COMPUTER SIMULATION OF SULPHURIC ACID PLANTS

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For:

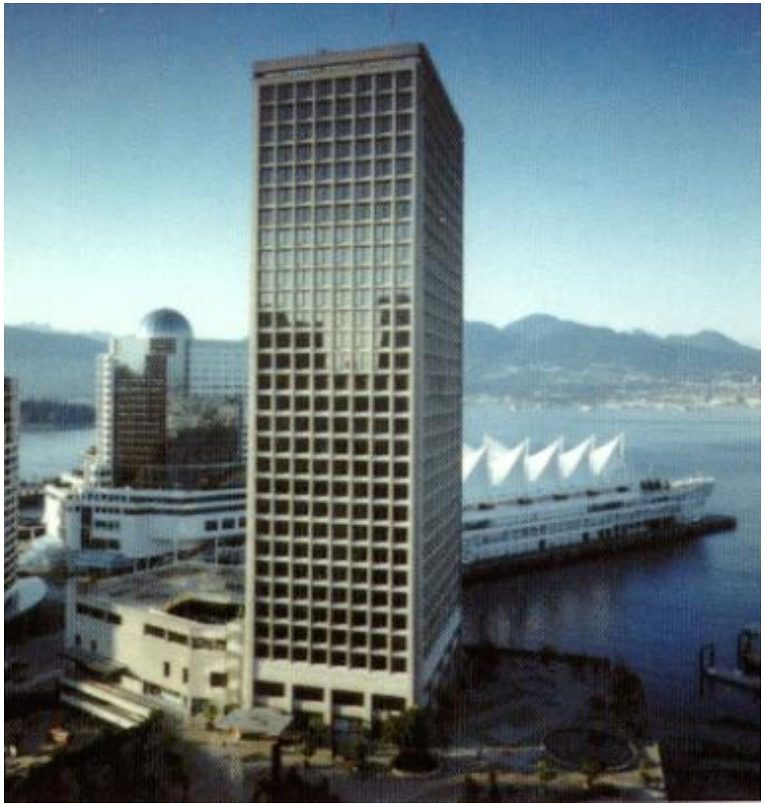
Lead Zinc Sulfuric Acid Short Course

October 3, 2010,
Vancouver, BC

Agenda

- Why Simulate Your Plant
- Challenges
- History
- Tools Available
- Modeling an Acid Plant (steady-state)
- Dynamic Modeling
- Summary

Who is NORAM?



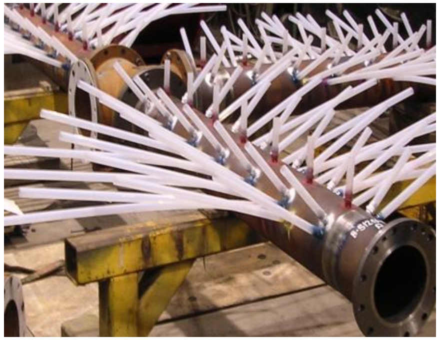
- Based in Vancouver
- Founded in 1988
- 100 employees – chemical and mechanical
- Performed over 144 acid plant studies
- Supplied over 150 acid plant components
- Own a fabrication shop, 80 employees
- Licensor to Simon Carves UK -

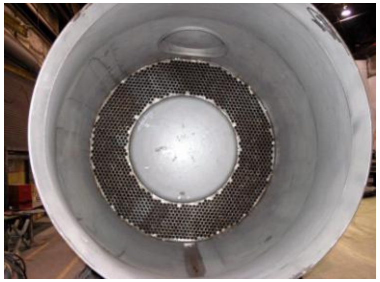
  450 mtpd acid plant UAE
- Licensor to Bateman South Africa –

  Two 2850 mtpd acid plants Madagascar

NORAM's Sulfuric Acid Equipment

Axton Fabrication Shop




2010 Winter Olympics - Vancouver

Why Simulate Your Acid Plant ?

