

A large, white, cylindrical industrial storage tank is the central focus of the image. It is surrounded by a complex network of pipes, scaffolding, and walkways. The tank has several horizontal bands and a spiral staircase on its left side. The background shows a clear blue sky with some light clouds. The overall scene is an industrial chemical processing facility.

**CHEMCAD 6
DYNAMIC SIMULATION
SPECIALITY, FINE AND PHARMA
PROCESS APPLICATIONS**

By John E. Edwards

Contents

Introduction	3
Piping Distribution System Study	4
Cryogenic Reactor System	6
Reactor Control with Real OHTC	10
VOC Emission Control	11
Heat Exchanger Network Analysis	13

CHEMCAD 6.0 DYNAMIC APPLICATIONS – SPECIALITY, FINE AND PHARMA

Batch processing techniques are used extensively in the manufacture of a wide variety of speciality chemicals, fine chemicals and pharmaceutical products and involve the following general criteria:

- Low to medium capital investment
- Low to medium cost to rectify design errors
- Low volume high value products
- Low to medium production costs
- Limited savings from yield improvements and reduced cycle times
- Multi-purpose capability often required

Batch processes are inherently transient in nature and to validate the equipment design the performance needs to be analysed dynamically using the physical properties of the process and service fluids under operating conditions.

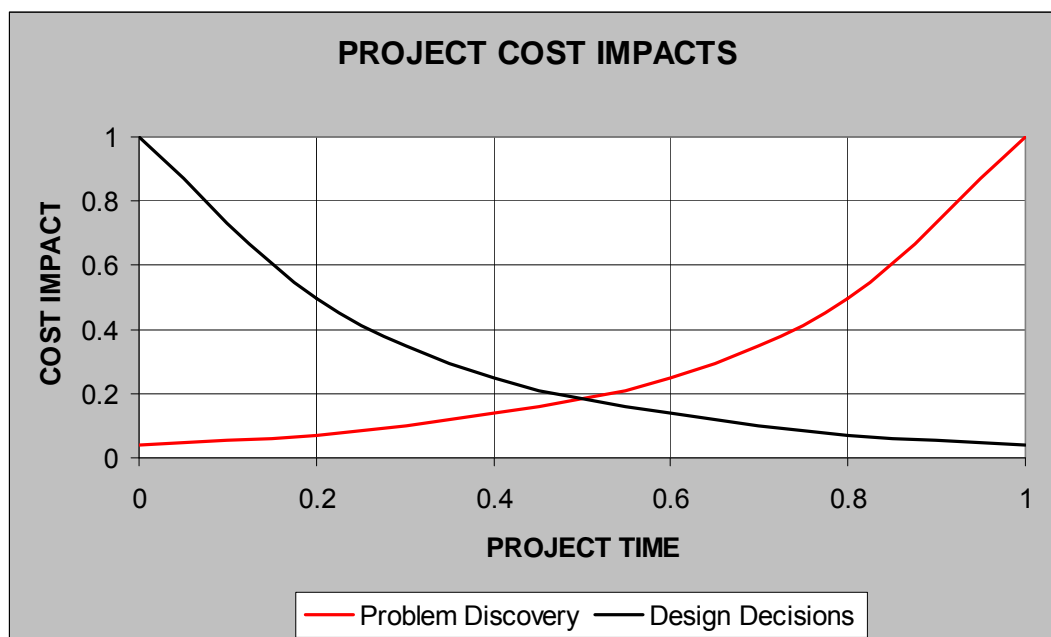
The central item of equipment is normally the stirred tank reactor. The capacity and thermal properties can be readily predicted to enable the operating performance and thermal behaviour to be characterised.

The refrigeration process is used extensively in these industry sectors to carry out a wide range of below ambient cooling duties. These applications include low temperature condensation, to minimise volatile organic compound emission, heat removal on low temperature reactions and a variety of product separation and stability applications.

The characteristic properties and design parameters are analysed dynamically using the Dynamics module from the CHEMCAD™ range of software by Chemstations of Houston. Dynamic modelling tests the capability to achieve stable and reproducible operating conditions to achieve the product purity, yield, cycle times to satisfy the commercial requirements and the safety and environmental issues for the regulatory authorities.

This paper reviews dynamic modelling of pipe networks, heat exchanger networks, batch reactor control, cryogenic operations and VOC control using wet scrubbing.

Dynamic simulation can achieve significant savings in the design process and to identify errors at an early stage in the project life. The project cost impact curves show the benefits of testing design decisions to avoid the increased costs to rectify later in the project life cycle.



CHEMCAD 6.0 DYNAMIC APPLICATIONS – PIPING DISTRIBUTION SYSTEM STUDY

PROCESS DESCRIPTION

This case study investigates the dynamic performance of a typical services piping distribution system. Heat transfer fluid (HTF) is used to supply a network of heaters.

The HTF is supplied at 7 barg and 330°C at a flow of 67 m³/h. The HTF is to be returned at a minimum pressure of 4 barg and a minimum temperature of 285°C.

The piping layout details have been obtained from isometric drawings and are shown in Excel spreadsheet “**Piping Distribution System Dynamics**” to be found in the electronic media, a part of which is shown below. This spreadsheet summarises the details of each piping section to facilitate data entry into CHEMCAD.

P & I Design Ltd
www.pidesign.co.uk

Project: Piping Distribution System Dynamics
Process: Heat Transfer System
Operation: Process Heaters
Document: Excel Pipe Network Data Entry
Signatory: J.E. Edwards
Issue: Preliminary
Date: 20/11/2008

Data Entry Format for CHEMCAD PIPE NETWORKS

References
1) Crane, Flow of Fluids through Valves, Fittings and Pipe, 410M
2) CHEMCAD Help Pipe UnitOp
Units Used Alt SI D in mm > L & d(ELEVATION) in metres d(ELEV) [+] -
Instructions
1) Enter all valves and fittings in EQUIVALENT LENGTH CALCULATOR for PIPE UNITOP Section
2) Copy relevant results from CHEMCAD Library and User Library Results Tables
3) Paste Special Format and then Paste Special Values into appropriate PIPE UNITOP section on REPORT Sheet
4) Enter total L/D into PIPE UNITOP under User Specified Valves and Fittings
5) Enter velocity head loss details on Fittings sheet in CHEMCAD

EQUIVALENT LENGTH CALCULATOR
Version 5.01

Supply Header				Supply Header				Supply Header			
UNITOP NUMBER	D	L	d(ELEV)	UNITOP NUMBER	D	L	d(ELEV)	UNITOP NUMBER	D	L	d(ELEV)
1	150	20	15	7	150	5	5	8	150	15	10
VALVE TYPE				VALVE TYPE				VALVE TYPE			
GLOBE - GUIDED	450.00	2	900.0	GLOBE - GUIDED	450.00	1	450.0	GLOBE - GUIDED	450.00	1	450.0
Total L/D				Total L/D				Total L/D			
900.0				450.0				450.0			
FITTING TYPE				FITTING TYPE				FITTING TYPE			
STANDARD ELBOW 90°	30.0	10	300	STANDARD ELBOW 90°	30.00	1	30	STANDARD T FLOW IN RUN	20.00	1	20
Total L/D				Total L/D				Total L/D			
300.0				30.0				180			
UNITOP Total L/D				UNITOP Total L/D				UNITOP Total L/D			
1200.0				581.6				200.0			

