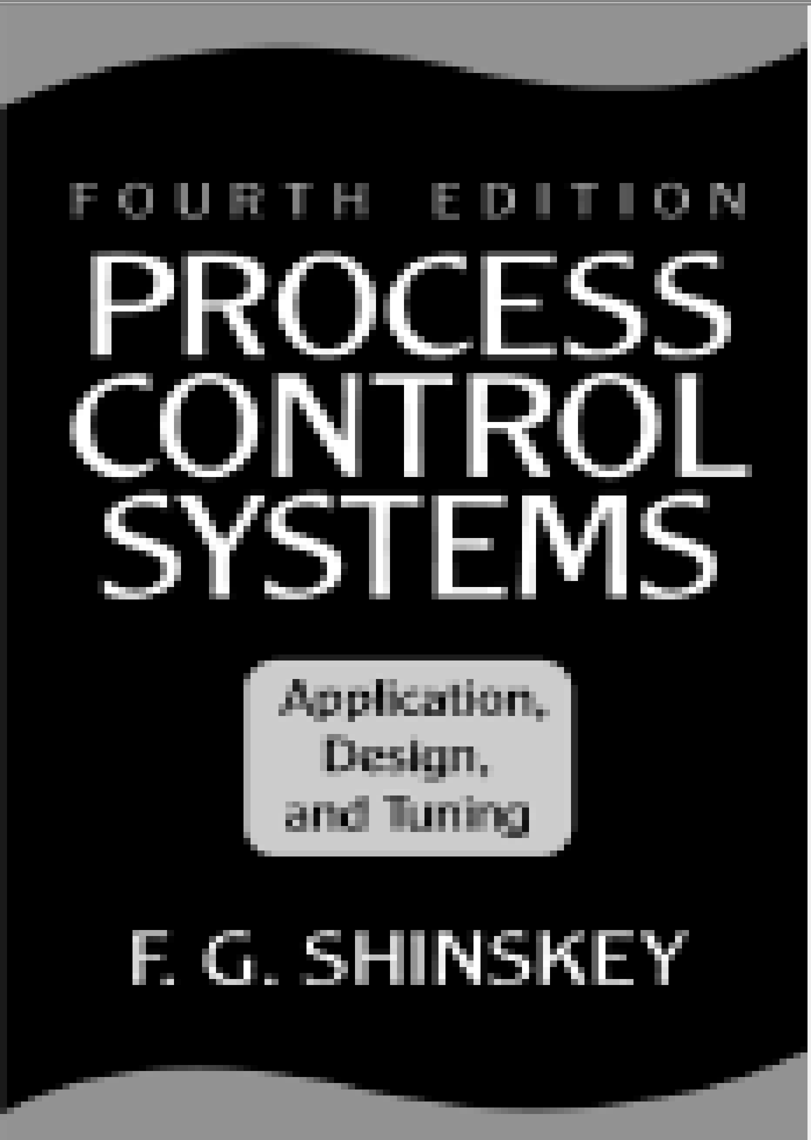
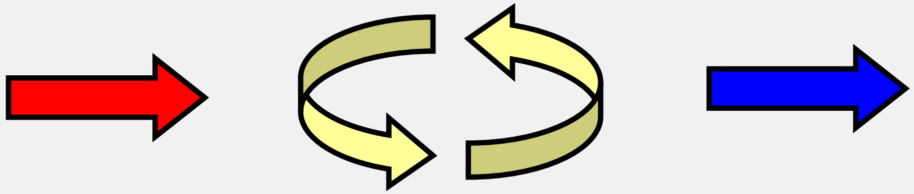


PROCESS CONTROL SYSTEMS

Application > Design > Adjustment

Based on F.G. Shinskey's 1967 Edition



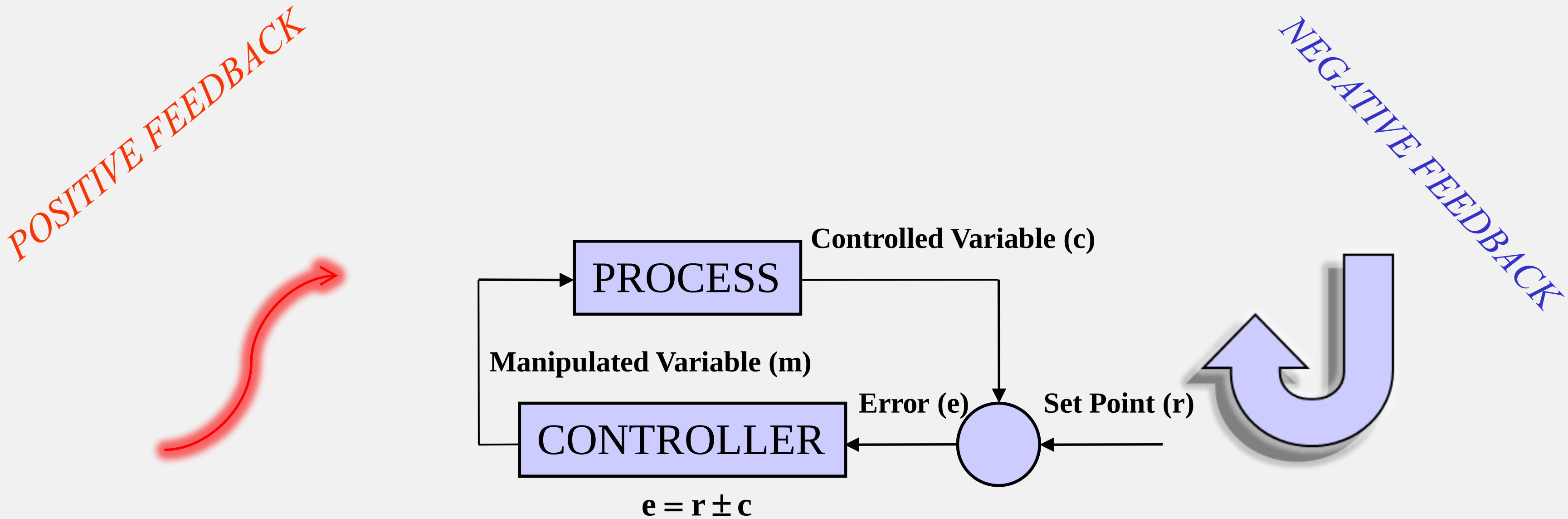
Presenter John Edwards
P & I Design Ltd, UK

Contact: jee@pidesign.co.uk

PROCESS CONTROL SYSTEMS COURSE OBJECTIVES REVIEW

Course Objectives are to study

- ***Feedback Control and Control Loop Structure***
- ***Multiple Control Loops***
- ***Appreciation of Basic Instrumentation***
- ***Controller Equations and Control Modes***
- ***Control Loop Behaviour***
- ***Control Valve Types - Flow Characteristics - Actions***
- ***Control Loop Dynamics - Dead Time – Capacity – Resistance***
- ***Appreciation of Behaviour of Common Control Loops***
- ***CHEMCAD Control Models***
- ***Control Loop Tuning***



INCREASES IMBALANCE
CONTROL RUNAWAY

RESTORES BALANCE
CONTROL STABILITY

PROCESS CONTROL SYSTEMS
CONTROL LOOP STRUCTURE

P & I DESIGN

FUNCTIONS & SIGNALS

MEASURE

Thermocouple mV
Resistance bulb Ω
Transmitter 4-20 mA
Transmitter 0.2-1.0 bar

CONVERT

Thermocouple Curve (mV/I)
Square Root Extraction (√)
Pneumatic to Current (I/P)

Characterise Measurement
Linear 4-20 mA Signal

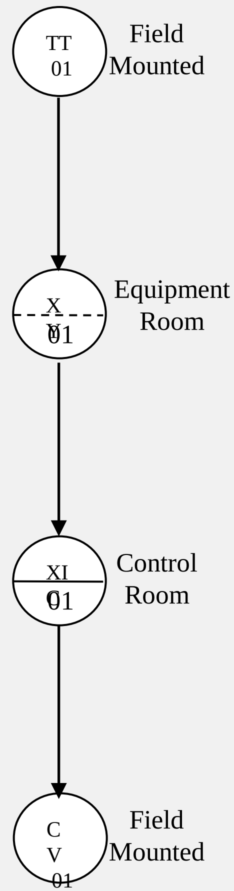
CONTROL

4-20 mA Signal

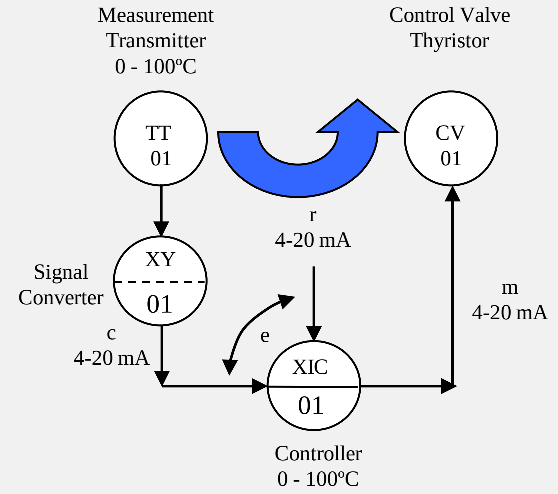
CONTROL DEVICE

Valve Actuator 4-20 mA
I/P 4-20 mA to 0.2-1 bar
Valve Actuator 0.2-1 bar
Positioner 0.2-1 bar

LOCATIONS & TAGGING



LOOP SCHEMATIC



PROCESS CONTROL SYSTEMS
MULTIPLE CONTROL LOOPS

P & I DESIGN

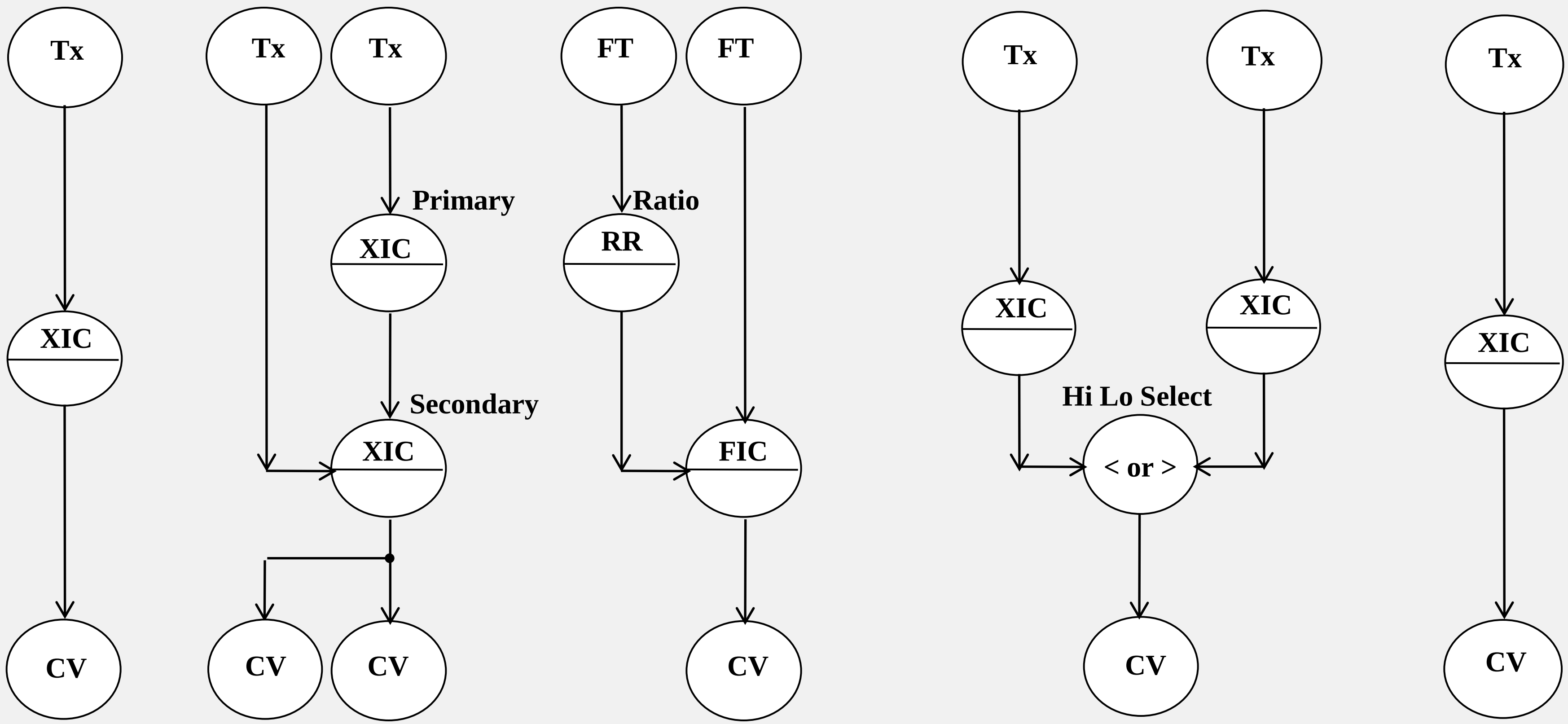
Single | **Cascade** Ch6, p154 | **Ratio** Ch6, p160 | **Auto Select** Ch6, p167 | **Adaptive** Ch6, p170

Cascade: Secondary Primary

Ratio: Wild Controlled

Auto Select: Squeaky wheel gets the grease

Adaptive: PID Adjust



Single Valve

Split Range Valves

Ratio of controlled flow to wild flow

Auto selection of controlled variable

Adapts - models needs of process

PROCESS CONTROL SYSTEMS TYPICAL INSTRUMENTATION

P & I DESIGN

Controller

PV Process Variable

SV Set Point

Measurement Transmitters (4 to 20 mA dc)