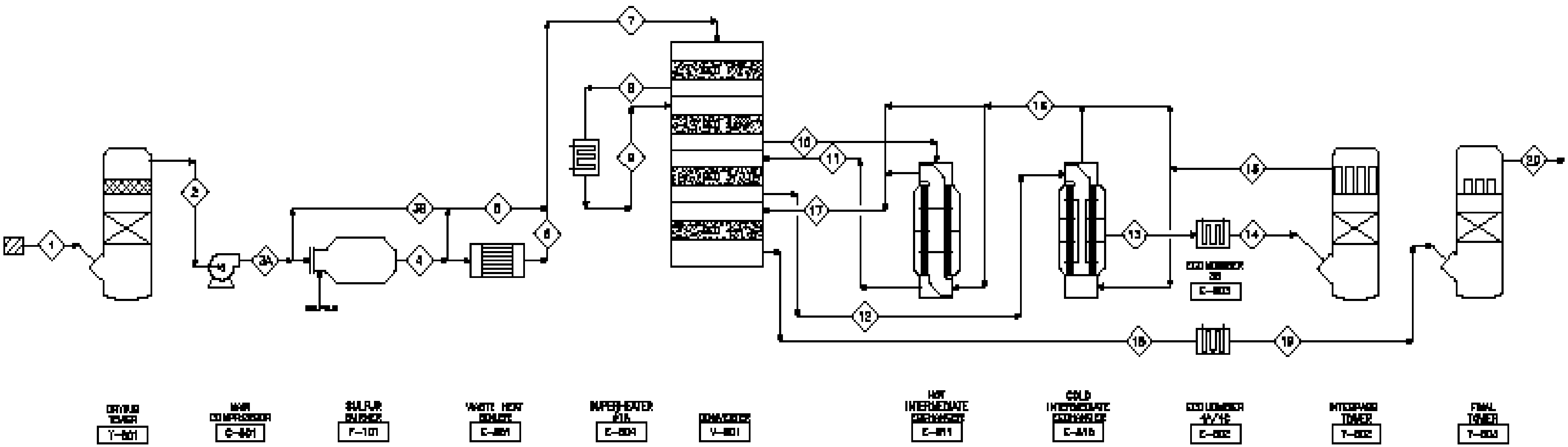
- Allows you to change process inputs and see how your plant will perform
- Identify process bottlenecks
- Determine benefits of new equipment
- Confirm accuracy of process measurements
- Improve plant control; parametric analysis

In general, allows a better understand of your acid plant

Sounds great, but… it ain't easy to model and get the above benefits!

Generic Sulphuric Acid Plant

Sulphur Burning



Gas Process Flow Diagram

Challenges in Simulating Your Acid Plant

- Don’t trust all your process readings (some are flakier than others)
- Missing important equipment information
- Don’t know what software to use
- Software may not be easy to use
- Don’t have time

History of Process Simulators

- In-House Process Simulators
  - Popular 1960's-1980's
  - Created by in-house engineers of major oil & gas, chemical companies
  - Ran on computer mainframes

- Simulation Sciences, *Process*, later, *PRO/II*
  - *Process* Ran on Main Frame
  - Appeared on the scene late '70's
  - PRO/II came out about 1990. PC-based batch operation

- Hyprotech, *Hysim*, later *Hysys*
  - First major PC Based Simulation
  - Calgary Based, U of C, appeared in mid '80's
  - Interactive, backward calculation capability gave increased flexibility
  - Hysys introduced in the '90's was Windows version of Hysim
  - NORAM used it for gas side. Acid side done on spreadsheet

History of Process Simulators (cont'd)

- Aspen Technology Inc. *Aspen Plus*, & *Hysys*,
  - Created in 1981. Joint research project MIT and US DOE. Advanced System for Process Engineering (ASPEN)
  - Acquired Hyprotech in 2004 and divested Hysys code to Honeywell (FTC)
  - Offer suite packages
- Honeywell, *UniSim*, formerly *Hysys*
  - Bought the code to Hysys in 2004
  - Markets under the name UniSim
  - Offer suite packages

The suite packages offered include steady state, dynamic modeling, special physical property packages, heat exchangers, pipe pressure drop, plant optimization, basic engineering, … next presentations for sulphuric acid plant courses

Tools Available
(for Process Simulation)

- Commercial Generic Simulators
  - Aspen Hysys, Apen Plus, Honeywell Unisim
  - Need to develop equipment models and select property packages
  - Somewhat flexible for new equipment
  - Lease costs can be high