Supply Header				Return Header				Return Header			
UNITOP NUMBER	D	L	d(ELEV)	UNITOP NUMBER	D	L	d(ELEV)	UNITOP NUMBER	D	L	d(ELEV)
31	150	10	0	47	150	15	0	41	150	30	-25
VALVE TYPE				VALVE TYPE				VALVE TYPE			
GLOBE - GUIDED	450.00	1	450.0	GLOBE - GUIDED	450.00	1	450.0	GLOBE - GUIDED	450.00	1	450.0
Total L/D				Total L/D				Total L/D			
450.0				450.0				450.0			
FITTING TYPE				FITTING TYPE				FITTING TYPE			
STANDARD ELBOW 90°	30.00	1	30	STANDARD ELBOW 90°	30.00	1	30	STANDARD T FLOW IN RUN	20.00	1	20
RETURN BEND 180°	50.00	1	50	RETURN BEND 180°	50.00	1	50	STANDARD ELBOW 90°	30.00	6	180
STANDARD T FLOW TO BRANCH	60.00	1	60	T 100% FLOW IN RUN	8.40	1	8.4	Total L/D			
STANDARD T FLOW IN RUN	20.00	1	20	T 100% FLOW IN FROM BRANCH	43.20	1	43.2	UNITOP Total L/D			
Total L/D				Total L/D				200.0			
160.0				131.6				200.0			
UNITOP Total L/D				UNITOP Total L/D				UNITOP Total L/D			
610.0				581.6				200.0			

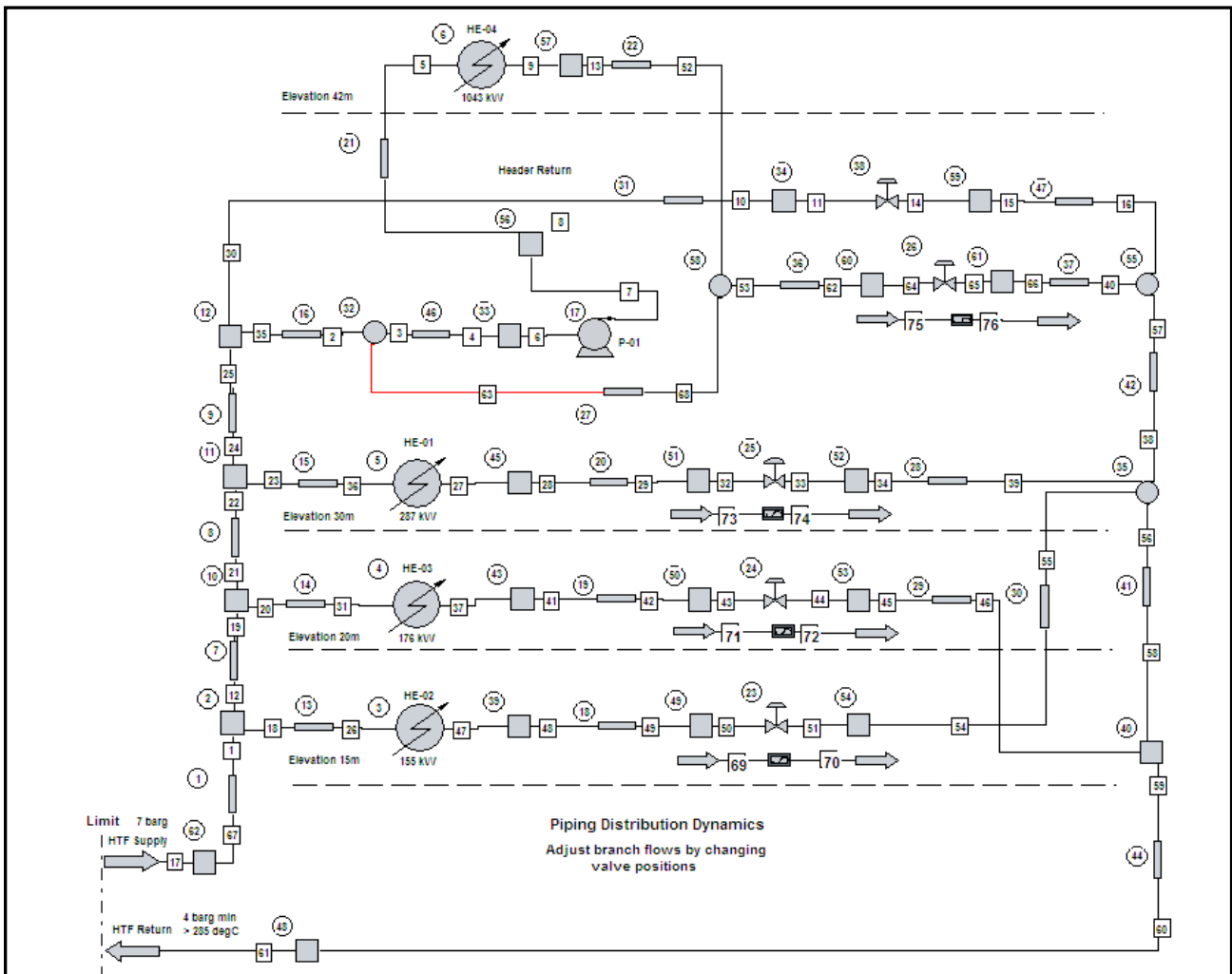
Return Header				Supply to 110-20-E-02				Supply to 110-20-E-03			
UNITOP NUMBER	D	L	d(ELEV)	UNITOP NUMBER	D	L	d(ELEV)	UNITOP NUMBER	D	L	d(ELEV)
44	150	10	-5	13	50	10		14	50	10	
VALVE TYPE				VALVE TYPE				VALVE TYPE			
GLOBE - GUIDED	450.00	2	900.0	GLOBE - GUIDED	450.00	1	450.0	GLOBE - GUIDED	450.00	1	450.0
Total L/D				Total L/D				Total L/D			
900.0				450.0				450.0			
FITTING TYPE				FITTING TYPE				FITTING TYPE			
STANDARD T FLOW IN RUN	20.00	1	20	T 100% FLOW OUT TO BRANCH	98.00	1	58	T 100% FLOW OUT TO BRANCH	58.00	1	58
STANDARD ELBOW 90°	30.00	1	30	STANDARD ELBOW 90°	30.00	4	120	STANDARD ELBOW 90°	30.00	5	150
Total L/D				Total L/D				Total L/D			
50.0				198.0				208.0			
UNITOP Total L/D				UNITOP Total L/D				UNITOP Total L/D			
950.0				648.0				658.0			

Piping and control valves sizing are to be checked for acceptability based on supplying the heaters with the thermal ratings as shown in the model diagram. The maximum heating duties attainable with the pipe network design are to be determined.

The piping network is to be analysed for potential bottlenecks that could occur as a result of plant changes or future expansion.

CHEMCAD MODEL

For practice you can build the model or use the model called “**Piping Distribution Dynamics**” in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the piping schematic.



MODEL CONFIGURATION

This model introduces the concept of Dynamic Pressure Nodes which are used to drive the piping network to a mass and pressure balance. The basic principle is that flows in the Upstream and Downstream UnitOps are adjusted by Nodes until the Stream pressures converging at junctions are equal. The only UnitOps that can be used to adjust flow in this manner are Pipe(in Sizing Option 5), Control Valve and Pump with characteristic curve. The Nodes inserted between these types of UnitOp are set for Flow Set by Upstream and Downstream UnitOps.

The network inlet and outlet conditions are fixed by the Node as a Free Inlet or Outlet stream at a Fixed Pressure which sets the basis for the network calculations. For more details on the use of Nodes in pipe networks refer to P&I Design Ltd document MNL063B.

The Control Valves are in Manual position mode with the flowrate adjusted (by a Node) for a fixed valve position(set by Ramp).