Temperature

Flow

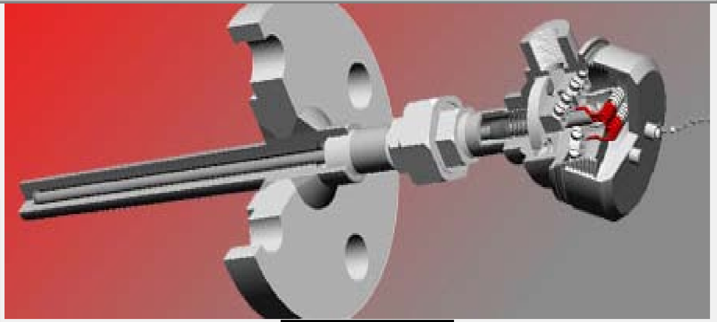
Pressure

Level

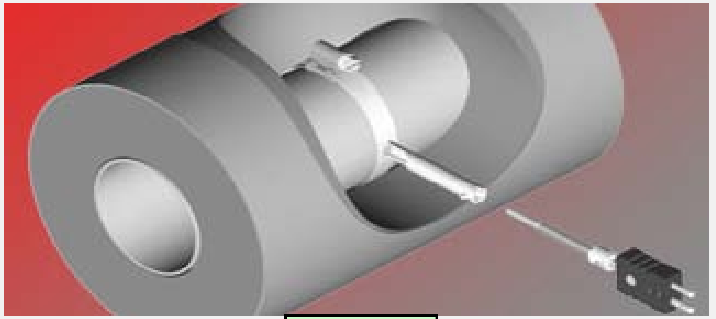
PROCESS CONTROL SYSTEMS
THERMOCOUPLE DATA

P & I DESIGN

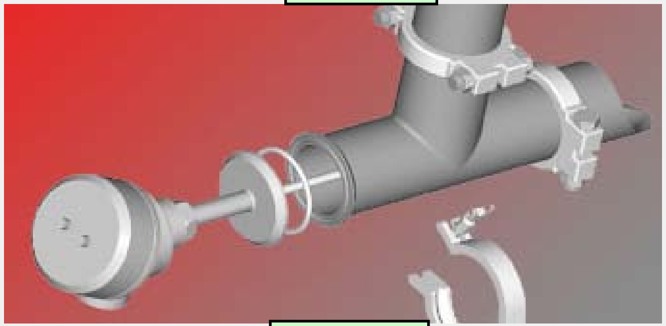
TYPE (Letter)	Conductor Material	POLARITY	Initial Calibration Tolerances (* Whichever is greater) Standard	Special	U.S.A.	FRANCE	U.K.	GERMANY	JAPAN	IEC	Application Range
J	Iron	+	±4.0 F or ±.75%*	±2.0 F or ±.4%*							32 to 1400° F 0 to 760° C
	Constantan	–									
K	Chromel	+	±4.0 F or ±.75%*	±2.0 F or ±.4%*							32 to 2300° F 0 to 1260° C
	Alumel	–									
T	Copper	+	±1.8 F or ±1.5%*	±0.9 F or ±.8%*							32 to 700° F 0 to 370° C
	Constantan	–									
E	Chromel	+	±3.0 F or ±.5%*	±1.8 F or ±.4%*							32 to 1600° F 0 to 870° C
	Constantan	–									
N	Nicrosil	+	±4.0 F or ±.75%*	±2.0 F or ±.4%*		Not Established		Not Established	Not Established		32 to 2300° F 0 to 1260° C
	NISIL	–									
R	Platinum 13% Rhodium	+	±2.7 F or ±.25%*	±1.1 F or ±.1%*							32 to 2700° F 0 to 1480° C
	Platinum	–									
S	Platinum 10% Rhodium	+	±2.7 F or ±.25%*	±1.1 F or ±.1%*							32 to 2700° F 0 to 1480° C
	Platinum	–									
B	Platinum 30% Rhodium	+	.5%	.25%		Not Established	Not Established			Not Established	1600 to 3100° F 870 to 1700° C
	Platinum 6% Rhodium	–									



Industrial



Surface



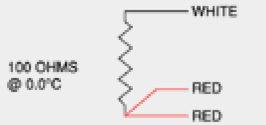
Sanitary

Reference Thermo Electric Company www.te-direct.com

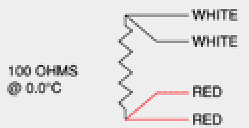
PROCESS CONTROL SYSTEMS
RESISTANCE BULB DATA

P & I DESIGN

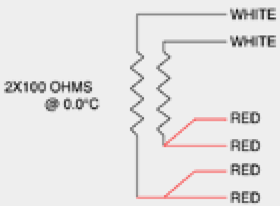
WIRING DIAGRAM



SINGLE 3 WIRE CONSTRUCTION



SINGLE 4 WIRE CONSTRUCTION



DUPLEX 4 WIRE CONSTRUCTION

Bulb Construction

Platinum thin film on a ceramic substrate, glass sealed. Lead wires of nickel platinum-clad Connection protected by temperature stable enamel.

Tolerance Compliance

ASTM E1137, IEC 751, DIN 60751(Formally DIN 43760)

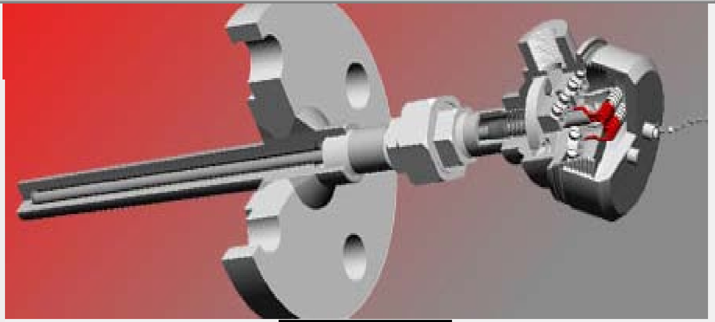
ACCURACY	ASTM E1137	DIN EN 60751
CLASS B	± .10% @ 0°C (32°F)	± .12% @ 0°C (32°F)
CLASS A	± .05% @ 0°C (32°F)	± .06% @ 0°C (32°F)

Temperature Coefficient of Resistance (TCR): 0.00385 Ohms/Ohm/°C
Resistance at 0°C: 100 Ohms

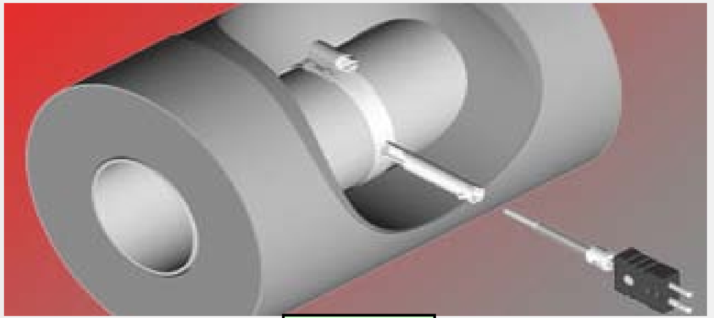
Long Term Stability: Max. Ro drift 0.04% after 1000 H @ 500° C
Time Constant in Water Moving at 3 fps, 25" Diameter: 5.0 seconds

Self Heating: Less than 0.20° C
Vibration Resistance: 10 to 500Hz @ 1 octave/minute acceleration of 20 to 30m/s2 peak-to-peak

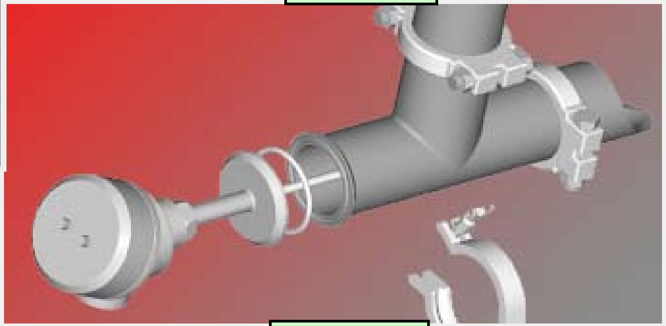
TEMPERATURE	ASTM E1137 °C (°F)		DIN EN 60751 °C (°F)	
	CLASS B	CLASS A	CLASS B	CLASS A
-50°C (-58°F)	±0.460 (0.828)	±0.215 (0.387)	±0.550 (0.990)	±0.250 (0.450)
-0°C (32°F)	±0.250 (0.450)	±0.130 (0.234)	±0.300 (0.540)	±0.150 (0.270)
25°C (77°F)	±0.355 (0.639)	±0.173 (0.311)	±0.425 (0.765)	±0.200 (0.360)
50°C (122°F)	±0.460 (0.828)	±0.215 (0.387)	±0.550 (0.990)	±0.250 (0.450)
75°C (167°F)	±0.565 (1.017)	±0.258 (0.464)	±0.675 (1.215)	±0.300 (0.540)
100°C (212°F)	±0.670 (1.206)	±0.300 (0.540)	±0.800 (1.440)	±0.350 (0.630)
125°C (257°F)	±0.775 (1.395)	±0.343 (0.617)	±0.925 (1.665)	±0.400 (0.720)
150°C (302°F)	±0.880 (1.564)	±0.385 (0.693)	±1.050 (1.890)	±0.450 (0.810)
175°C (347°F)	±0.985 (1.773)	±0.428 (0.770)	±1.175 (2.115)	±0.500 (0.900)
200°C (392°F)	±1.090 (1.962)	±0.470 (0.846)	±1.300 (2.340)	±0.550 (0.990)
225°C (437°F)	±1.195 (2.151)	±0.513 (0.923)	±1.425 (2.565)	±0.600 (1.080)
260°C (500°F)	±1.342 (2.416)	±0.572 (1.030)	±1.600 (2.880)	±0.670 (1.206)



Industrial



Surface



Sanitary

Reference Thermo Electric Company www.te-direct.com

PROCESS CONTROL SYSTEMS
TEMPERATURE HEAD TRANSMITTERS

Head Transmitter

- Temperature transmitter, PC-programable
- Application: RTD
- 2-wire 4-20mA
- Fault reaction: NAMUR NE 43
- Mounting: head form B, DIN43729
- UL listed, GL (German Llyod) Marine

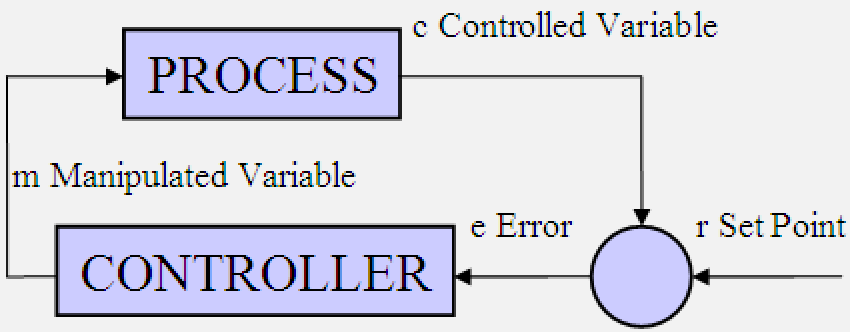
- Temperature transmitter, PC-programmable
- Application: RTD, TC, Ohm, mV
- 2-wire 4-20mA, galvanic isolation
- Fault reaction: NAMUR NE 43
- Mounting: head form B, DIN43729
- UL listed, GL (German Llyod) Marine

- Temperature transmitter, Protocol HART
- Application: RTD, TC, Ohm, mV
- 2-wire 4-20mA, SIL2, galvanic isolation
- Fault reaction: NAMUR NE 43
- Mounting: head form B, DIN43729
- UL listed, GL (German Llyod) Marine

- Temperature transmitter
- Application: RTD
- Fixed adjusted measurement range
- 2-wire 4-20mA, galvanic isolation
- Fault reaction: NAMUR NE 43
- Mounting: head form B, DIN43729
- UL listed, GL (German Llyod) Marine

Reference Endress + Hauser www.uk.endress.com

PROCESS CONTROL SYSTEMS
CONTROLLER MODES & EQUATIONS



$e = r \pm c$

Proportional (P)

$$m = \frac{100}{P} e + b$$

P = PB %

b =output bias

m = b for e = 0

$$\text{Gain} = \frac{100}{P}$$

P↓ Gain↑
Decreasing P
Increases Δm

Proportional + Integral (PI)

$$m = \frac{100}{P}\left(e + \frac{1}{R}\int e\,dt\right)$$

R = integral time (min)

dm/dt = e/R

R↓ dm/dt↑
Never set R faster
than process $\tau + \tau_d$

Proportional + Derivative (PD)

$$m = \frac{100}{P}\left(e + D\frac{de}{dt}\right) + b$$

D =derivative time (min)
Note D↑ dm/dt↑
Use D when sustained error
End point control:
pH – target temperature