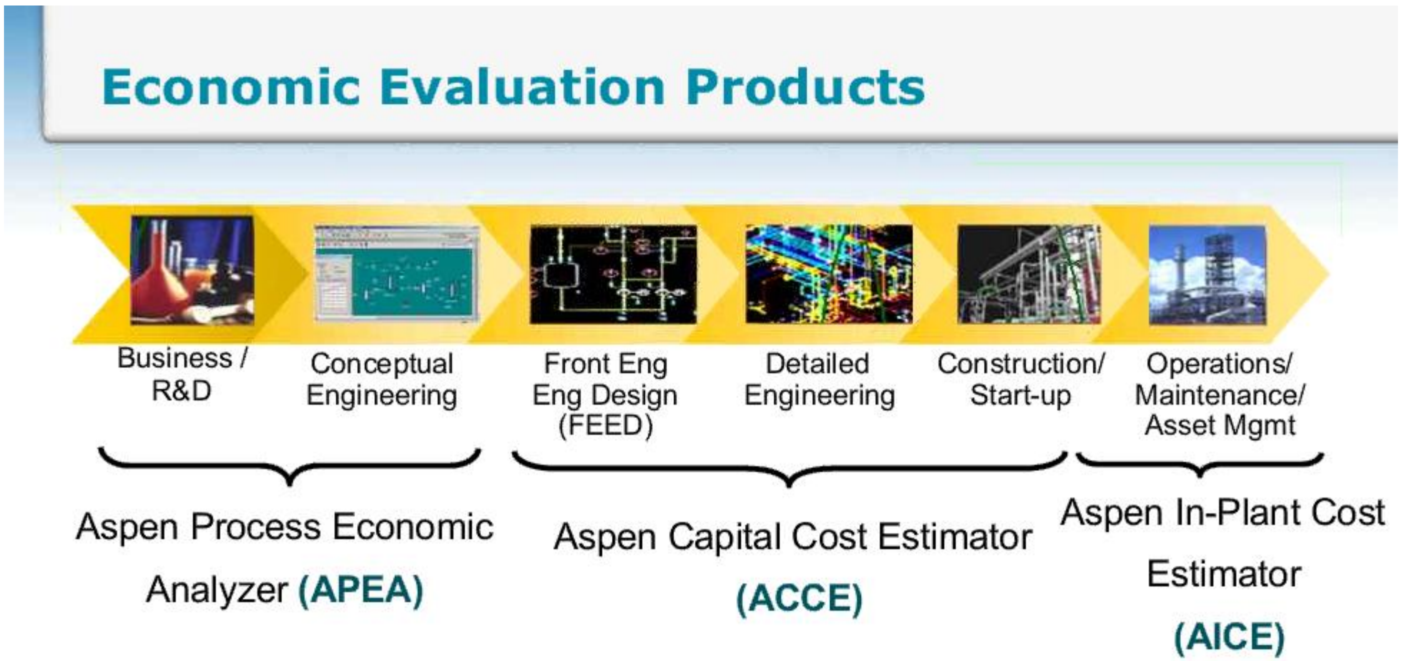
- Third Party Dedicated Software
  - Shiv Shukla, India *Sulphuric*, and others
  - Limited in flexibility
  - Pre-configured
  - Relatively low cost <$2000

Tools Available (cont'd)

(for Process Simulation)

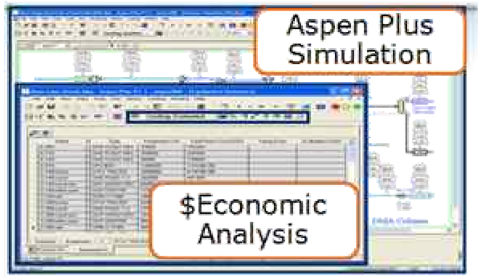
- User Created Spreadsheet Models
  - User creates models of individual equipment or entire acid plant
  - Requires good understanding of unit operations
  - Requires source of physical property data correlations
  - Provides good flexibility in data input/output
  - Requires checking of connectivity
  - Requires good documentation and internal notes for use by others

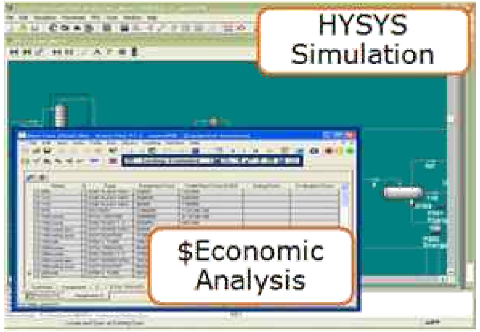
Tools Available (cont'd)
Suite Packages

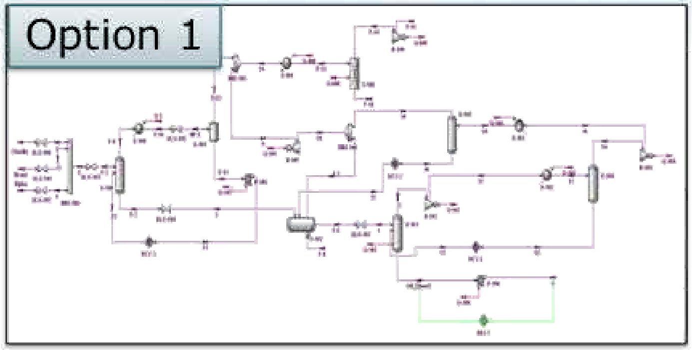


Tools Available (cont'd)
Suite Packages

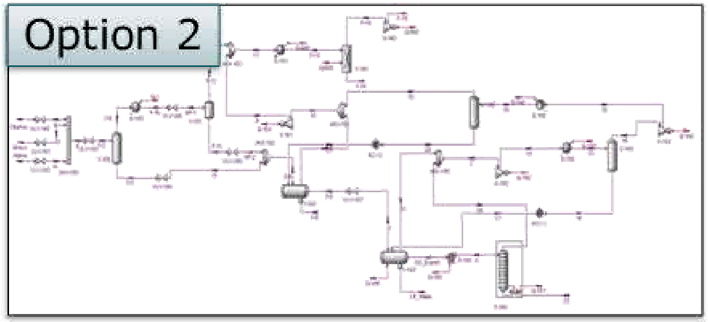
Compare based on Technology & Economics!