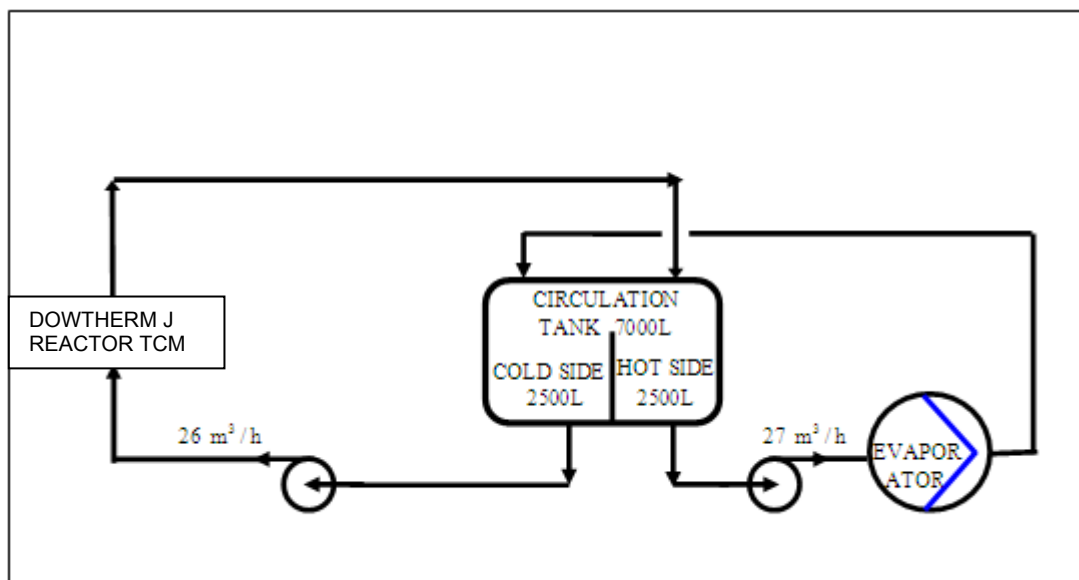
RESULTS

The maximum capacity of the network is determined by using the Ramps to drive the control valves to 100% opening giving maximum flow conditions. This allows the prediction of maximum heating duty for each branch and the investigation of any flow restrictions that might occur in the network.

CHEMCAD 6.0 DYNAMIC APPLICATIONS – CRYOGENIC REACTOR SYSTEM

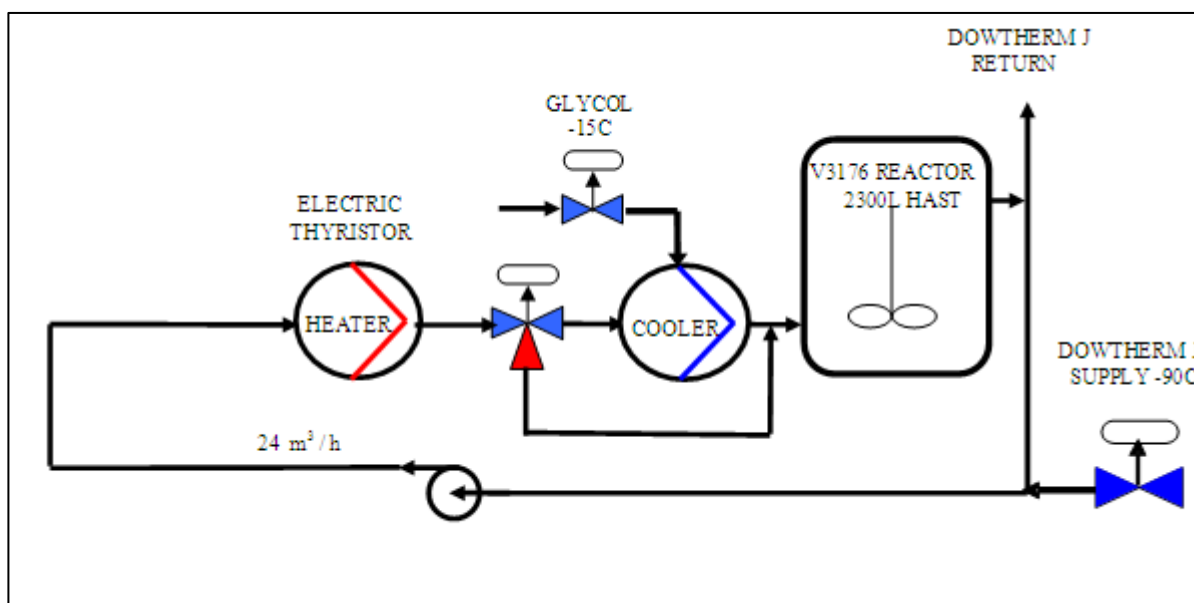
PROCESS DESCRIPTION

The process scheme consists of a Dowtherm J circulation system operating at a nominal temperature of -90°C and a flow of $27\text{ m}^3/\text{h}$. The low temperature refrigeration plant evaporator is located in the recirculation line as shown in the schematic. The hot/cold side arrangement provides a cold reservoir of Dowtherm J, which protects the evaporator from high jacket return temperatures and maintains a constant flow across the evaporator. Plant supply will be pumped, at a nominal flow of $26\text{ m}^3/\text{h}$, from the cold side with return to the hot side. This arrangement minimises the impact of hot process return temperatures on refrigeration unit performance and provides a constant flow through the evaporator.



Reactor temperature control module (TCM) consists of a thyristor controlled electric heater, to avoid freezing problems, and cooler with service of 50% ethylene glycol/water at -15°C . Dowtherm J is circulated through the reactor jacket and half-coils in series at a constant flow rate of $24\text{ m}^3/\text{h}$ to ensure acceptable velocity for heat transfer.

The system was simulated with the circulation tank containing a Dowtherm J charge of 5000L at a temperature of -90°C . The reactor contents were set at -10°C and the reactor contents TIC set point was set at -80°C . The evaporator heat duty was calculated on the basis of achieving a constant off coil temperature of -90°C throughout the simulations. The reactor was charged with 2050 L of THF giving an initial heat transfer area (HTA) of 6.0 m^2 .



CHEMCAD MODEL

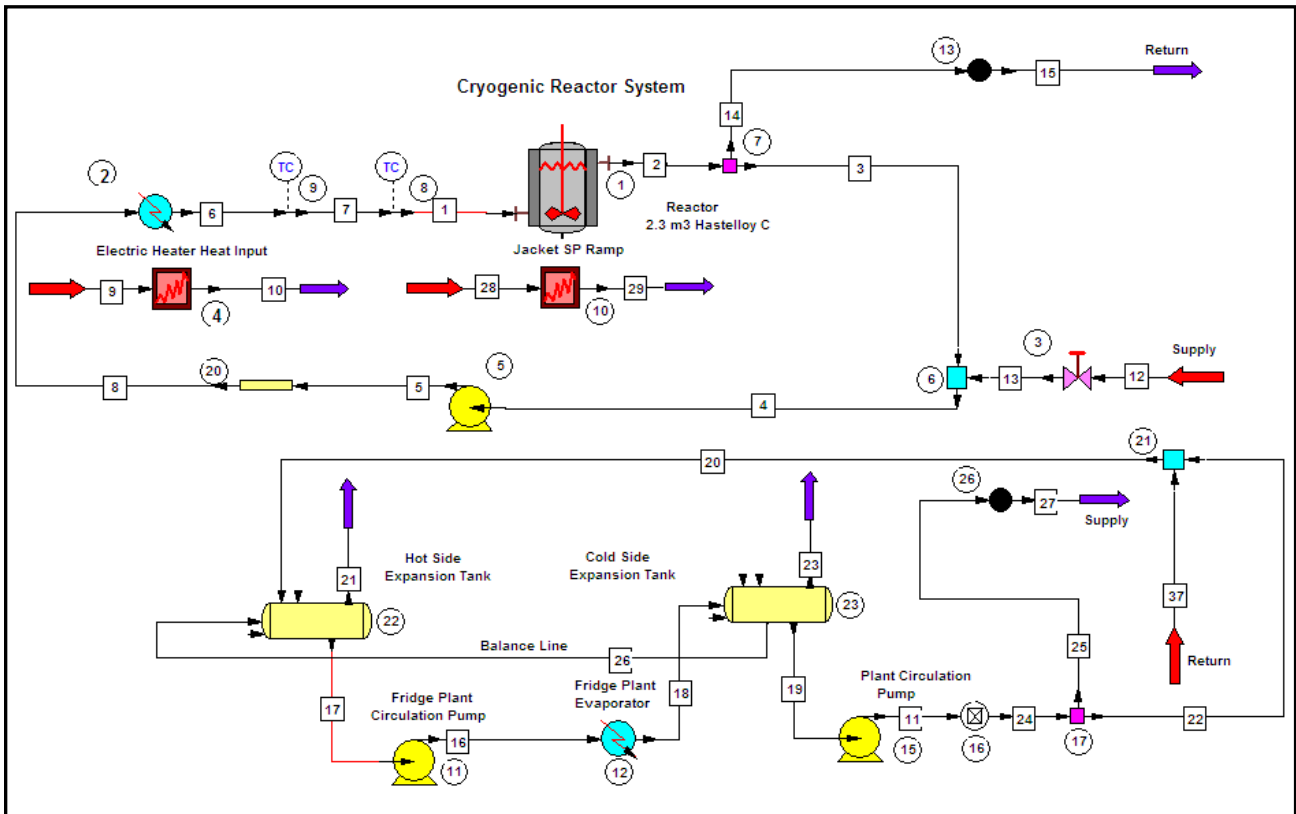
The following points have been considered in the design:

Refrigerant proposed R23

Evaporator temperatures on at -85°C off at -90°C

Cooling duty specified to be based on Dowtherm J at design evaporator conditions

For practice you can build the model or use the model called “**Cryogenic Reactor System**” in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the plant schematic.



The circulation flow is maintained constant in the recirculation loop regardless of the coolant injection flowrate. The recirculation loop is incompressible. Whatever flow there is into the loop the same flow must leave the loop. This is achieved by referencing the coolant Control Valve 3 mass flowrate transfer to Divider 7 Output Stream 14, the outlet stream.

The reactor process temperature schedule is achieved by setting the controller set point.

MODEL CONFIGURATION

The specifications for the UnitOps are presented in the tables following:

Heat Exchanger UnitOps Specifications				
UnitOp	OHTC	Area	Tubeside ΔP	Shellside ΔP
	W / m ² °K	m ²	bar	bar
Heat Exchanger 15	800	5		

Control Valve UnitOps Specifications						
UnitOp	Type	C _v	Fail & Signal Action	Rangeability	Critical Flow Factor	Downstream P
			mA			bar
Control Valve 10	Linear	21	Close 12(CI) – 20(Op)	50:1	0.98	Jacket Inlet
Control Valve 3	Linear	7	Open 4(Op) – 12(CI)	50:1	0.98	3.0
Control Valve 4	Linear	14	Close 4(CI) – 20(Op)	10:1	0.98	9.0

Mass Flowrate Transfer Option is used by Control Valve 10 to Divider 11 Output 2 (Stream 6) and Control Valve 3 to Divider 7 Output 1 (Stream 11) with both control valves being assigned to Controller 9. Control Valve 4 is assigned to Controller 13. Forced forward flow option is selected.

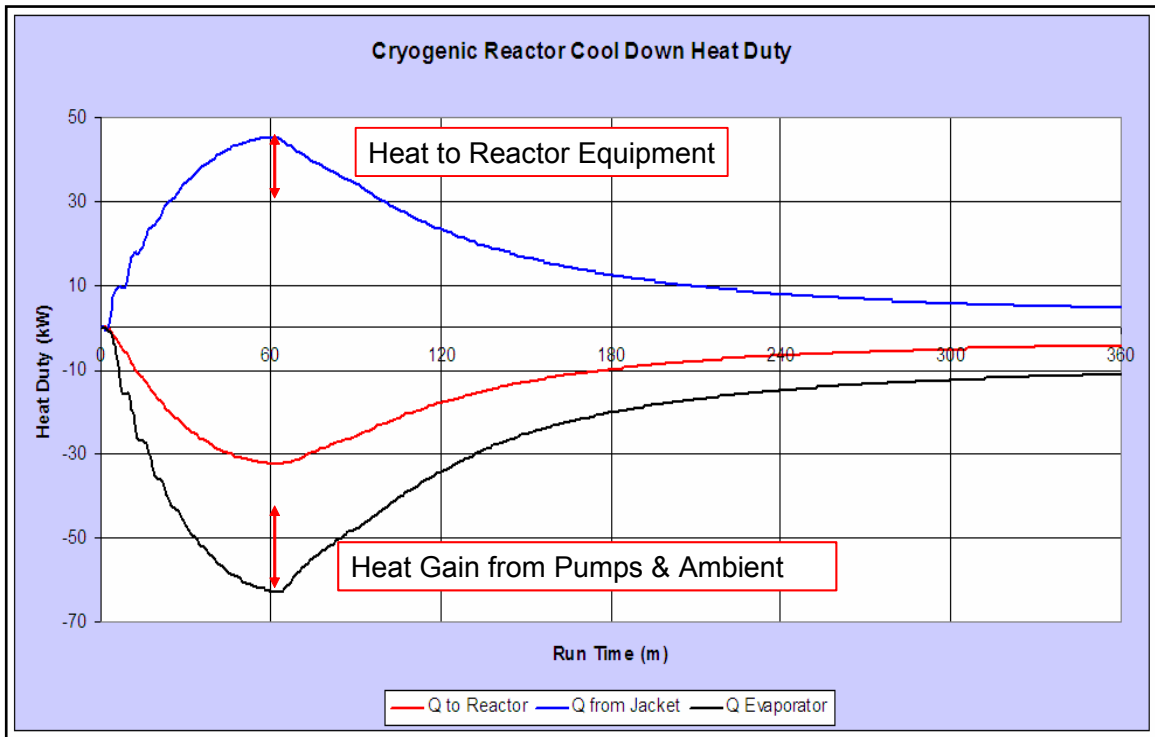
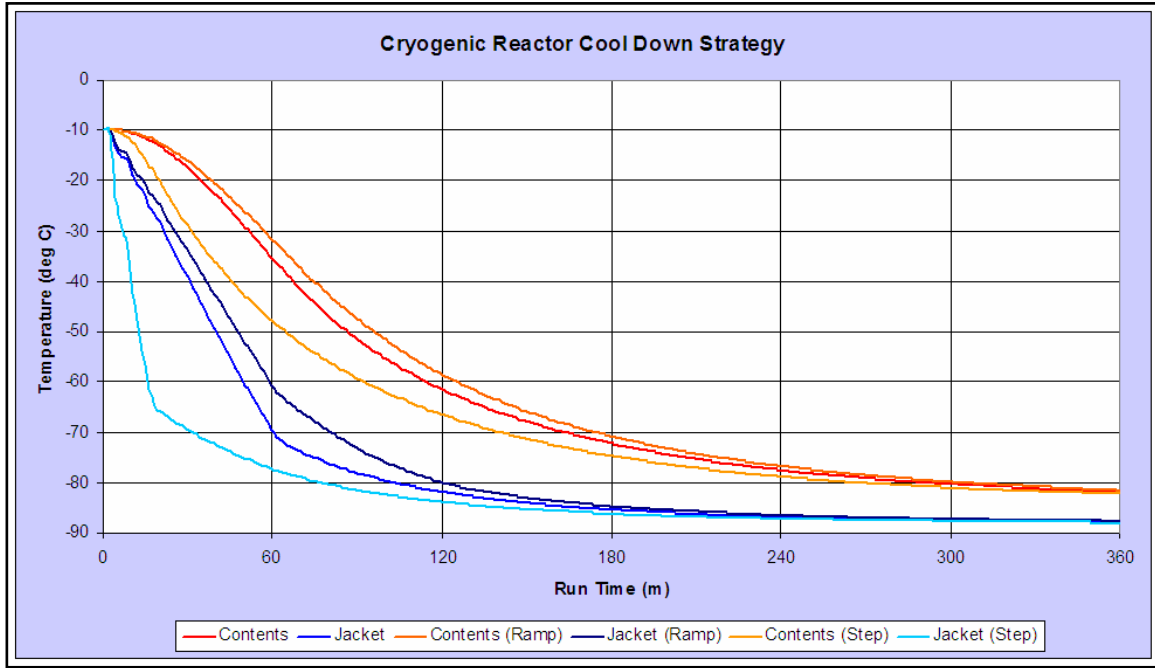
Controller UnitOps Specifications								
UnitOp	Measurement			Action	Set Point	Tuning Parameters		
	Object	Range °C (mA)	Type			P %	I min	D min
Controller 13	St 19 Vapor wf	0 (4) to 1.0 (20)	Linear	Reverse	0.3 wf	150		
Controller 8	Unit 1 Temperature	-40 (4) to 180 (20)	Linear	Reverse	50 °C	100	15	5
Controller 9	Str 1 Temperature	-40 (4) to 180 (20)	Linear	Reverse	20 °C	15	5	

The batch reactor is entered as a Pfaudler BE6300 Glass Line reactor providing automatic entry of all required parameters.