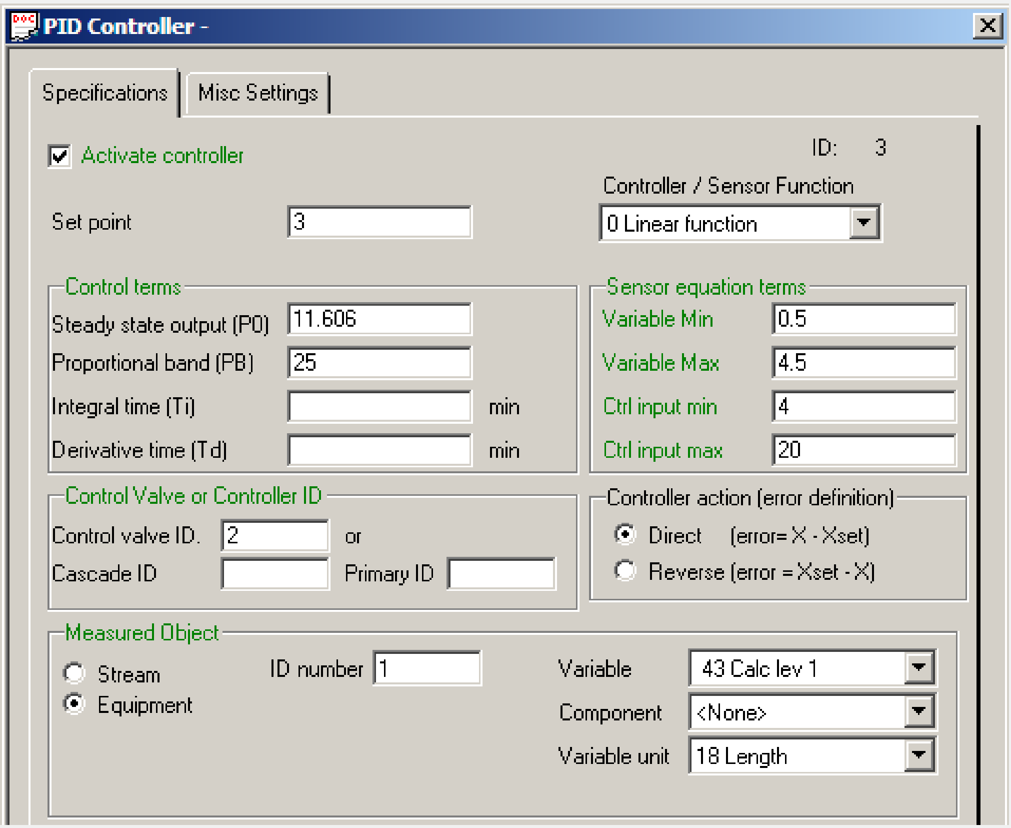
Proportional + Integral + Derivative (PID) 3Mode

$$m = \frac{100}{P}\left(e + \frac{1}{R}\int edt + D\frac{de}{dt}\right)$$

Low R on fast processes:
Flow – Liquid Pressure
High R on slow processes:
Batch reactor temperature

Never D on noisy processes:
Flow – Level – Liquid Pressure

DYNAMIC SIMULATION
CHEMCAD CONTROLLER SET UP



LEVEL MEASUREMENT
LINEAR 0.5 to 4.5 metre
SIGNAL 4.0 to 20 mA
INC LEVEL ↑ INC SIGNAL ↑

CONTROLLER ACTION
DIRECT
INC LEVEL ↑ INC OUTPUT ↑

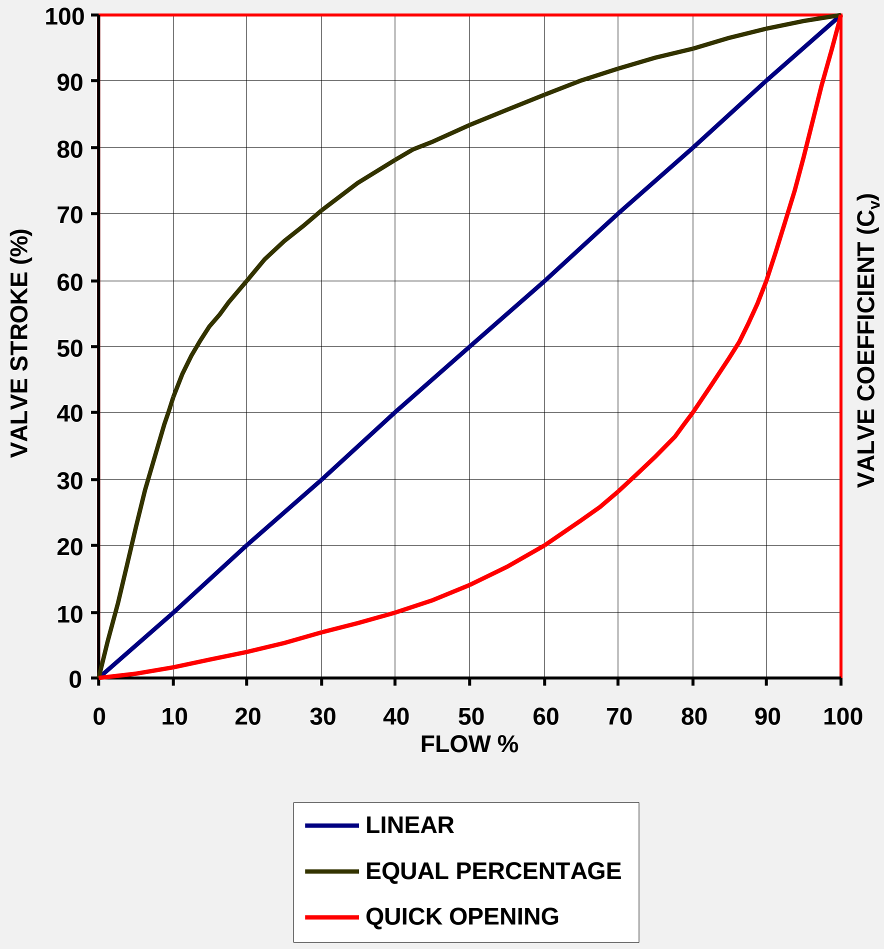
FAIL CLOSED VALVE
ON OUTLET (OPENS)

FAIL OPEN VALVE
ON INLET (CLOSES)

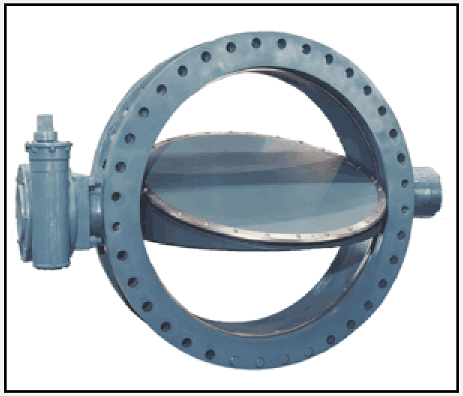
PROCESS CONTROL SYSTEMS
CONTROL VALVE CHARACTERISTICS

ANY
CHARACTERISTIC

VALVE
POSITIONER

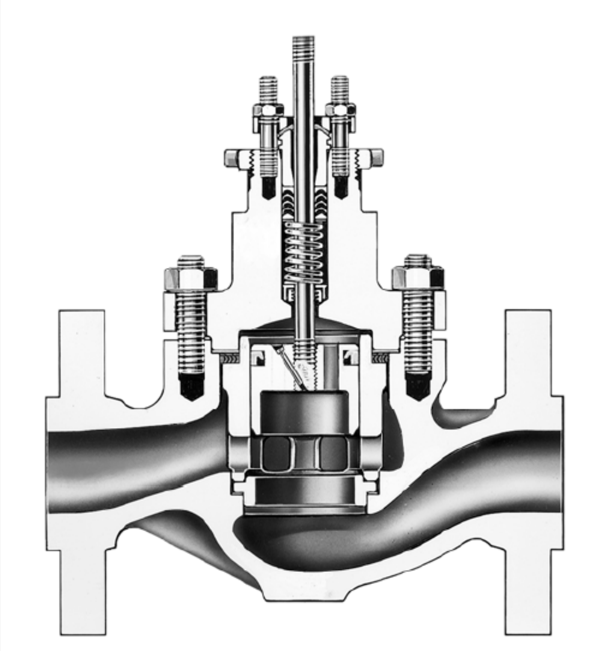


QUICK OPENING
CHARACTERISTIC



BUTTERFLY
VALVE

PROCESS CONTROL SYSTEMS
CONTROL VALVE CHARACTERISTICS



FISHER EASY E GLOBE VALVE SIZING COEFFICIENTS		
SIZE	Cv Quick Opening	Cv Equal %
25	21	17
40	38	33
50	67	56
80	150	121
100	235	203
140	469	357
200	875	808

W0957

Quick Opening Cage

W0959

Equal Percentage Cage

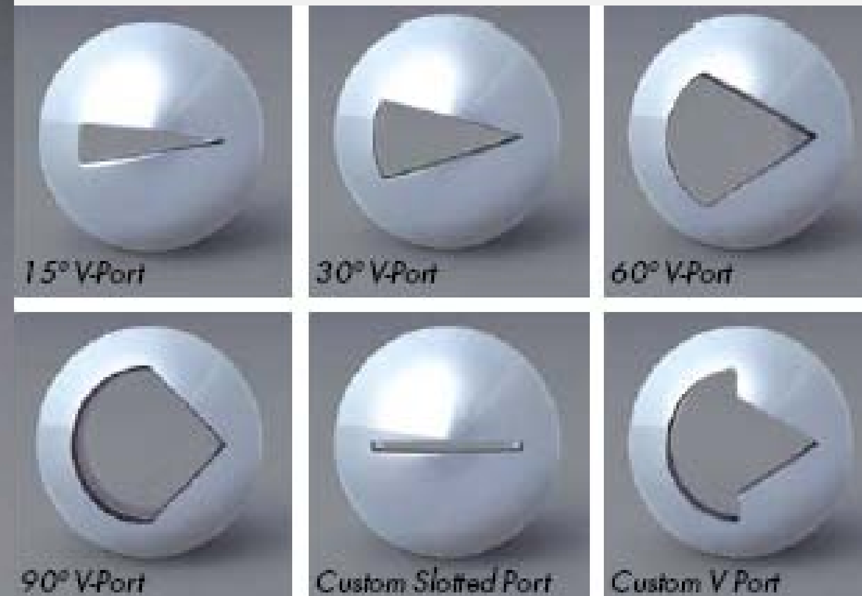
W0961

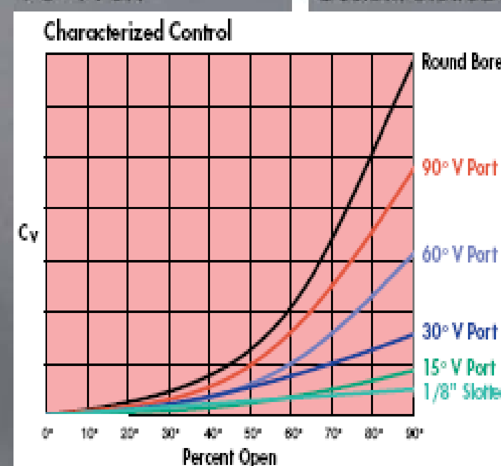
Linear Cage

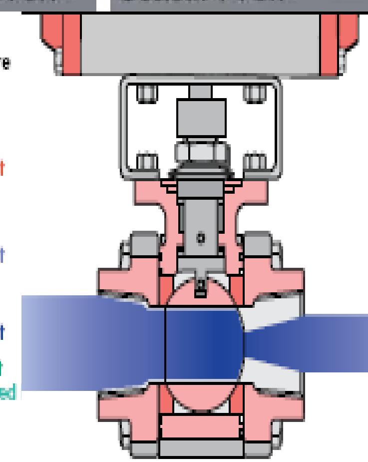
Whisper Trim® Cage
for Noise Attenuation

PROCESS CONTROL SYSTEMS
CONTROL VALVE CHARACTERISTICS

Flow-Tek Vee Ball

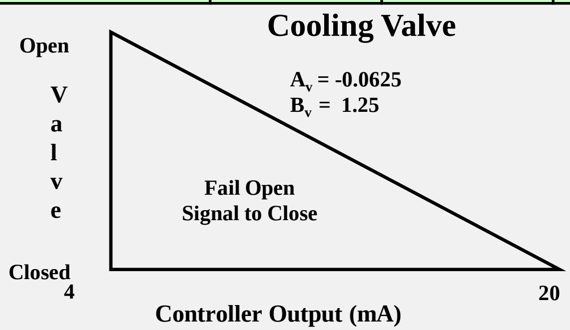


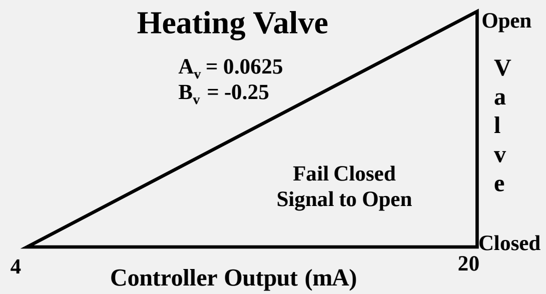




PROCESS CONTROL SYSTEMS
CONTROL VALVE CALIBRATION-ACTION

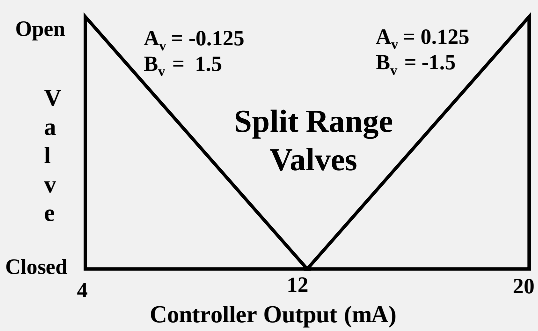
SINGLE CONTROL VALVE OPERATIONS							
ACTION	CONTROL OUTPUT		POSITION	STATE	LOGIC EQUATION	COEFFICIENTS	
	mA	%				A_v	B_v
FAIL CLOSED	4	0	Closed	0	$0 = 4A_v+B_v$	0.0625	-0.25
	20	100	Open	1	$1 = 20A_v+B_v$		
FAIL OPEN	4	0	Open	1	$1 = 4A_v+B_v$	-0.0625	1.25
	20	100	Closed	0	$0 = 20A_v+B_v$		