Capital = $30M; Operating = $13M/yr



Capital = $28M; Operating = $11M/yr

Tools Available (cont'd)
Hysys vs Aspen Plus

Aspen HYSYS Benefits

Aspen HYSYS is a proven, industry-standard solution with over twenty years of use in the field. Customers have recognized and reported:

- $15 million per year in incremental profitability from process optimization
- $10 million per year in capital savings resulting from improved designs
- $1 million per year of reduced engineering cost

Aspen Plus is a proven, industry-standard solution with over twenty years of use in the field. Customers have recognized and reported:

- $15 million per year in incremental profitability from process optimization
- $10 million per year in capital savings resulting from improved designs
- $1 million per year of reduced labor costs from improved conceptual engineering workflow

Physical Property Prediction

- Important part of simulation is ensuring accurate physical property prediction
- In simple terms, Equations of State are formula and coefficients used to predict component and stream physical properties under varying conditions
- For sulphuric acid plants, gas, steam and acid generally use separate equations of state to predict Cp, Volume, Density, conductivity, and so forth

Various Equations of State

1. Overview
2 Historical
 - 2.1 Boyle's law (1662)
 - 2.2 Charles's law or Law of Charles and Gay-Lussac (1787)
 - 2.3 Dalton's law of partial pressures (1801)
 - 2.4 The ideal gas law (1834)
 - 2.5 Van der Waals equation of state

3 Major equations of state
 - 3.1 Classical ideal gas law

4 Cubic equations of state
 - 4.1 Van der Waals equation of state
 - 4.2 Redlich–Kwong equation of state
 - 4.3 Soave modification of Redlich-Kwong
 - 4.4 Peng-Robinson equation of state
 - 4.5 Elliott, Suresh, Donohue equation of state

5 Non-cubic equations of state
 - 5.1 Dieterici equation of state

6 Virial equations of state
 - 6.1 Virial equation of state
 - 6.2 The BWR equation of state

7 Multiparameter equations of state
 - 7.1 Helmholtz Function form

8 Other equations of state of interest
 - 8.1 Stiffened equation of state
 - 8.2 Ultrarelativistic equation of state
 - 8.3 Ideal Bose equation of state

9 Equations of state for solids

Physical Property Prediction (cont'd)

Reference: AICHE Conference, Salt Lake City, UT; 7Nov2007

Summary

- The SO_2-H_2O-H_2SO_4 system in the HyS cycle poses significant modeling challenges
- Existing models for SO_2 solubility in sulfuric acid are deficient
  - Speciation most likely not correct
  - Differences between models lead to different performance predictions for SO_2-handling operations
- Aspen Plus™ modified Oleum model needs three distinct parameter/speciation sets to describe SO_2-H_2O-H_2SO_4 system
  - divided into low-/high-temperature and SO_2 VLE/VLLE regions
  - Good performance within each regime, but discontinuous transitions
- OLI Systems' Mixed Solvent Electrolyte model gives comparable fit
  - No need to change model for temperature, VLLE reasons
  - Can be used as a property option set within Aspen Plus™

Modeling an Acid Plant

Unit Operations

- Sulphur Furnace – Gibbs or Conversion model reactor
- Acid Towers – Component splitter, absorption module
- Blower – Compressor module
- Heat Exchanger/Acid Cooler – Heat exchanger module
  - UA input and predict two temperatures, or,
  - Three of four temperatures are input and fourth predicted
- Converter – Reactor module
  - Conversion. Input conversion.
  - Equilibrium. Input approach to equilibrium