Initial wall temp.	<input type="text" value="20"/>	C		
Reactor volume	<input type="text" value="6.30"/>	m ³	# of jackets and coils	<input type="text" value="1"/>
Reactor diameter	<input type="text" value="1.96"/>	m	Base volume	<input type="text" value="0.80"/>
Wall thickness	<input type="text" value="0.02"/>	m	Base area	<input type="text" value="3.96"/>
Wall density	<input type="text" value="8000.00"/>	kg/m ³		
Wall cp	<input type="text" value="1.4019"/>	kJ/kg-K	Optional for semi-batch	
Wall therm. cond.	<input type="text" value="10.56"/>	W/m-K	Holdup	<input type="text" value=""/>
Wall volume	<input type="text" value="0.42"/>	m ³		

Jacket type: <input type="text" value="Agitating Nozzle"/>	Initial conditions	ID: 1
Jacket total volume <input type="text" value="0.676"/> m ³	Pressure <input type="text" value="3"/> bar	
Jacket height <input type="text" value="2.23425"/> m	Temperature <input type="text" value="20"/> C	
Jacket annulus <input type="text" value="0.036"/> m	Initial liquid fraction <input type="text" value="1"/>	
Circ. nozzle diameter <input type="text" value="0.038"/> m		
Number of inlet nozzles <input type="text" value="3"/>	Jacket Flow (Suggested) <input type="text" value="23"/> m ³ /h	
Nozzle type <input type="text" value="Low Flow"/>		
Heat transfer specifications	Optional heat transfer to ambient	
Active area	Ambient area <input type="text" value=""/>	m ²
Reactor volume	Heat transfer coef. <input type="text" value=""/>	W/m ² -K
Minimum <input type="text" value="3.96"/> m ²		
Maximum <input type="text" value="18"/> m ²		
Utility stream definition	Utility origin	Optional Heat Transfer Coef.
Utility stream 1 <input type="text" value="Stream 1"/>	Stream ID <input type="text" value="2"/>	<input type="text" value=""/>
Utility stream 2 <input type="text" value="None"/>	<input type="text" value=""/>	W/m ² -K
Utility stream 3 <input type="text" value="None"/>	<input type="text" value=""/>	W/m ² -K
	Jacket fouling factor <input type="text" value=""/>	m ² -K/W
	Pressure drop <input type="text" value=""/>	bar

RESULTS



Based on the simulation results, shown following, a refrigeration plant to achieve a process cooling capability of 50 kW with a Dowtherm J on temperature of -85°C and off temperature of -90°C is design proposed. This duty equates to a Dowtherm J flow of 27 m³/h. It has been estimated that heat loss from equipment and heat input from pumping could be as high as 8.7 kW.

CHEMCAD 6.0 DYNAMIC APPLICATIONS – REACTOR CONTROL WITH REAL OHTC

PROCESS DESCRIPTION

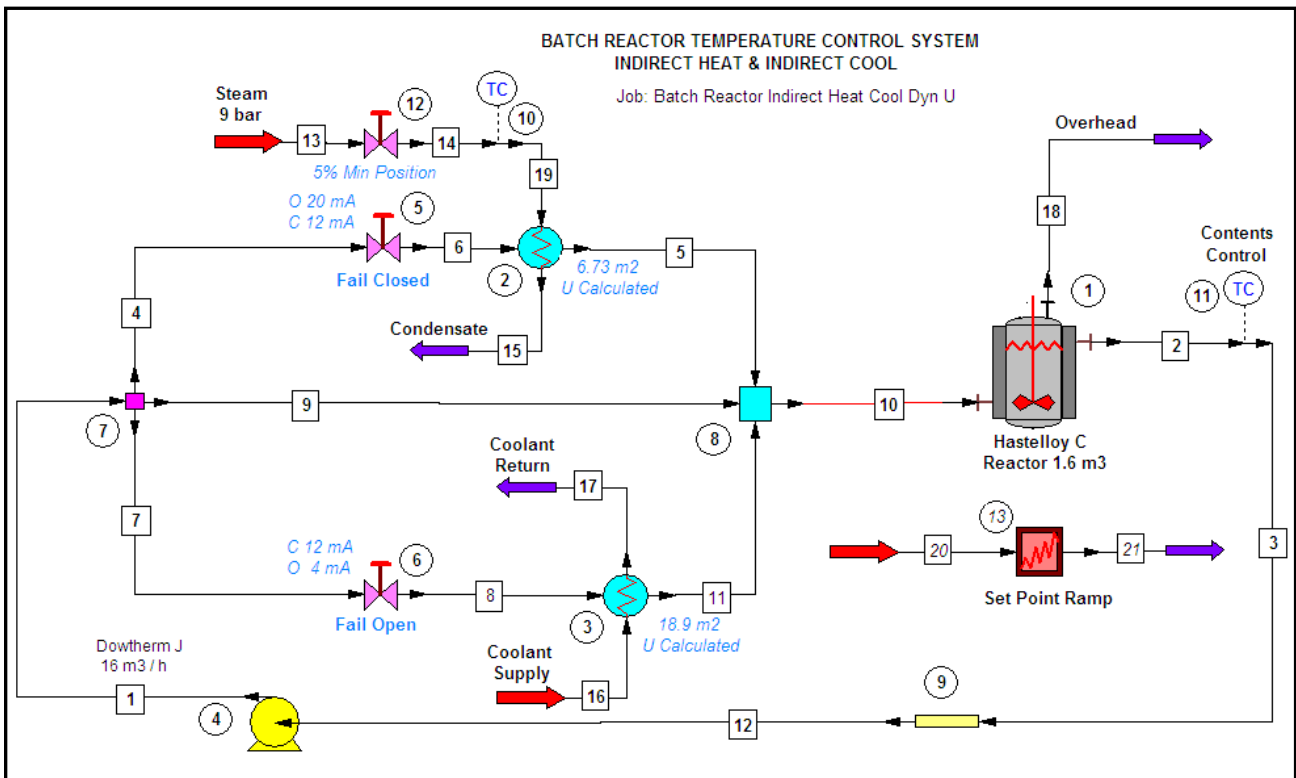
The Batch Reactor System Indirect Heat Indirect Cool studied previously used constant Overall Heat Transfer Coefficients (U values). In reality the U values are dependent on operating velocity and temperature dependent viscosity. The preferred heat exchanger in this application is the Shell and Plate which uses manufacturer’s proprietary information for predicting the U values. The manufacturer can issue a data matrix giving U values at different flows and temperatures, see below.

PLATE & SHELL COOLING OHTC PREDICTION				PLATE & SHELL HEATING OHTC PREDICTION									
Predicted OHTC	200	Row	Column Ref	Predicted OHTC	140	Row	Column Ref						
Operating Temperature	20.0		1	Operating Temperature	110.2		4						
Operating Flow	1138.0		1	Operating Flow	12000.0		3						
DATA ARRAY				DATA ARRAY									
				CIRCULATING FLOW (KG/H)									
				1000	5000	10000	15000	20000					
T	20	200	300	400	500	600							
E	30	350	450	550	650	750							
M	40	375	475	575	675	775							
P	50	390	490	590	690	790							
E	60	400	500	600	700	800							
R								20	200	300	400	500	600
A								REFERENCE ROW					

This data can be dynamically linked to the CHEMCAD model using the Data Map facilities.