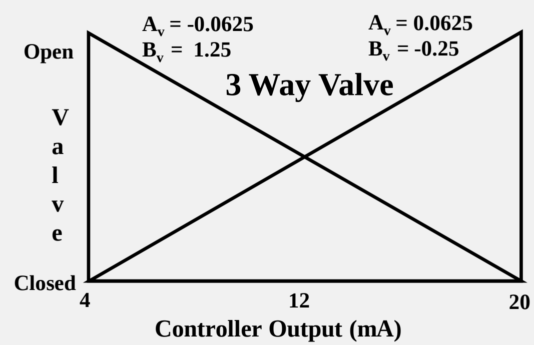




A_v and B_v are CHEMCAD scaling constants

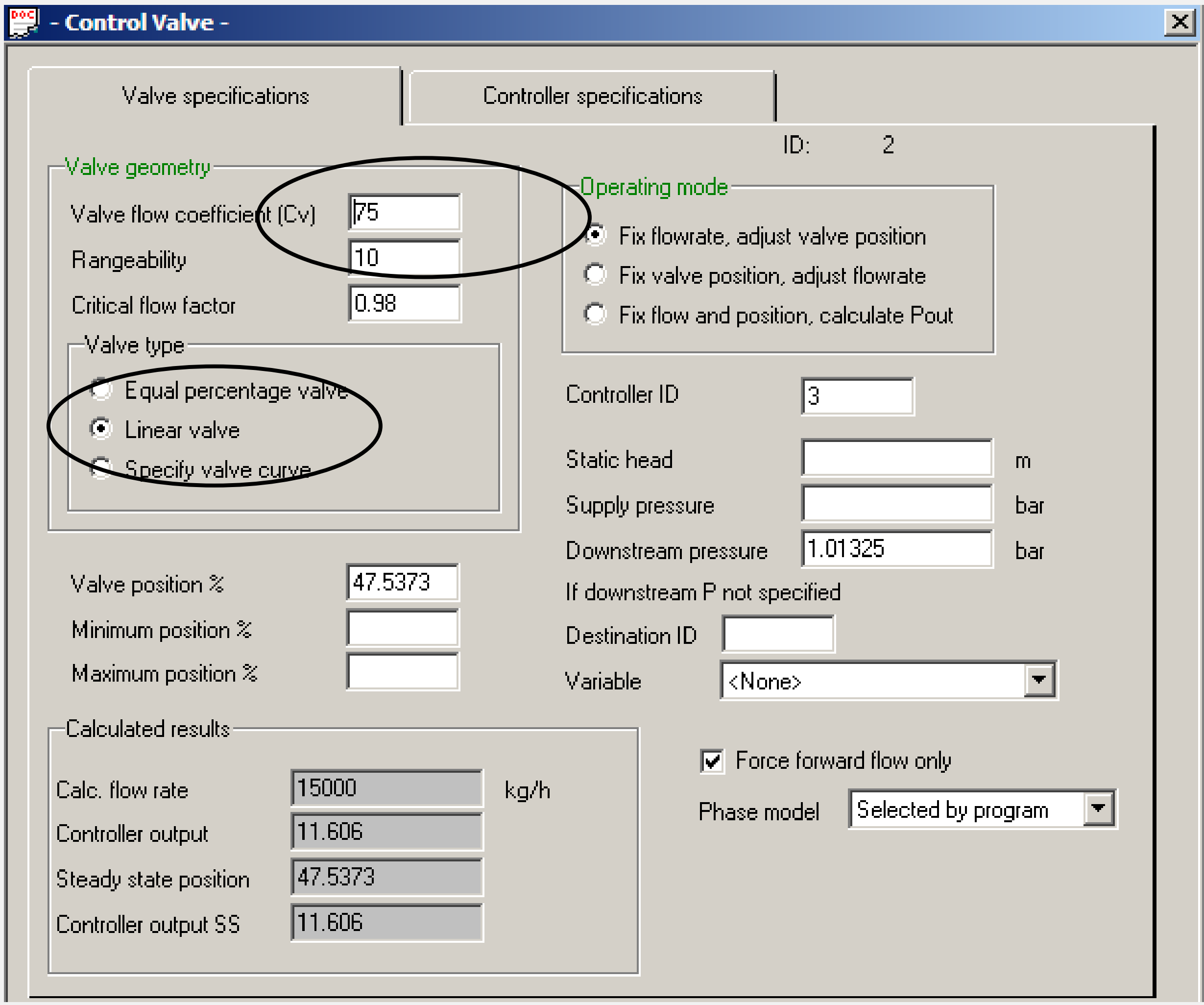
DUAL CONTROL VALVE OPERATIONS IN SPLIT RANGE							
ACTION	CONTROL OUTPUT		POSITION	STATE	LOGIC EQUATION	COEFFICIENTS	
	mA	%				A_v	B_v
FAIL CLOSED	12	50	Closed	0	$0 = 12A_v + B_v$	0.125	-1.5
	20	100	Open	1	$1 = 20A_v + B_v$		
FAIL OPEN	4	0	Open	1	$1 = 4A_v + B_v$	-0.125	1.5
	12	50	Closed	0	$0 = 12A_v + B_v$		

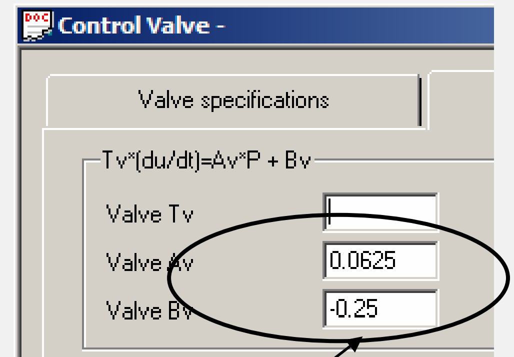




A_v and B_v are CHEMCAD scaling constants

DYNAMIC SIMULATION CHEMCAD CONTROL VALVE SETTINGS





Fail Closed
Signal to Open

PROCESS CONTROL SYSTEMS
PROPERTIES OF COMMON LOOPS

Chemstations Engineer extended™

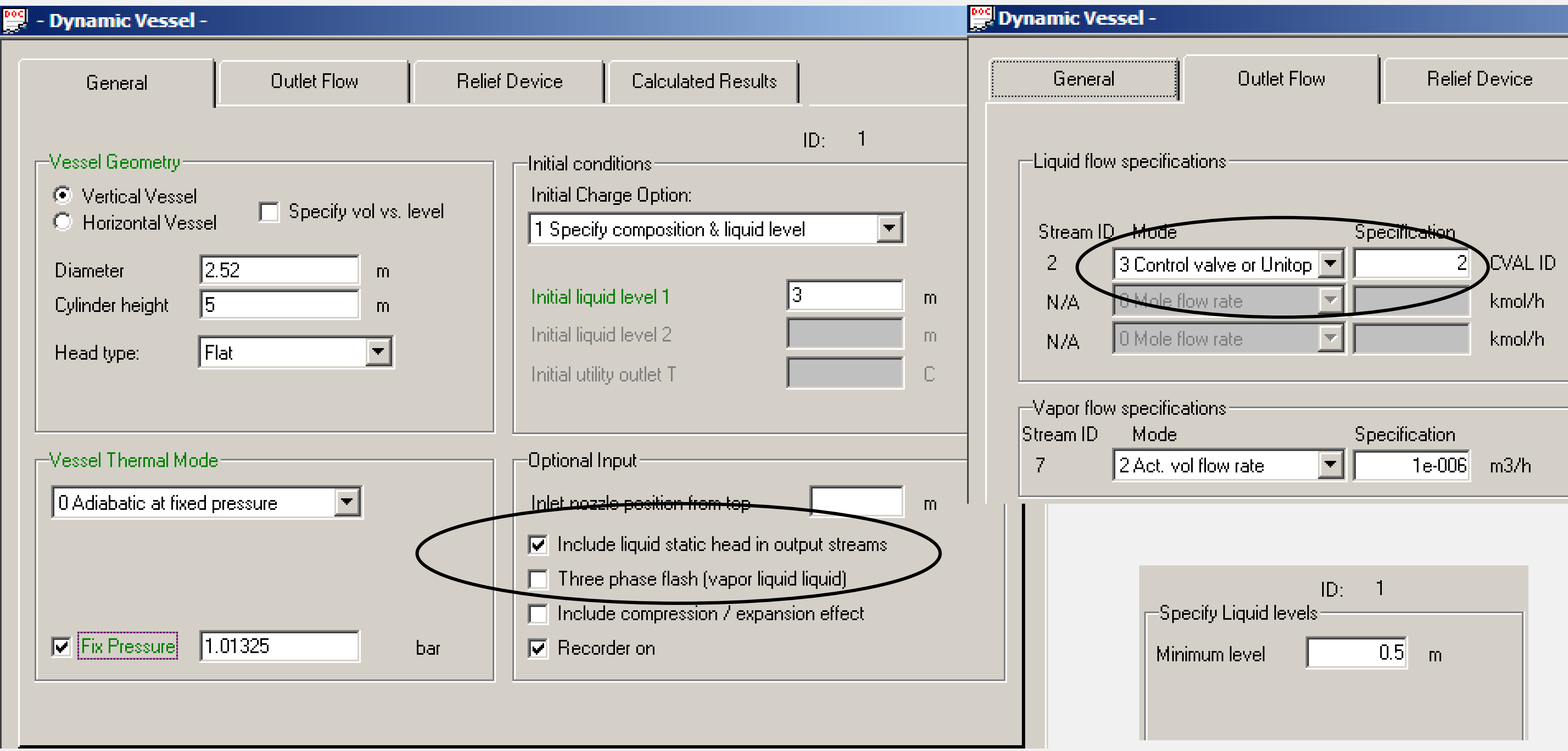
P & I DESIGN

COMMON LOOP CHARACTERISTICS & TUNING PARAMETER RANGES Ch3, Table 3.3				
PARAMETER	CHARACTERISTIC	P (%)	I (min)	D (min)
FLOW	FAST - NOISY	50 - 500	0.05 - 2	NO
PRESSURE (LIQUID)	FAST - NOISY	50 - 200	0.05 - 2	NO
COMPOSITION (GAS)	FAST - NOISY	50 – 500	0.05 – 2	NO
LEVEL	SLOW→FAST - NOISY	5 – 100	SOMETIMES	NO
TEMPERATURE	SLOW - STEADY	10 – 100	2 – 120	I/4 < D > I/2
COMPOSITION (LIQUID)	SLOW - STEADY	10 - 200	2 – 120	I/4 < D > I/2
PRESSURE (GAS)	SLOW - STEADY	1 - 5	UNNECCESSARY	UNNECCESSARY
VAPOR PRESSURE	SLOW - STEADY	10 - 100	2 - 120	I/4 < D > I/2

CONTROL MODES	P (%)	T_i (min)	T_d (min)
P	2 Pu		
P + I	2.2 Pu	T_u / 1.2	
P + I + D	1.6 Pu	T_u / 2.0	T_u / 8.0 = T_i /4

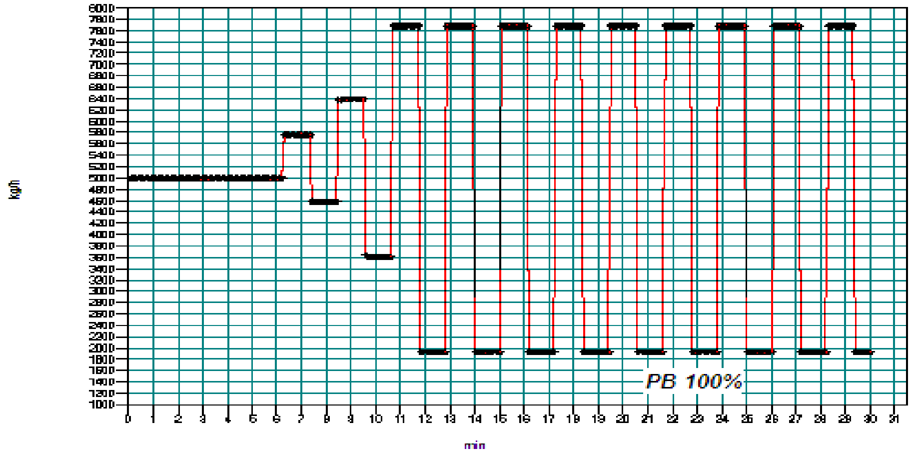
P_u measurement starts to oscillate at constant amplitude T_u for small SP changes

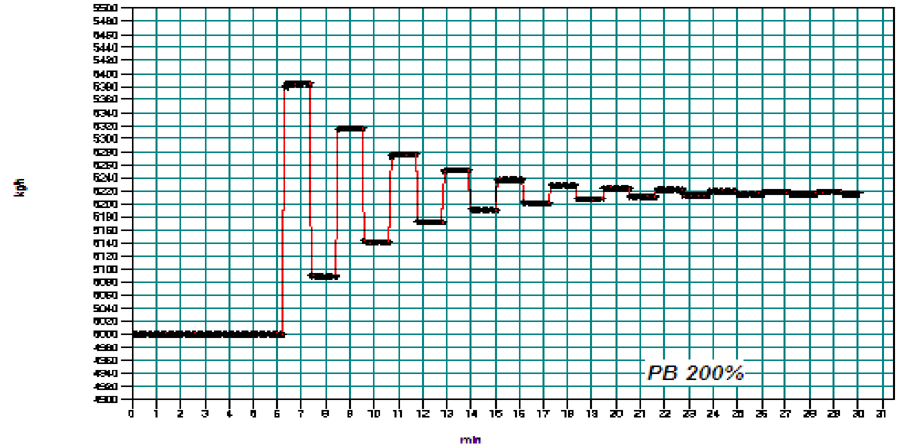
DYNAMIC SIMULATION
CHEMCAD DYNAMIC VESSEL SETTINGS