Modeling an Acid Plant

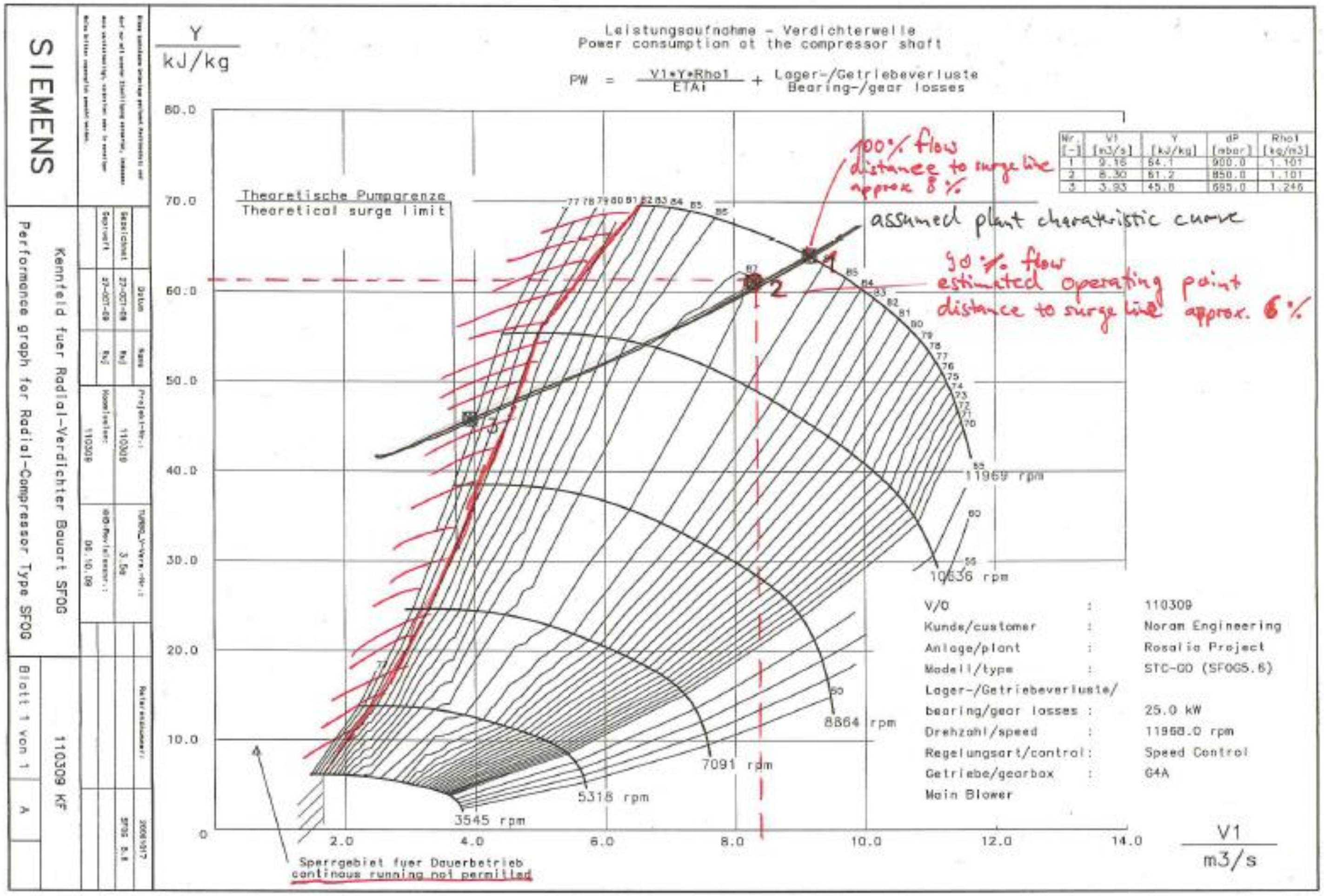
Building a model of the plant

- Get out plant process flow diagrams and piping and instrument diagrams
- Get exchanger drawings or rating sheets
- Take pressure profile and gas flow for starting point of model
- Record temperatures and flows of plant streams
- Enter stream and equipment data
- Model plant

It’s that easy. But most likely not!

Modeling an Acid Plant

Modeling blower performance from blower curve



Modeling an Acid Plant

Custom-built Spreadsheet

- Spreadsheet Set-Up
  - Mass and energy balances are simulated for the equipment components
  - Gas: Cp vs. Temperature for each component is from validated references
  - Acid: Solution enthalpy vs. Concentration and Temperature
  - Water: Cp is from steam tables

$$H = \int_{T_{REF}}^{T} \sum_i (y_i C_{Pi}) dT$$

  - Columns in spreadsheet are for streams
  - Unit operations carried out on the components in the streams
  - For SO2 to SO3 reaction enter approach to equilibrium or conversion

Modeling an Acid Plant (cont'd)