CHEMCAD MODEL

For practice you can build the model or use the model called “Batch Reactor Indirect Heat Cool Dyn U” in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the plant.



CONFIGURATION AND RESULTS

Refer to P&I Design Ltd paper MNL 062 for further discussion on this model arrangement.

CHEMCAD 6.0 DYNAMIC APPLICATIONS – VOC EMISSION CONTROL

PROCESS DESCRIPTION

It is required to remove volatile organic compounds (VOCs) from a plant extract system. The VOC contamination will consist of mixtures including n-butanol, MIBK and xylene. The maximum inlet concentration, as total VOC, is estimated to be 550 mg/m³. The target design outlet concentrations has been set at 50 mg/m³, with volume referenced to 15°C, with a consent up to 100 mg/m³.

A wet scrubbing system, incorporating a packed tower, is proposed. A packed height of 6m maximum is to be used with operation being based on using fresh scrubbing liquor. The scrubbing liquor to be considered was a vegetable oil. The liquor flow has been set at a nominal 20000 kg/h. Vegetable oil density of 900 kg/m³ gives volumetric flow of 22.18 m³/h.

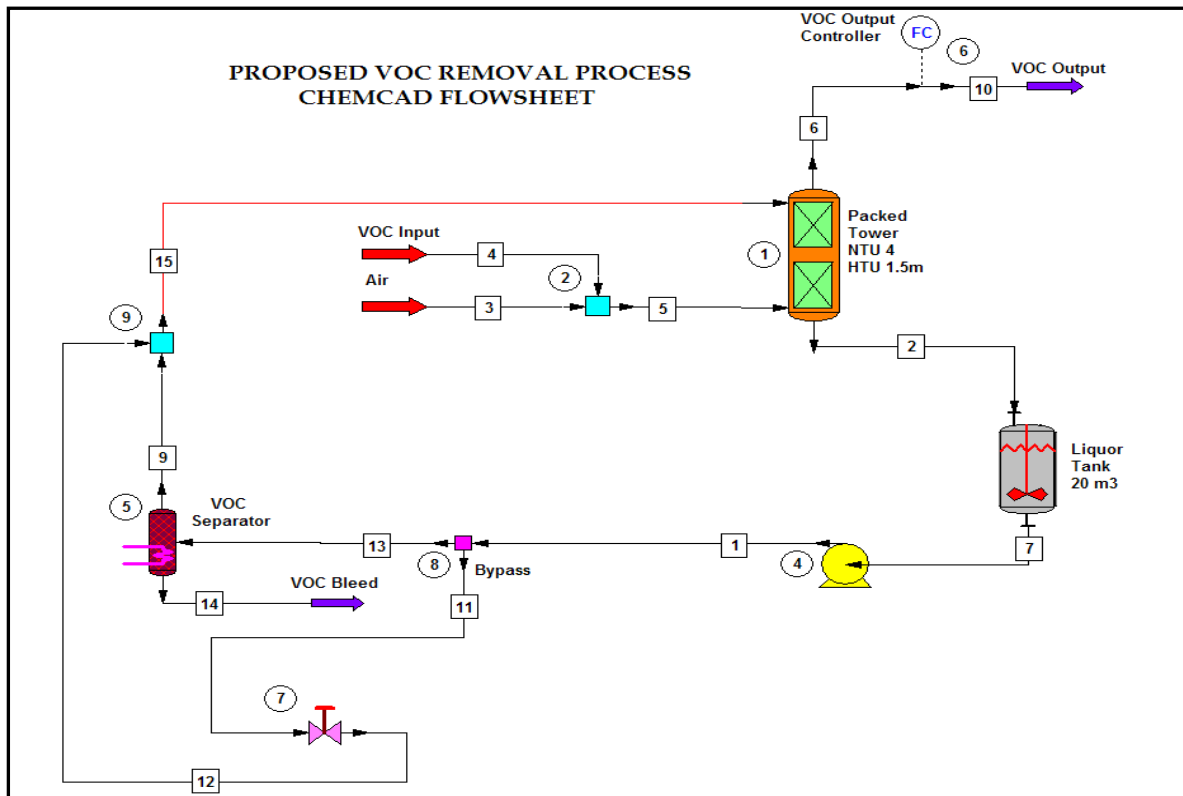
The scrubber design specification is summarised below:

Air flow maximum	72,700 m ³ /h at 15°C and 1.01325 bar
Gas Density	1.2205 kg/m ³
Maximum mass flow	88732 kg/h
Maximum inlet conc.	550 mg/m ³ (=40.00 kg/h)
Design outlet conc.	50 mg/m ³ (=3.635 kg/h)
Allowable outlet conc.	100 mg/m ³ (=7.27 kg/h)

The K-Model selected was modified UNIFAC (Dortmund) which includes temperature dependent interaction parameters. This method uses van der Waals (Q and R) properties which are slightly different to those used in the original UNIFAC method. The main advantages of the modified UNIFAC method are a better prediction of the temperature dependency, real behaviour in the dilute region and more reliable for systems involving molecules very different in size. The H-Model selected was Latent Heat.

CHEMCAD MODEL

The dynamic model called “Emission” controls the VOC emission to atmosphere at the consent flow of 7.27 kg/h for the single component species under consideration by removing dissolved VOC from the system. The VOC input flow was set at 36.35 kg/h (500mg/m³) based on the single component species under consideration with the air flow at maximum design of 88732 kg/h. The separator has a constant VOC bleed split ratio of 0.6 weight basis which applies throughout the simulation. The point at which the VOC bleed rate is increased to control the emission is where the emission curve kicks, namely at 70 min. for N-Butanol and 155 min. for O-Xylene.



MODEL CONFIGURATION

The key aspect of this model is the use of a controller and a component separator to control the concentration of xylene in the emission to atmosphere.

SCDS Distillation Column -

General | Specifications | Convergence | Cost Estimation 1 | Cost Estimation 2

General Model Parameters ID: _____

Condenser type: 0 Total or none

Subcooled delta T: _____ C

Top pressure: 1.01 bar

Cond press drop: _____ bar

Colm press drop: _____ bar

Reflux pump press.: _____ bar

Bottom pump press.: _____ bar

No. of stages: 4

Feed stages:
 Feed stage for stream 15: 1
 Feed stage for stream 5: 4

Simulation model: Regular VLE model

Check here for reactive distillation

Ambient Heat Transfer

Heat transfer area/stage: _____ m2

Heat transfer coeff. (U): _____ W/m2.K

Ambient temperature: _____ C

Optional three phase control:

Use local three phase model

Three phase stage from: _____

Three phase stage to: _____

- Component Separator (CSEP) -

Top stream: 9 Mode: _____ ID: 5

Bottom stream: 14 Mode: _____

Pressure out: _____ bar Pressure drop: 0.1 bar

Split basis: 0 Split fractions

Split destination: 1 Specifications (below) refer to bottom stream

Split Fractions:

Oxygen	_____	Stearic Acid	_____
Nitrogen	_____	Hexadecanoic Acid	_____
N-Butanol	_____	Methanol	_____
Linoleic Acid	_____	O-Xylene	0.6
Oleic Acid	_____	Ethyl Acetate	_____

- PID Controller -

Specifications | Misc Settings

Activate controller ID: 6

Set point: 0.067 Controller / Sensor Function: 0 Linear function

Control terms

Steady state output (P0): 16.9041

Proportional band (PB): 10

Integral time (Ti): 5 min

Derivative time (Td): _____ min

Sensor equation terms

Variable Min: 1e-006

Variable Max: 1

Ctrl input min: 4

Ctrl input max: 20

Control Valve or Controller ID

Control valve ID: 7 or Cascade ID: _____ Primary ID: _____

Controller action (error definition)