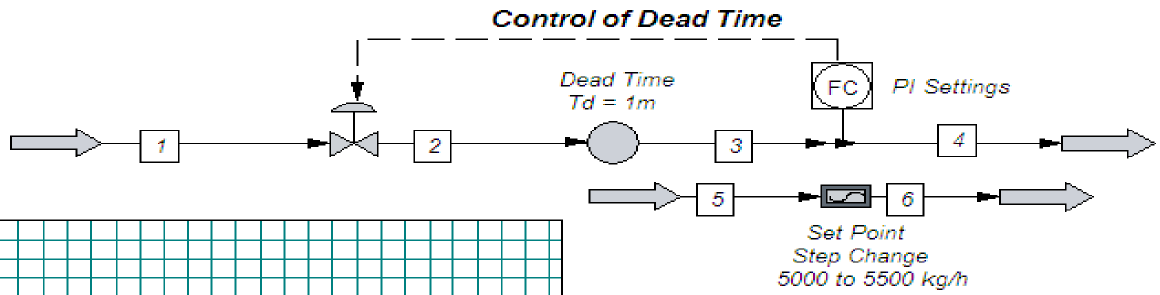


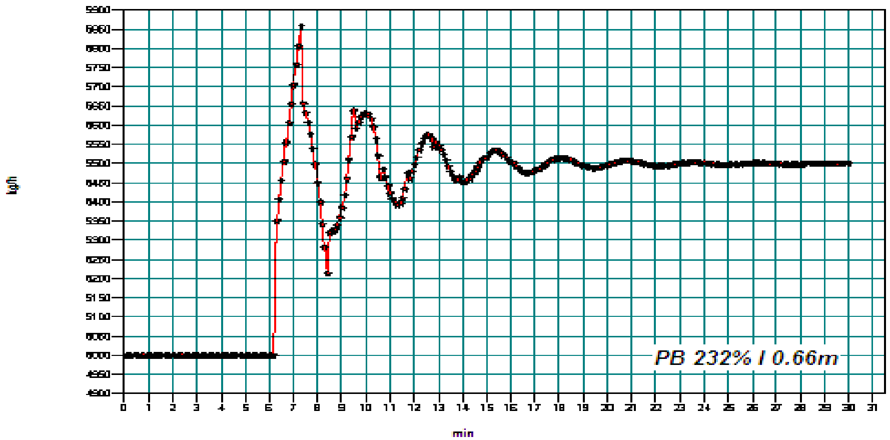
PROCESS CONTROL SYSTEMS
CONTROL OF DEAD TIME