- User Created Spreadsheet Models

C2 | Inlet Air

	A	B	C	D	E	F	G	H	I	J	K	L
1			Extract of Spreadsheet Model of Sulphuric Acid Plant									
2			Inlet Air		X Blower	Dry Air		Furnace	WHB1 By	X WHB1	X Super	Bed 1 In
3			G1		G2	G3		G4	G5	G6	G7	G8
4	Pressure	psig	-0.14		6.20	5.92		5.56	5.56	4.95	4.76	4.73
5		in WC (g)	-4.0		171.9	164		154.1	154.1	137	132	131.0
6		bar a	0.94		1.38	1.36		1.34	1.34	1.29	1.28	1.28
7	Temperature	°F	80		168	175		1,848	1,848	833	750	795
8		°C	26.7		75.7	79.4		1,009	1,008.6	444.9	398.8	424.1
9												424.0
10	SO2	kgmol/hr	0	0.00%	0	0	0.00%	77	3	74	74	77.4
11	SO3	kgmol/hr	0	0.00%	0	0	0.00%	0	0	0	0	0.0
12	H2O_vap	kgmol/hr	21	2.75%	21	0	0.00%	0	0	0	0	0.0
13	O2	kgmol/hr	154	20.37%	154	154	20.95%	77	3	74	74	77.0
14	Ar	kgmol/hr	7	0.91%	7	7	0.93%	7	0	7	7	6.9
15	N2	kgmol/hr	576	75.97%	576	576	78.12%	576	22	553	553	575.7
16	Flow	kgmol/hr	758	100.00%	758	737	100.00%	737	29	708	708	736.9
17		Nm3/hr	16,983		16,983	16,517		16,517	644	15,873	15,873	16,517
18		SCFM	9,996		9,996	9,721		9,721	379	9,342	9,342	9,721
19	Diameter	in	27		27	27		36	18	27	27	36
20	Velocity Head	in WC	0.49		0.39	0.38		0.50	0.01	0.85	0.80	0.29
21	Mole Wt	kg/kgmol	28.66		28.66	28.96		32.33	32.33	32.33	32.33	32.33
22		ACFM	11,780		9,362	9,338		34,565	1,348	19,219	18,163	19,646
23		m3/hr	20,014		15,907	15,865		58,726	2,290	32,653	30,858	33,379
24	Cross sec are	m2										
25	velocity	m/s										
26	Re		6.38E+05	#DIV/0!	5.66E+05	5.47E+05	#DIV/0!	1.86E+05	1.45E+04	3.53E+05	3.71E+05	2.82E+05
27		kg/hr	21,715		21,715	21,340		23,821	929	22,892	22,892	23,821
28	Density	kg/m3	1.09		1.37	1.35		0.41	0.41	0.70	0.74	0.71
29		lb/ft3			0.085	0.084						
30	Viscosity	Pa s	1.75E-05	1.63E-05	1.98E-05	2.01E-05	1.65E-05	4.97E-05	4.97E-05	3.34E-05	3.18E-05	3.27E-05
31	Conductivity	W/m K	2.56E-02	2.36E-02	2.91E-02	2.95E-02	2.38E-02	7.30E-02	7.30E-02	4.81E-02	4.58E-02	4.71E-02
32	Heat capacity	kJ/kg K	1.02	#DIV/0!	1.02	1.01	#DIV/0!	1.13	1.13	1.02	1.01	1.02
33	Enthalpy	kJ/kgmol	1,310		2,743	1,585		57,470	57,470	37,731	36,214	37,043
34		kJ/hr	9.93E+05		2.08E+06	1.17E+06		4.23E+07	1.65E+06	2.67E+07	2.56E+07	2.73E+07
35	Duty	kJ/hr	Blower head		1.09E+06	9.11E+05		Heat loss		1.40E+07	1.07E+06	
36	Conversion	Bedwise	Cp	29.2	efficiency			0.5%		1.33E+07	1.02E+06	BTU/hr

Modeling an Acid Plant (cont'd)

- User Created Spreadsheet Models

A1

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		MTPD as 100% H2SO4													
2	10.50%	SO2, Bed 1	Inlet		1/10/2010 13:46										
3	99.60%	Conversion													
4	95.5	kPa Site Pressure													
5			Sulphur	Inlet Air	X Blower	Dry Air	Furnace	WHB1 By	X WHB1	X Super	Bed 1 In	Bed 1 Out	WHB2 By	Bed 2 In	Bed 2
6			S	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G1
7	Pressure	in WC (g)		-4	172	164	154	154	137	132	131	118	118	108	
8	Temperature	F		80	168	175	1,848	1,848	833	750	795	1,118	1,118	869	1,
9	SO2	lbmol/hr		0	0	0	171	7	164	164	171	70	14	70	2
10	SO3	lbmol/hr		0	0	0	0	0	0	0	0	101	21	101	14
11	H2O_vap	lbmol/hr		46	46	0	0	0	0	0	0	0	0	0	
12	O2	lbmol/hr		340	340	340	170	7	163	163	170	119	24	119	9
13	Ar	lbmol/hr		15	15	15	15	1	15	15	15	15	3	15	1
14	N2	lbmol/hr		1,269	1,269	1,269	1,269	49	1,220	1,220	1,269	1,269	260	1,269	1,26
15	Flow	lbmol/hr	171	1,670	1,670	1,625	1,625	63	1,561	1,561	1,625	1,574	323	1,574	1,
16		SCFM		9,996	9,996	9,721	9,721	379	9,342	9,342	9,721	9,420	1,931	9,420	9,
17		ACFM		11,780	9,362	9,338	34,565	1,348	19,219	18,163	19,646	24,573	5,037	21,124	23,
18		lb/hr	5,470	47,874	47,874	47,048	52,517	2,048	50,469	50,469	52,517	52,517	10,766	52,517	52,
19	Density	lb/ft3		0.0677	0.0852	0.0840	0.0253	0.0253	0.0438	0.0463	0.0446	0.0356	0.0356	0.0414	0.0
20	Enthalpy	BTU/lbmol		563	1,179	681	24,708	24,707	16,222	15,569	15,925	16,434	16,434	14,344	14,
21		BTU/hr		9.41E+05	1.97E+06	1.11E+06	4.01E+07	1.57E+06	2.53E+07	2.43E+07	2.59E+07	2.59E+07	5.30E+06	2.26E+07	2.26E
22															