Direct (error = X - Xset)

Reverse (error = Xset - X)

Measured Object

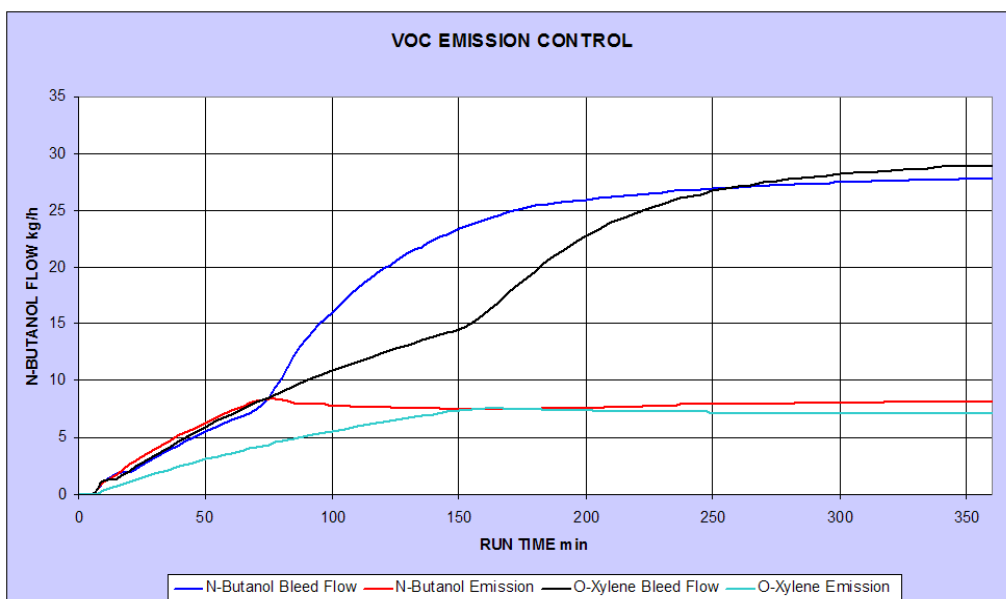
Stream ID number: 6 Variable: Comp mole rate

Equipment

Component: 9 O-Xylene Variable unit: 1 Mole/Mass

RESULTS

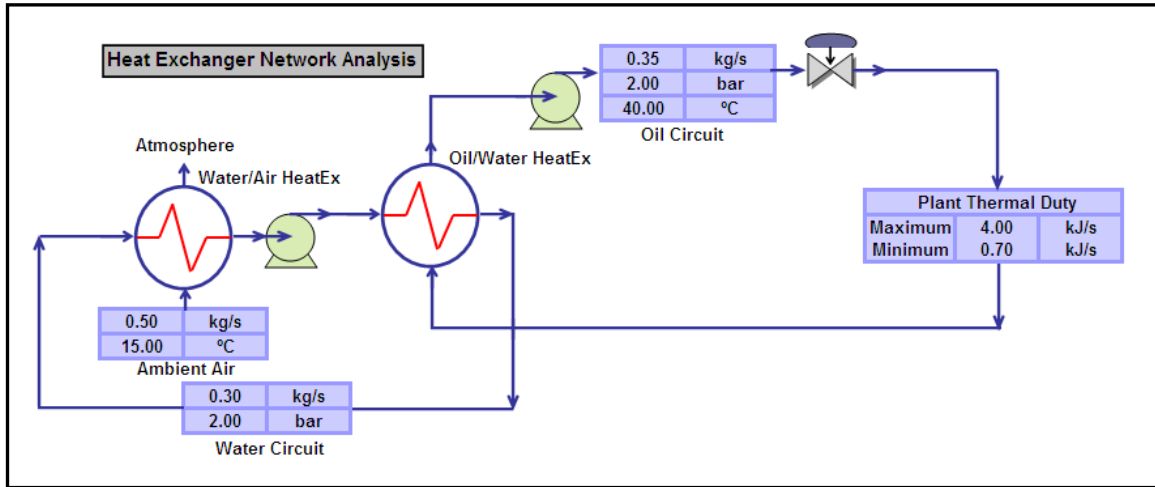
The dynamic simulation results shown in the curves below demonstrate that continuous recirculation without removal of some of the dissolved VOC will result in consent level non-compliance.



CHEMCAD 6.0 DYNAMIC APPLICATIONS – HEAT EXCHANGER NETWORK ANALYSIS

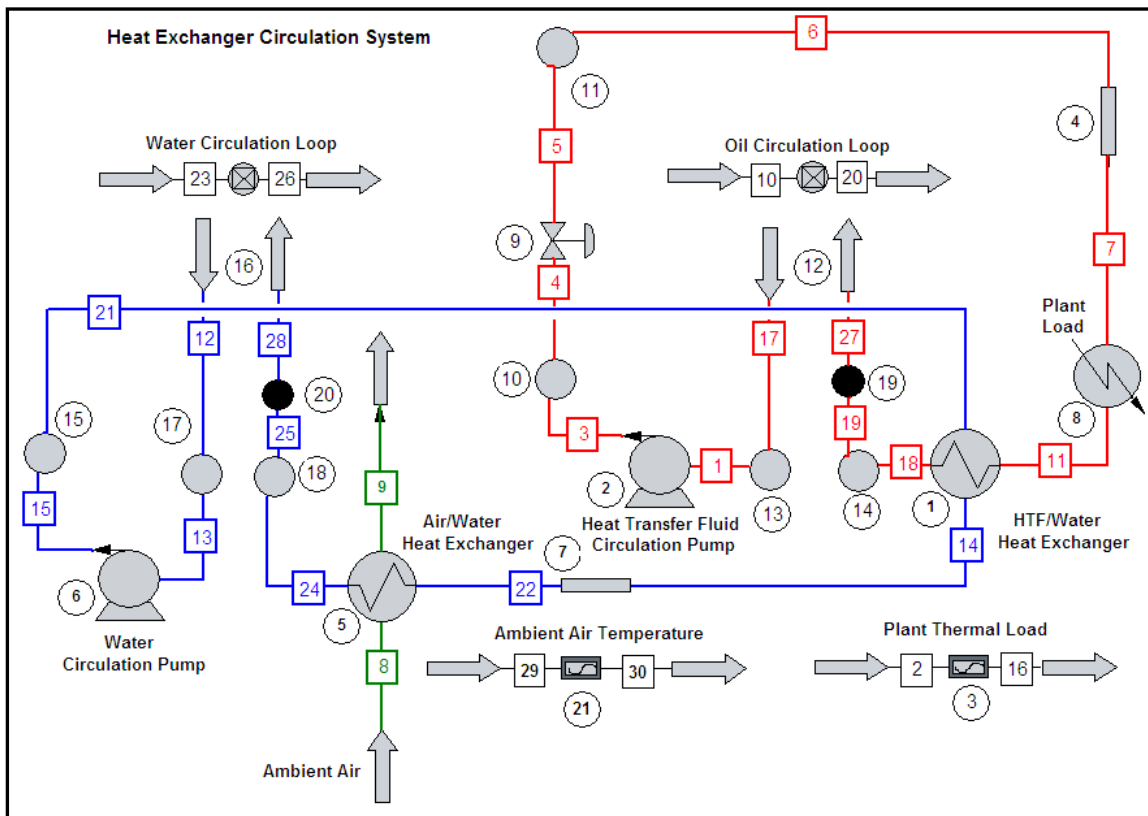
PROCESS DESCRIPTION

The heat exchanger network, together with key parameters, is shown in the diagram below:



CHEMCAD MODEL

For practice you can build the model or use the model called “Heat Exchanger Circulation System” in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the network.



MODEL CONFIGURATION

The key to this model is the handling of the recycle streams. If the recycle streams were connected the recycle calculation would continue to increase the pressure on each iteration and convergence would result with an unrealistically high pressure.