P & I DESIGN

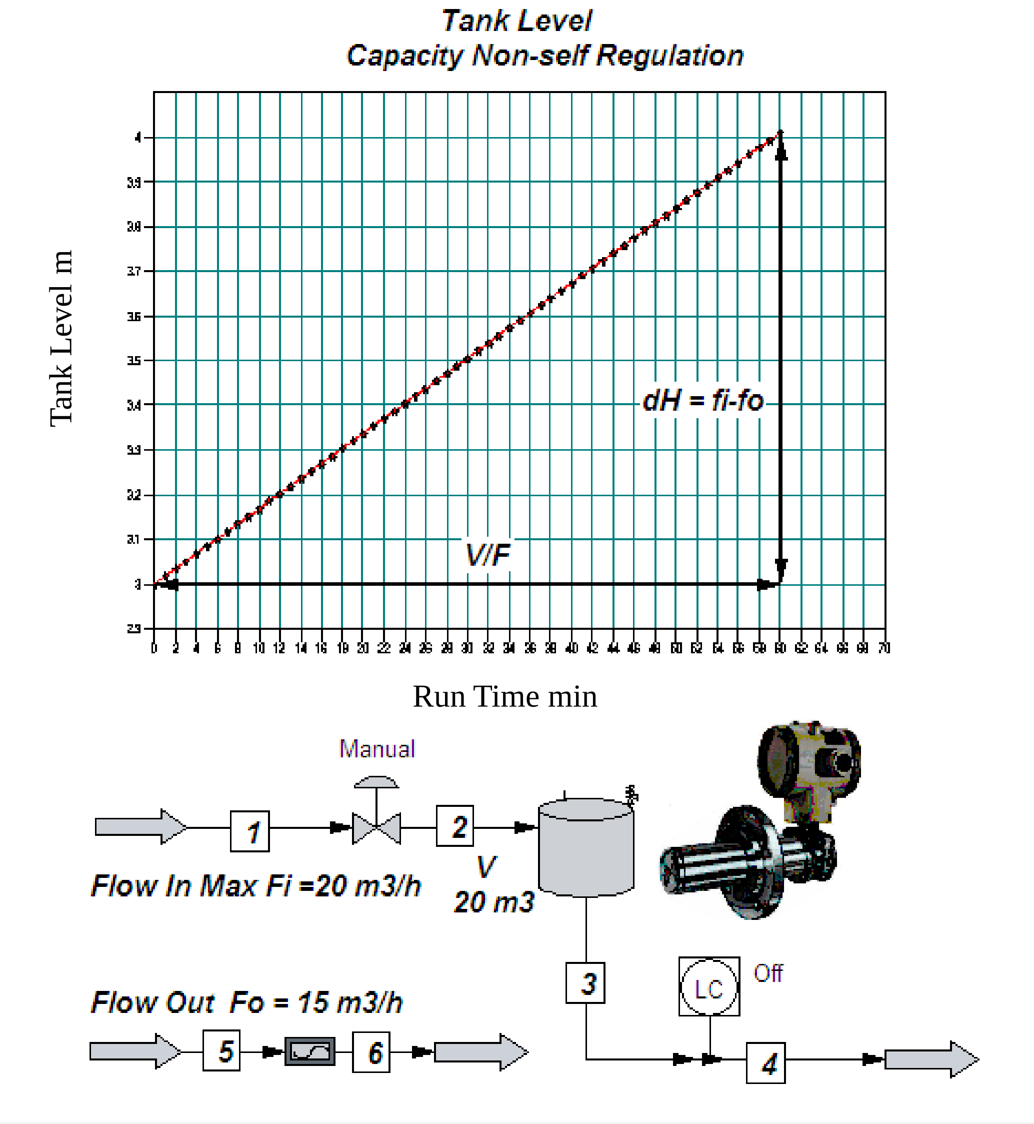






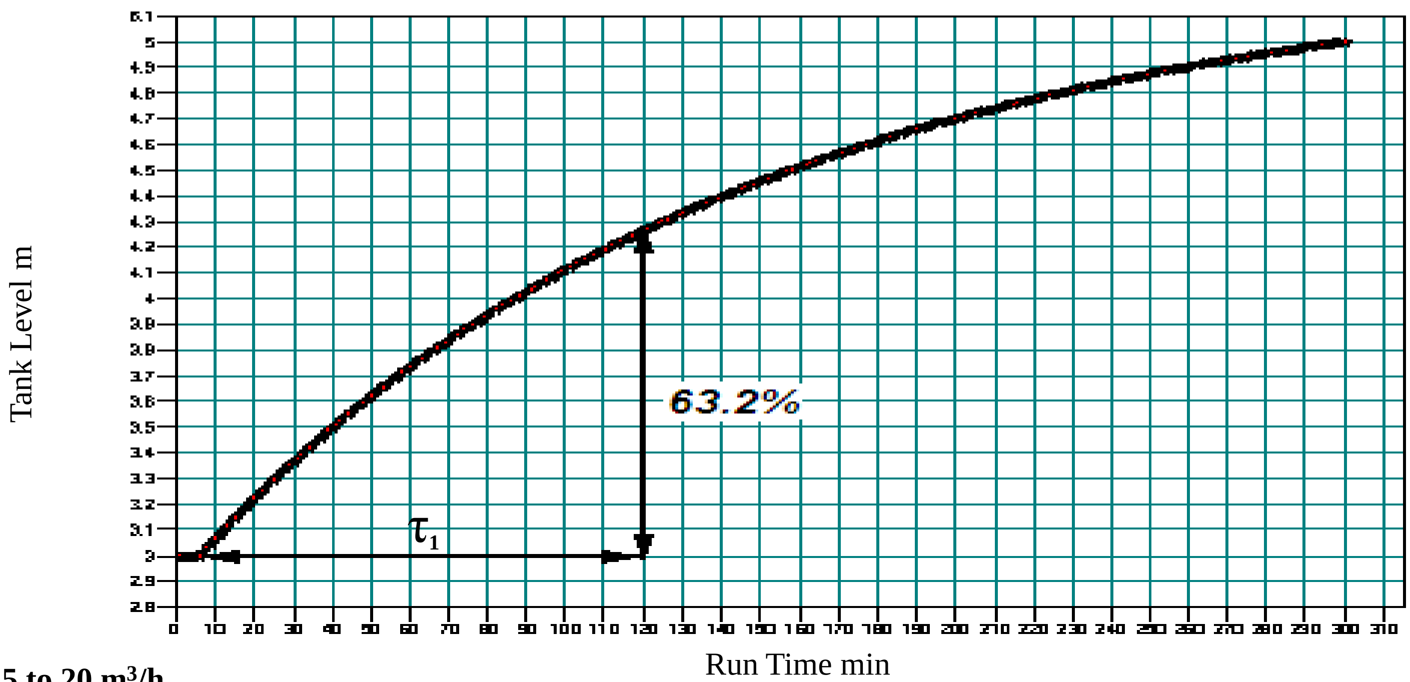


PROCESS CONTROL SYSTEMS CAPACITY TANK LEVEL

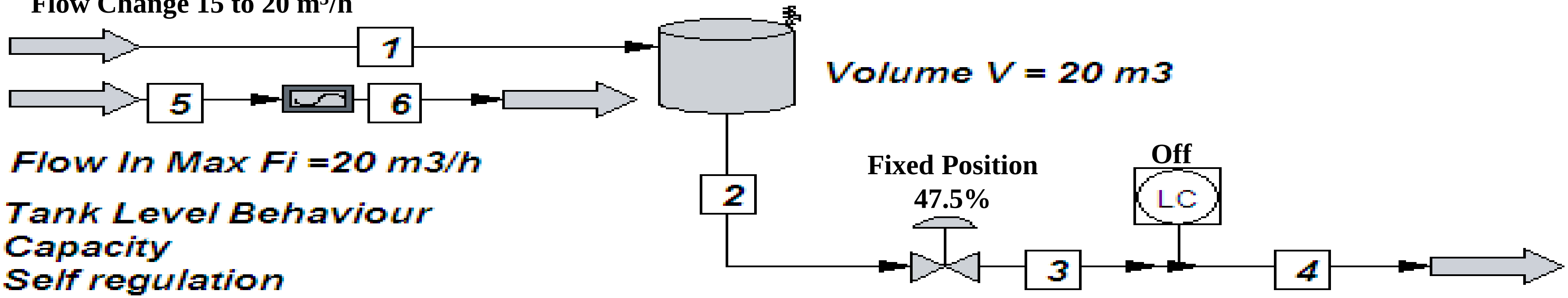


PROCESS CONTROL SYSTEMS
CAPACITY TANK LEVEL SELF REGULATE

$$\tau_1 = \frac{V}{Fk}$$



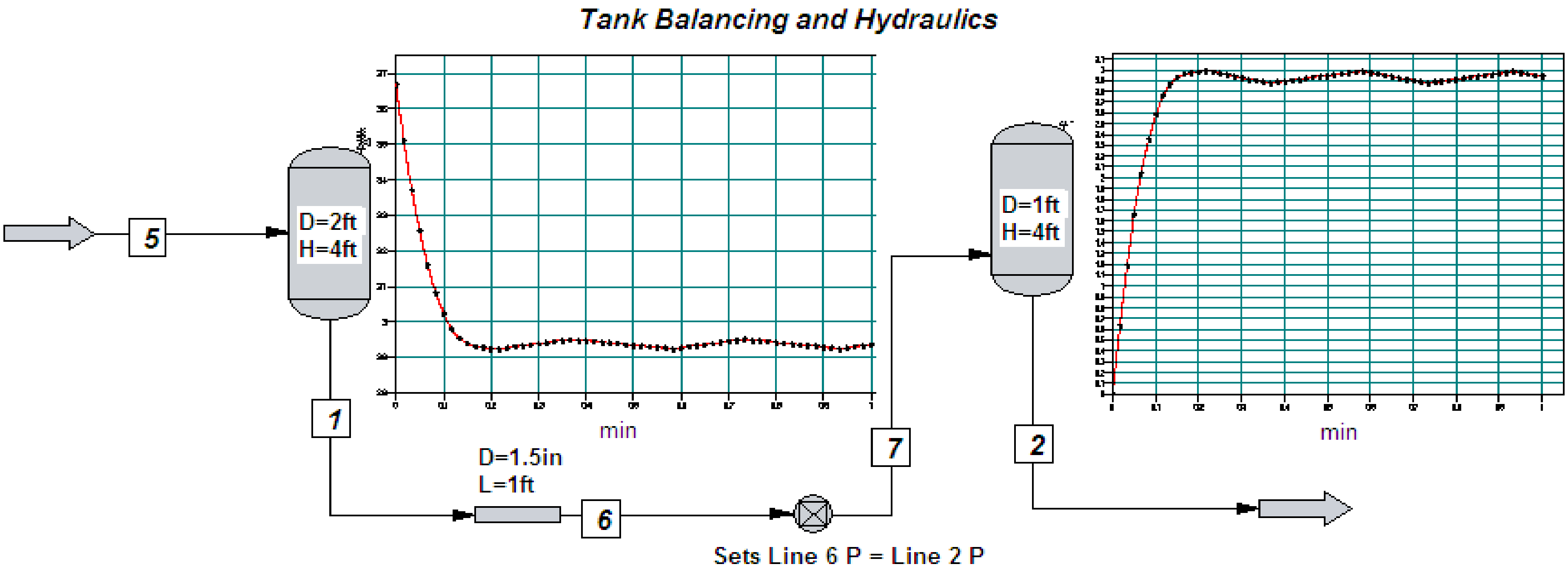
Flow Change 15 to 20 m³/h



Flow In Max Fi =20 m3/h

Tank Level Behaviour
Capacity
Self regulation

Flow Out Max Fo =20 m3/h



Period is function of wetted surface length only

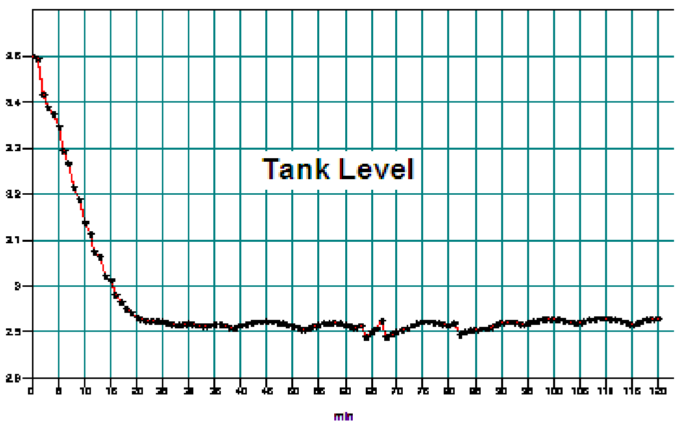
$$\tau_0 = 2\pi \left(\frac{L_1 + L_2}{2g} \right)^{0.5}$$

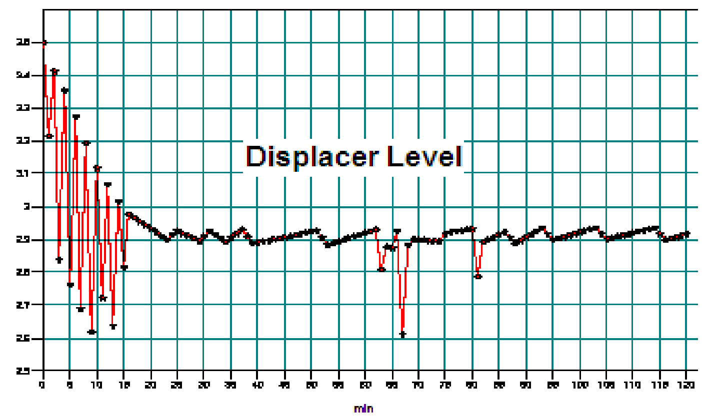
Throttling displacer valves reduces amplitude allowing narrower PB

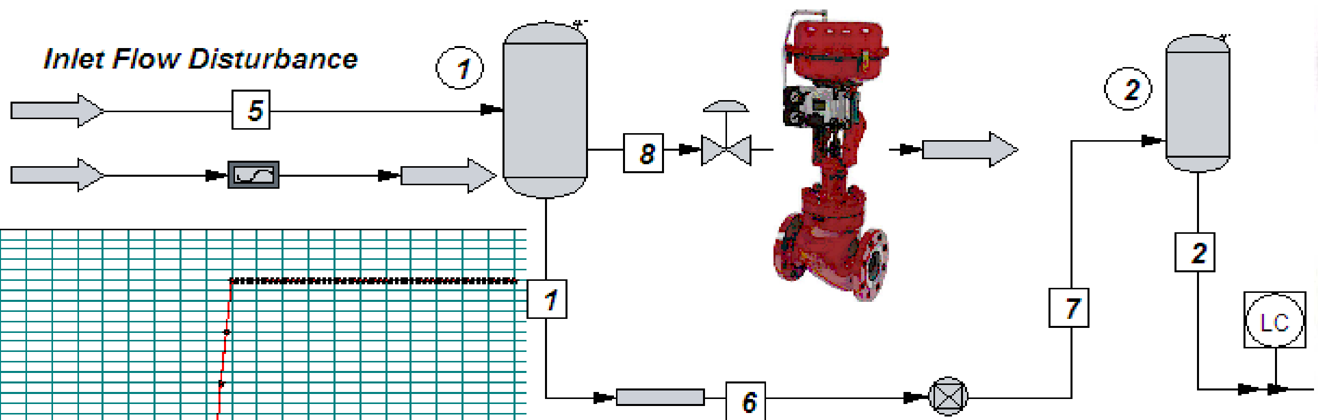
Chemstations
Engineer extended™

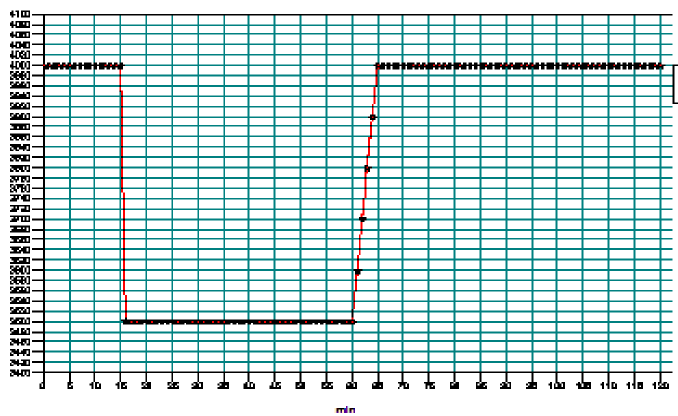
PROCESS CONTROL SYSTEMS
DISPLACER TANK LEVEL CONTROL

P & I DESIGN



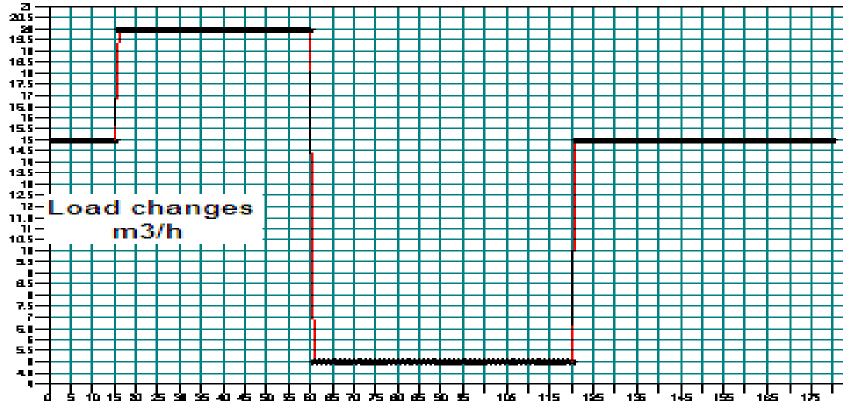


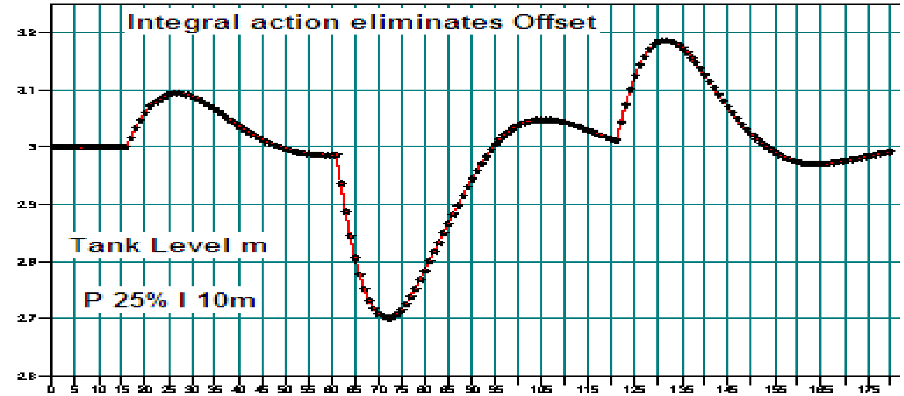


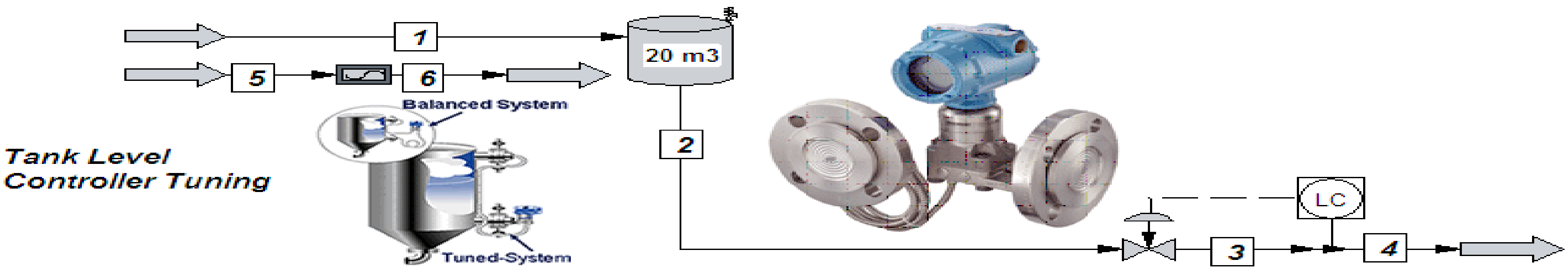


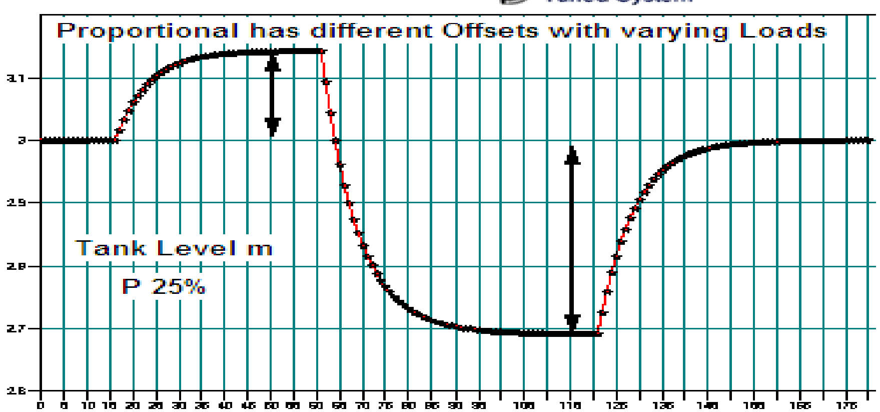
Displacer Tank Level
Measurement and Control

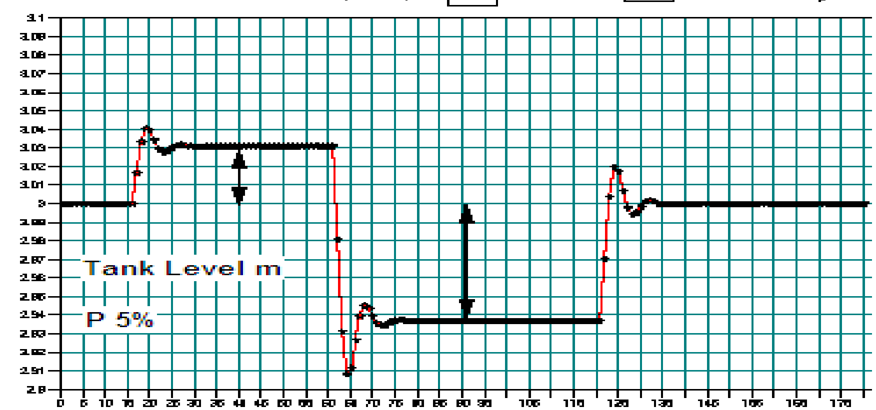
PROCESS CONTROL SYSTEMS
TANK LEVEL CONTROLLER TUNING