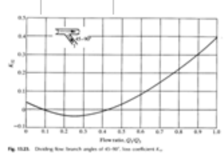
Modeling an Acid Plant (cont'd)

- User Created Spreadsheet Models

D59 =D55/D56

	A	B	C	D	E	F
1	**HIP pro-rating**		**Basis**	Current	Design 1	
2	Production rate	MTPD	175	181.4	58.975	
3	SO2 conc	%	10.51%	10.50%	10.25%	
4	Flow to Bed 1	Nm3/hr	15879	16517	5487	
5	vol. turndown	%	100%	104%	35%	
6	Prod. Turndown	%	100%	104%	34%	
7						
8	Tube OD	in	1			
9	Tube ID	in	0.834			
10	Effective tube length	ft	6.625			
11	Tube #		750			
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23	Tube Re		12137	12114	2751	
36	**Pressure drop**					
37	Tube dP	in WC	4.14	3.76	0.34	
38	Shell dP	in WC	2.24	2.42	0.36	
39	**Heat transfer**					
40	Tube side coeff	BTU/ft2 hr °F	11.71	11.36	3.67	
41	Shell side coeff	BTU/ft2 hr °F	21.05	21.60	11.11	
42	wall resist	ft2 hr °F/BTU	0.00063	0.00063	0.00063	
43	Tube fouling	ft2 hr °F/BTU	0.000	0.000	0.000	
44	Shell fouling	ft2 hr °F/BTU	0.000	0.000	0.000	
45	Tube side resist	ft2 hr °F/BTU	0.085	0.088	0.273	
46	Shell side resist	ft2 hr °F/BTU	0.048	0.046	0.090	
47	U outside	BTU/ft2 hr °F	7.49	7.41	2.75	
48		W/m2 K	42.5	42.1	15.6	
49	Area (out)	m2	121			
50		ft2	1301			
51	LMTD	K	100	128	73	
52	Effectiveness factor		0.979			
53	Effective LMTD	K	98.3	125.8	71.0	
54	**Duty**			226	128	
55	Performance	kJ/hr	1.82E+06	2.30E+06	4.82E+05	
56	Required	kJ/hr	1.69E+06	2.60E+06	5.69E+05	26% (col. K)
57	Safety factor		7.8%	-11.4%	-15.2%	
58	HIP Bypass			7.0%	33.0%	good till 43% bypass at 59MTPD rate and 22/20"ID (and K=8.6)
59	Solver target			0.886	0.848	good till 50% bypass at 59MTPD rate and 22/20"ID (and K=4.6)
60	Bypass ID	in		24	20	good till 55% bypass at 59MTPD rate and 24/22"ID (and K=4.6)
61	Main ID	in		Duct ID	Duct ID	
62	Bypass dP	in WC		0.04	0.17	
63	Main dP	in WC		5.12	0.40	

	H	I	J	K	L	M	N
1	**Bypass pressure balance**						
2	**Bypass**			**Main flow through HIP tubes**			A1/A3 Q1/(
3	Duct ID	22	in	Duct ID	26.875	in	#VALUE!
4	Vel. Head	0.01	in WC	Vel. Head	0.50	in WC	Bypass contrac
5	fittings	#	K-value	fittings	#	K-value	A2/A1
6	inlet nozzle (CIP ves	1	0.5	inlet nozzle (CIP v	1	0.5	1.19
7	damper ca. 55%	1	5	90° elbow, r/d=1	3	0.45	Main line contra
8	90° turn, r/d=1	0	0.7	Total		1.9	A2/A1
9	Total		5.5	dP (section)	0.92	in WC	1.07
10	dP (section)	0.03	in WC	Duct ID	27.75	in	
11	Duct ID	24	in	Vel. Head	0.44	in WC	
12	Vel. Head	0.00	in WC	fittings	#	K-value	
13	fittings	#	K-value	Abrupt contractio	0	0	
14	Abrupt contraction	1	0.06	inlet nozzle	1	1	
15	90° turn, r/d=1	0	1.0	Total		1.0	
16	entry	1	1	dP (section)	0.44	in WC	
17	Total		1.1	tubes	3.76	in WC	
18	dP (section)	0.00	in WC		0.36	in WC : predicted by Gas e	
19	dP TOTAL	0.04	in WC	dP TOTAL	5.12	in WC	
20	**Is Bypas dP < Main dP?**						
21	**YES**						