This configuration uses Pressure Nodes to fix the Inlet and Outlet pressures. A Controller, set in Feedforward mode, is used to transfer the Outlet Node pressure to the Inlet Node pressure. The Stream Reference UnitOp transfers all Stream properties, with the exception of pressure which is overwritten, from the Outlet Stream to the Inlet Stream. See below:

Oil Circulation Outlet Node

Oil Circulation Inlet Node

Oil Circulation Stream Reference

Oil Circulation Feedforward Controller

Oil Circulation Pump Curve

Performance Curve			
	Flow (m3/h)	Efficiency	Head (m)
1	0.12	0.85	18.2
2	0.24	0.85	17.4
3	0.36	0.85	16.8
4	0.48	0.85	16
5	0.6	0.85	15.4
6	0.72	0.85	14.9
7	0.84	0.85	14.1
8	0.96	0.85	13.3
9	1.08	0.85	12.5
10	1.2	0.85	11.4
11	1.32	0.85	10.001
12	0	0	0

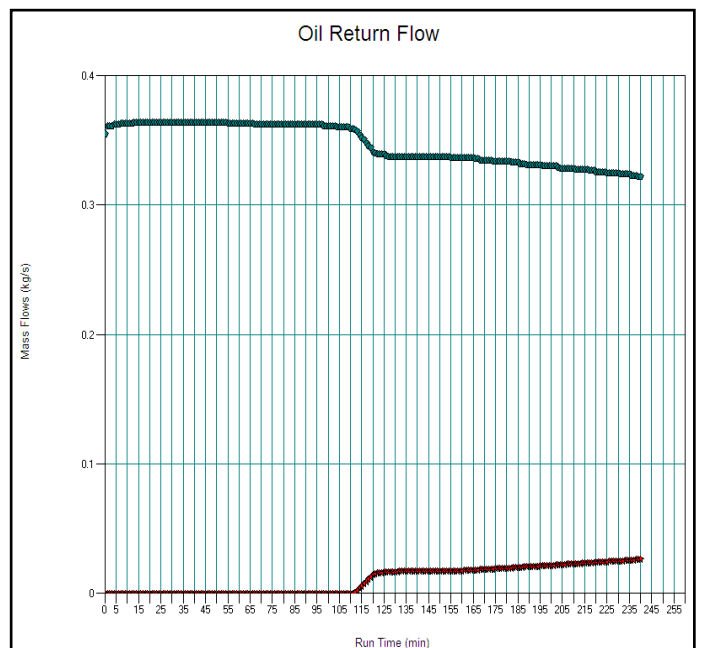
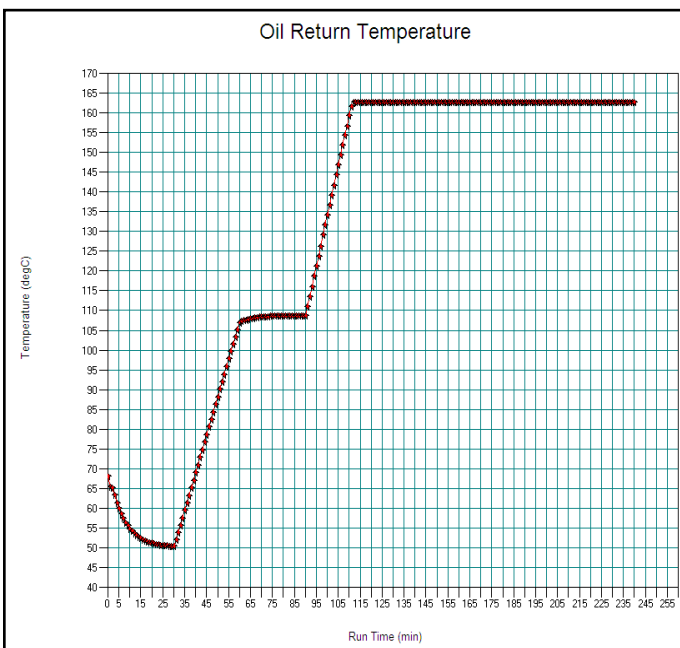
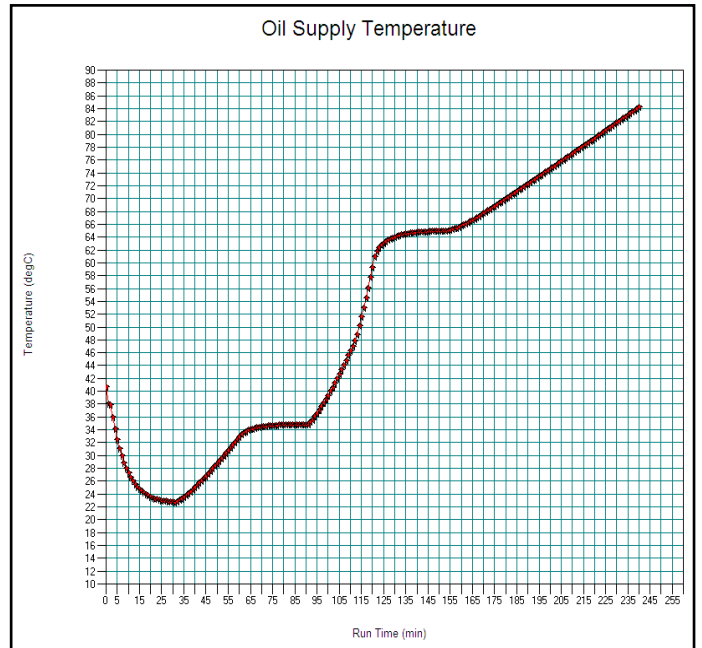
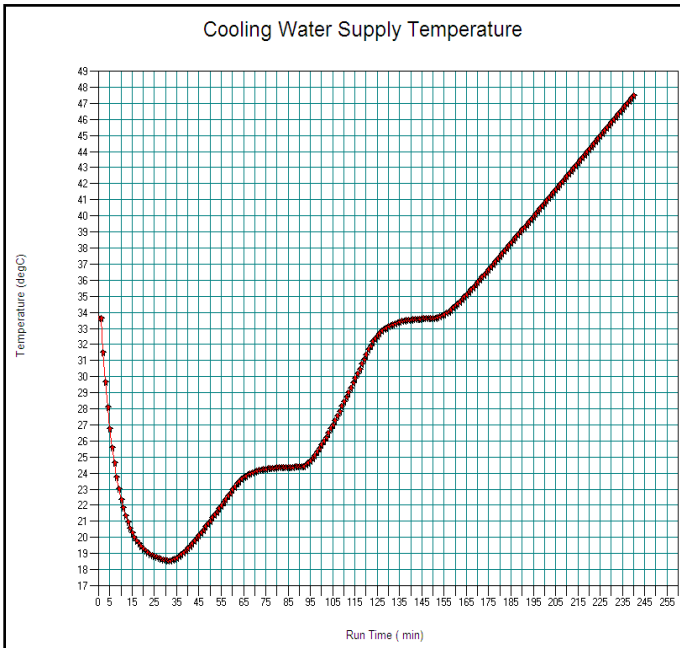
Water Circulation Pump Curve

For more details on the use of Nodes in pipe networks refer to P&I Design Ltd document MNL063B.

RESULTS

The Plant Load thermal duty is adjusted from 0.7 kJ/s to 4 kJ/s using Ramp UnitOp 3 and the Ambient Air temperature is adjusted from 15°C to 30°C using Ramp UnitOp 21 according to the following schedule.

Run Time	Plant Duty	Air Temperature
min	kJ/s	°C
0	0.7	15
30	0.7	15
60	2.0	15
90	2.0	15
120	4.0	15
150	4.0	15
240	4.0	30



The results show that two phase flow is taking place in the oil return header from the plant which is the reason for the constant temperature condition after 115 min. This demonstrates that the system pressure needs to be increased.