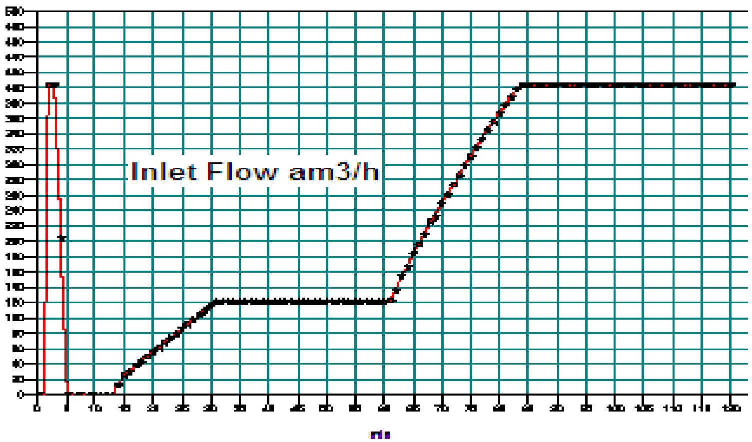






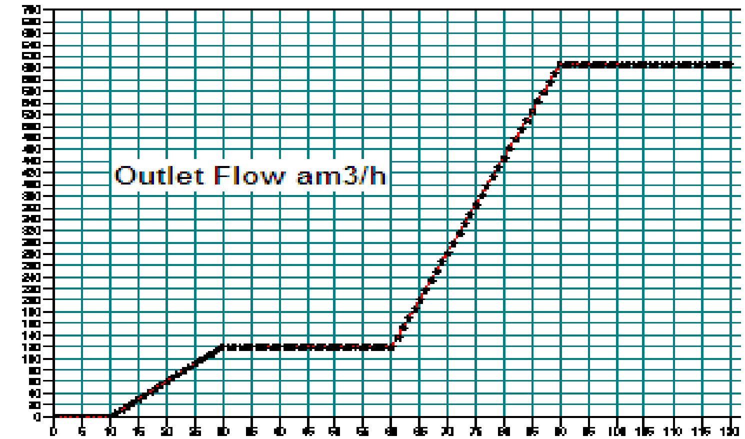


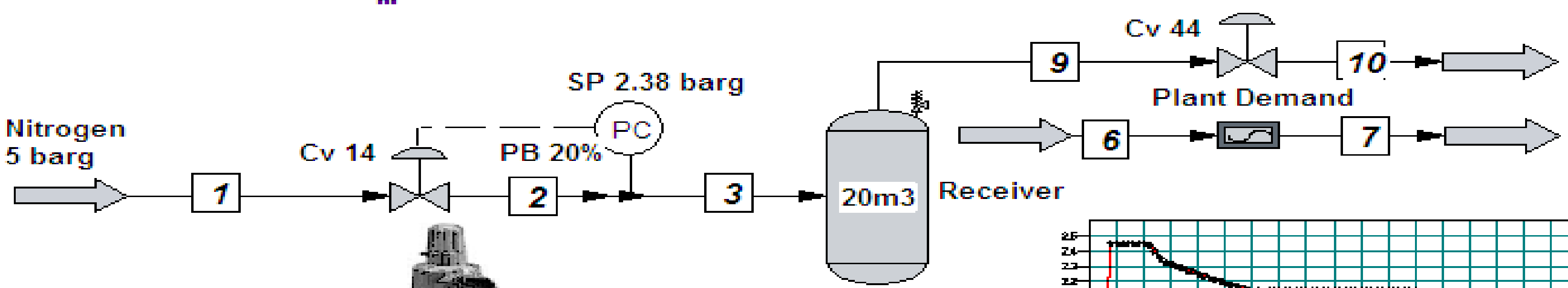
PROCESS CONTROL SYSTEMS
GAS PRESSURE CONTROL

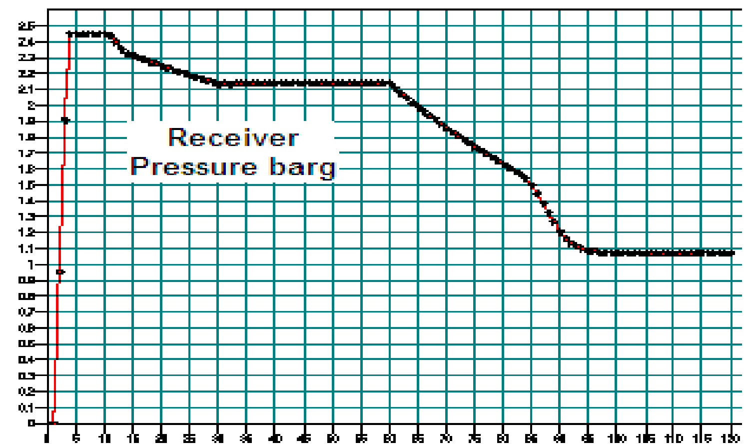


Gas Pressure Control

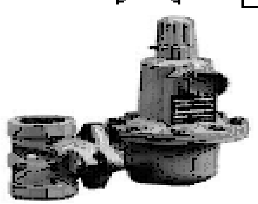
Narrow Band
P only Control





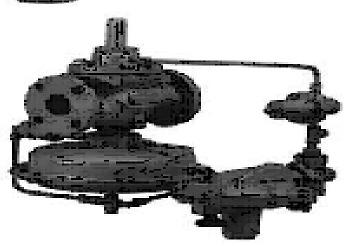


Pressure Regulator
Self-contained
Direct Operated



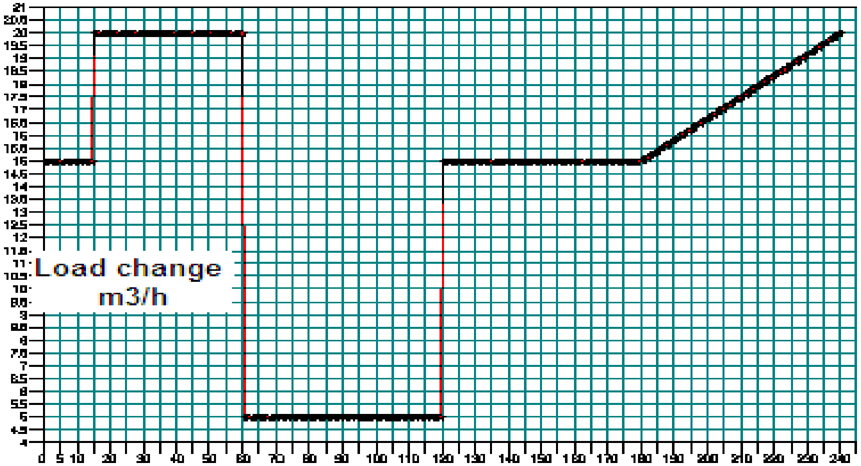
Regulator Pressure
varies with flow
exhibiting "droop"

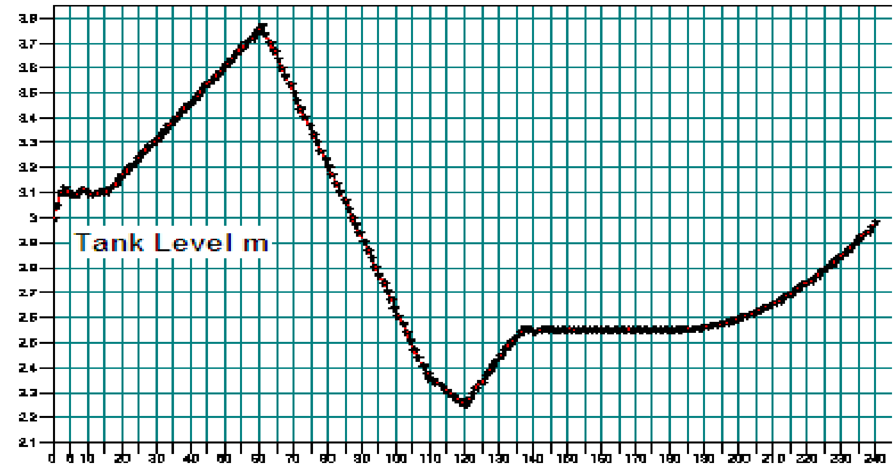
Pressure Regulator
Self-contained
Pilot Operated

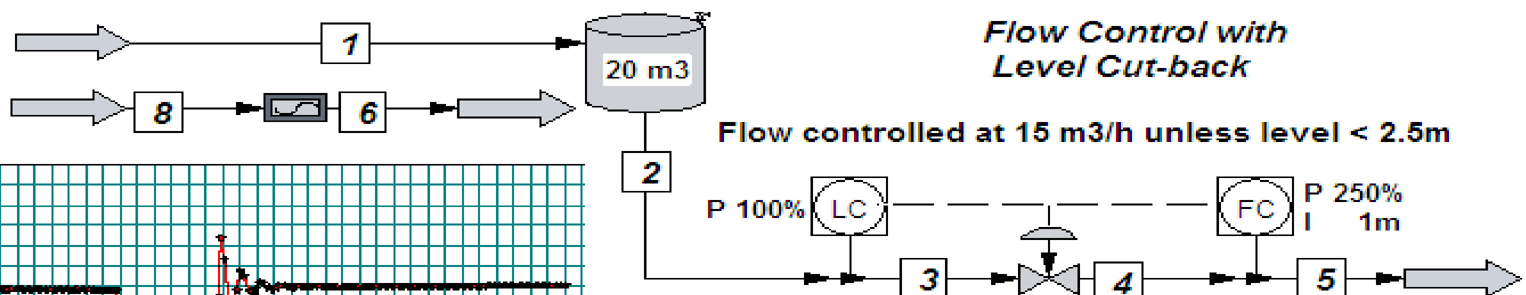


PROCESS CONTROL SYSTEMS
FLOW CONTROLLER TUNING

P & I DESIGN

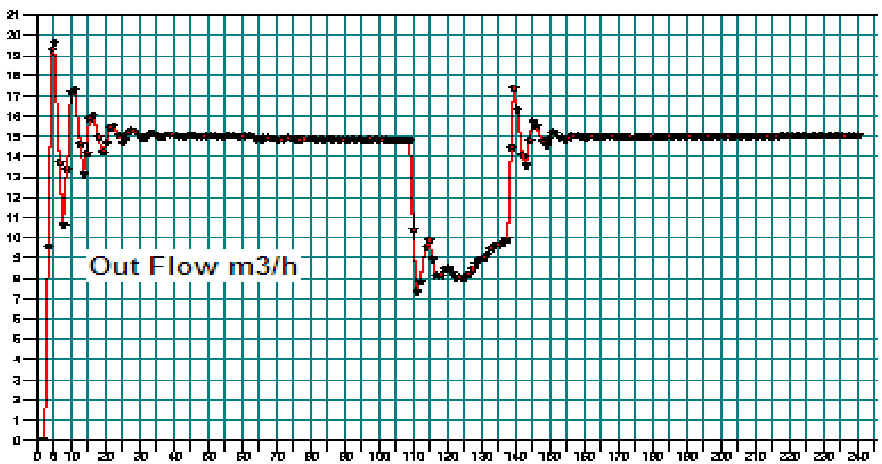


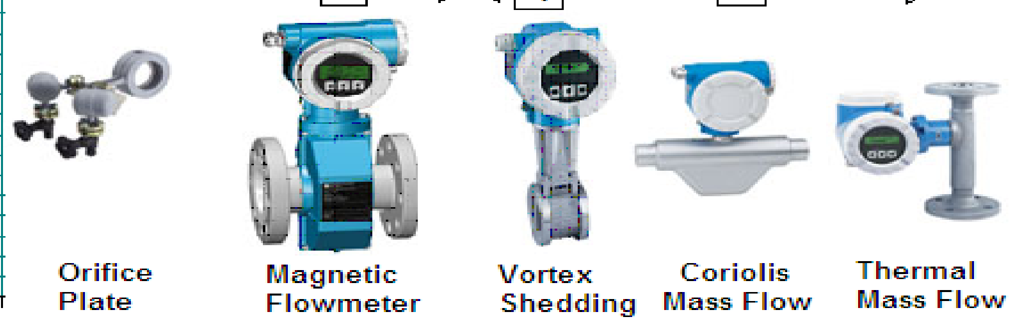




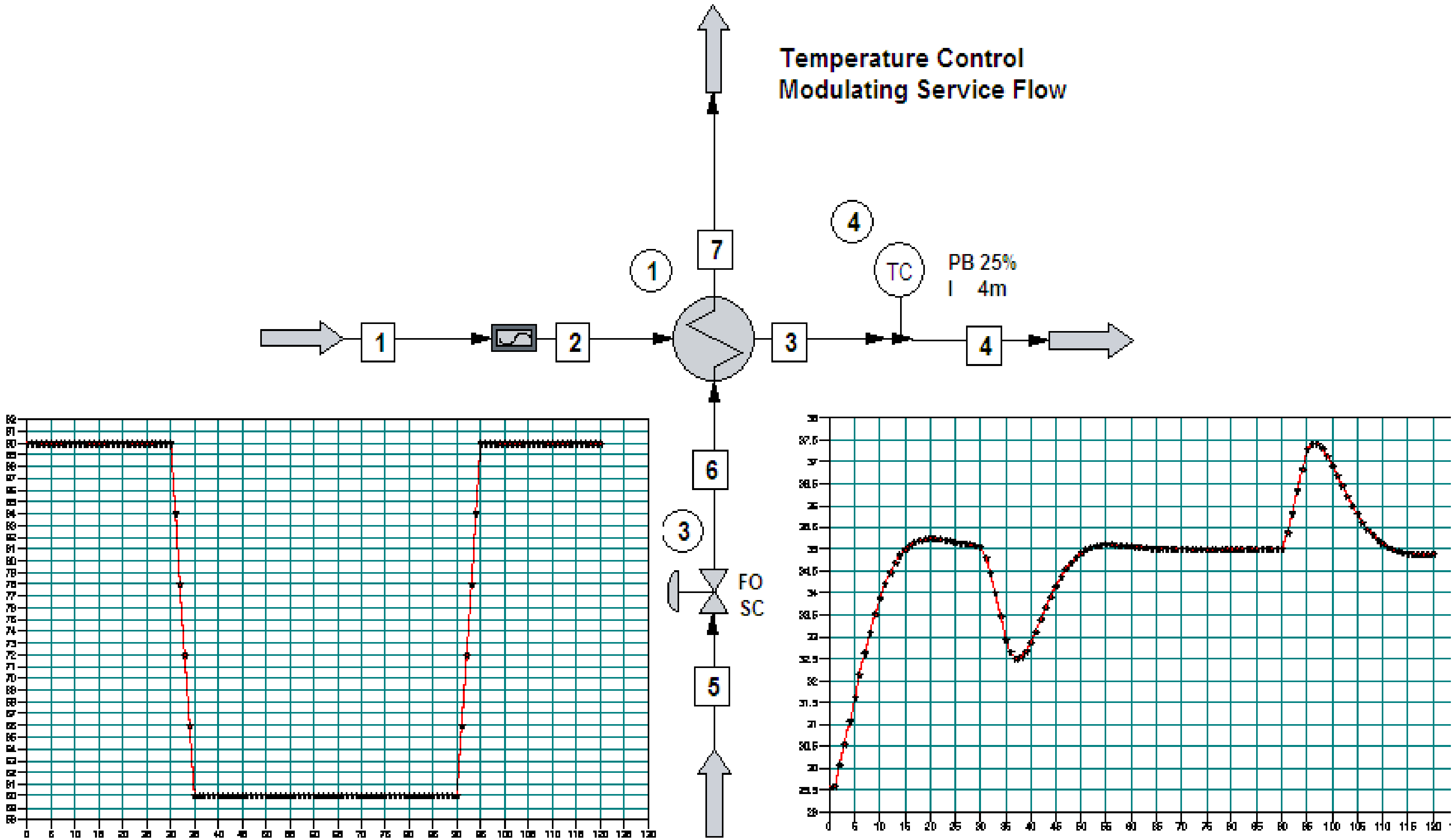
Flow Control with Level Cut-back

Flow controlled at 15 m3/h unless level < 2.5m





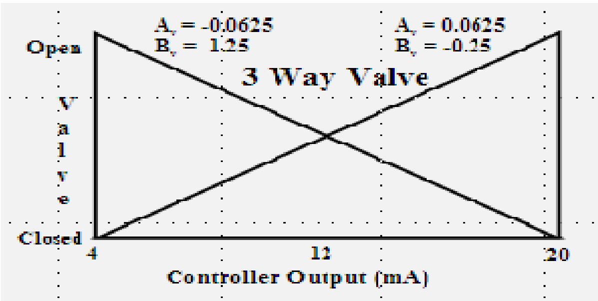
PROCESS CONTROL SYSTEMS
TEMPERATURE CONTROL

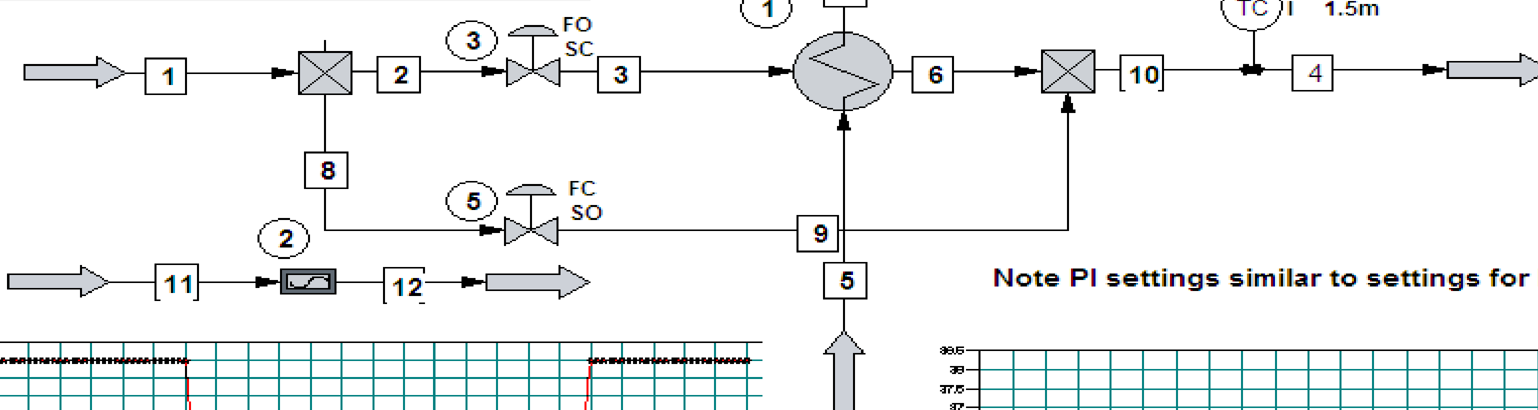


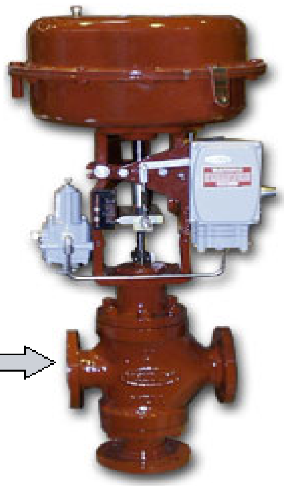
PROCESS CONTROL SYSTEMS
BYPASS TEMPERATURE CONTROL

P & I DESIGN

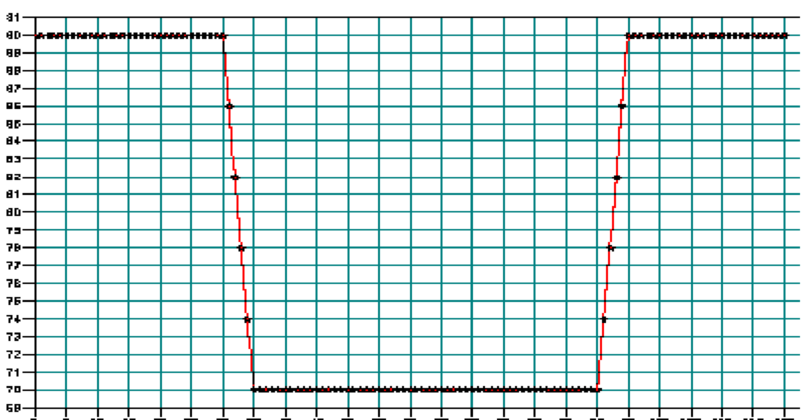
Temperature Control
3 Way Valve Bypass

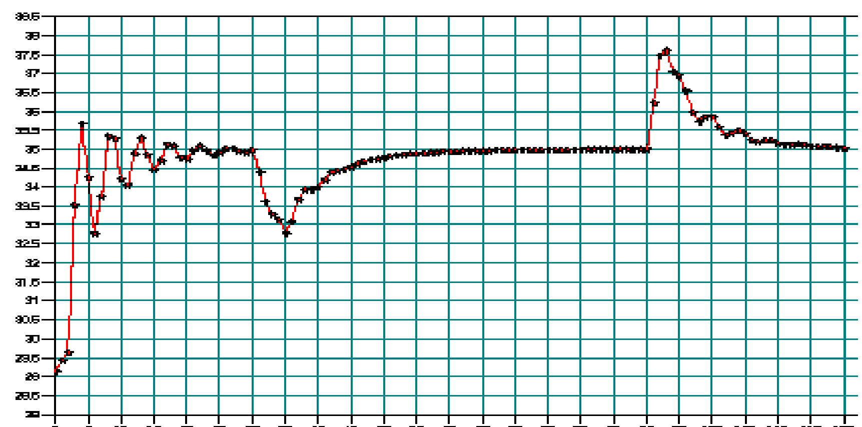


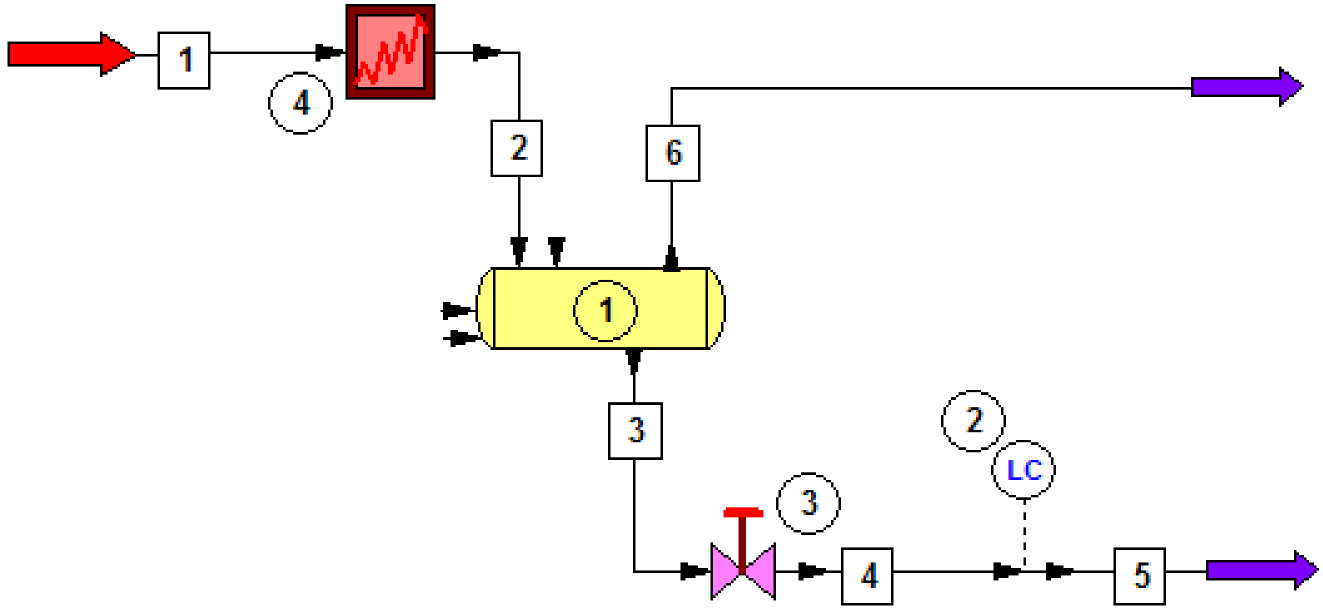




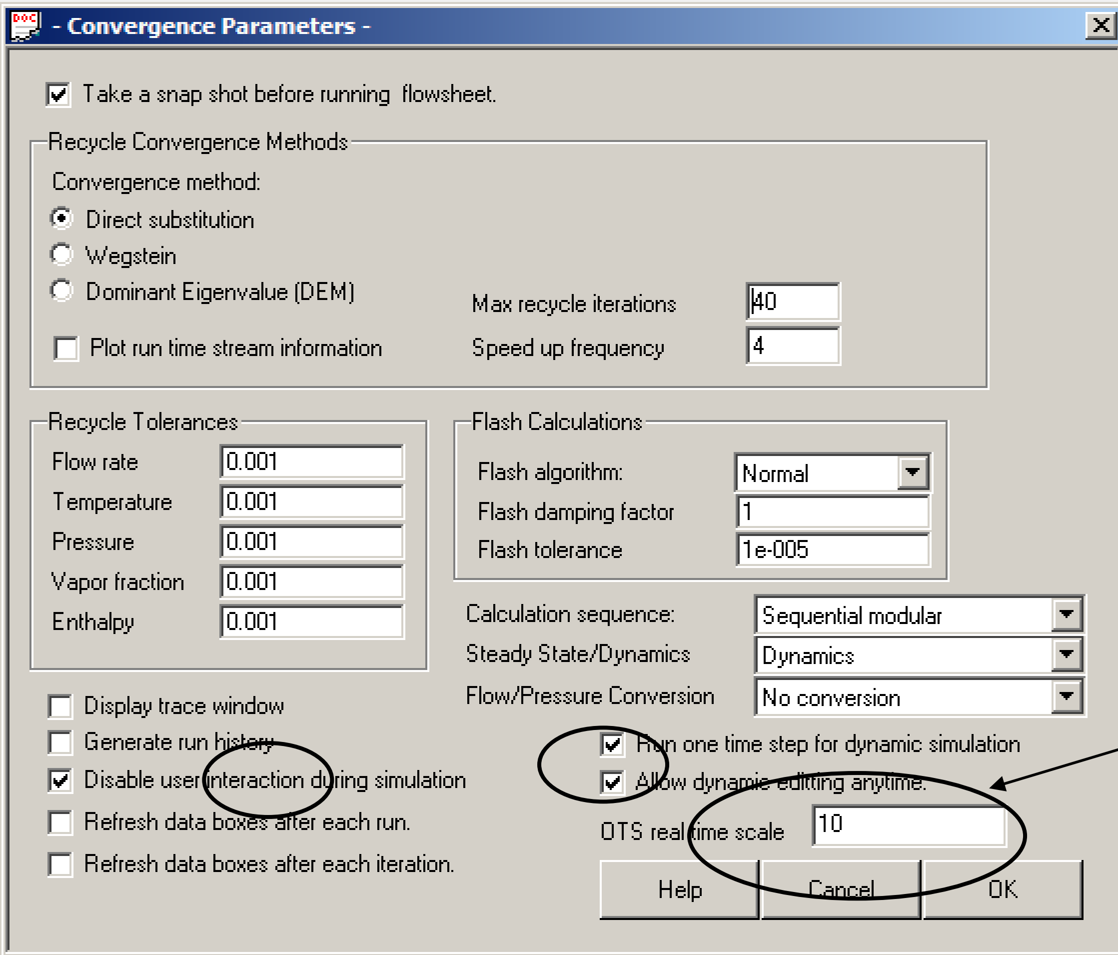
Note PI settings similar to settings for Flow






1
4
2
6
1
3
2
LC
3
4
5

DYNAMIC SIMULATION
TRAINING SIMULATOR OTS SETTINGS



Real Time Step 1.0m

Simulation Time 0.1m

DYNAMIC SIMULATION
TRAINING SIMULATOR GUI

Data Update Start	START	1
XL CHEMCAD Comms Status	Healthy	1
	RESET