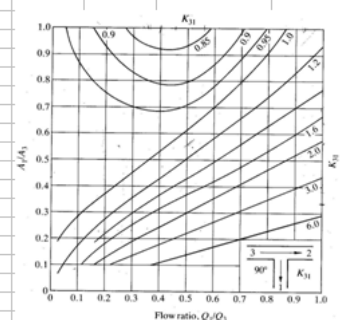


Fig. 13.21'. Dividing flow: branch angle 90°, loss coefficient K_{31}

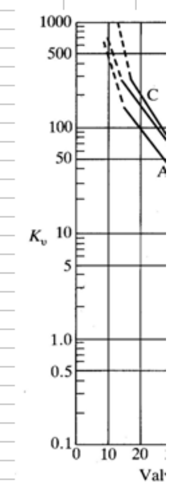


Fig. 14.19. Loss coef

Modeling an Acid Plant (cont'd)

- User Created Spreadsheet Models

Catalyst loads based on Topsoe Performance Prediction of Dec 7, 2009
10.5%SO2, 99.85% conversion
Production 181 MTPD (as 100% acid)
1/10/2010 13:46

Diameter	**12.5** ft						
XS area	**11.4** m2						
	Catalyst vol	Catalyst height	ΔP (incl. inerts)		Gas velocity	Total bed H	
	m3	ft	in WC	mm WC	Sft/min	ft	in
Bed 1	6.60	1.90	2.7	68	79	2.67	8.1
Bed 2	7.40	2.13	2.9	73	77	2.93	11.1
Bed 3	8.40	2.42	3.1	79	76	3.24	2.9
Bed 4	11.40	3.28	3.7	94	67	4.19	2.3
Overall	33.80	**9.73**	**12.4**				

Exsisting catalyst

Diameter	**12.3** ft			
XS area	**10.9** m2			
	Catalyst vo	Catalyst he	ΔP	Gas velocity
	m3	ft	in W.C.	Sft/min
Bed 1	5.67	1.70		82
Bed 2	5.80	1.74		80
Bed 3	7.98	2.39		79
Bed 4	12.00	3.60		70
Overall	31.45	**9.42**	**0.0**	

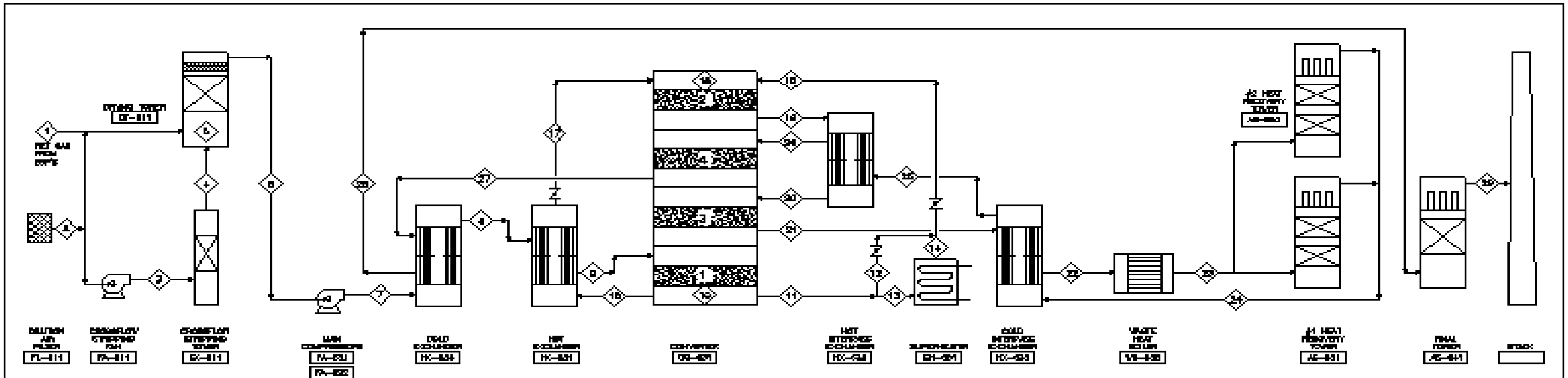
Catalyst loads based on
11%SO2, 99.85% convers
Production 183 MTPD

Diameter	**12.5** ft	
XS area	**11.4** m2	
	Catalyst vo	Catal
	m3	f
Bed 1	6.11	1.
Bed 2	9.17	2.
Bed 3	11.50	3.
Bed 4	10.97	3.
Overall	37.75	**10.**

entry nozzles: ratio 14-20%
exit nozzles: 20%
or 25-33% if tapered outlet nozzle, with no sharp

		Circular	Elliptical/rectang							**Converter diameter [ft]**	
		Diameter	Height	Width	additional	Area	Flow rate	Density	Head	**12.5**	
		in	in	in	height	m2	Am3/h	kg/m3	in W.C.	**Ratio nozzle head to ΔP_{bed}**	
Bed 1	Nozzle A	34				0.59	33379	0.71	0.36	13%	Ratio must be < 20%
	Duct to A	**27**				**0.37**	**33379**	**0.71**	**0.90**	34%	
	Nozzle B	Elliptical	24	48		0.58	41749	0.57	0.45	17%	
	Nozzle B	Rectangular	18	48		0.56	41749	0.57	0.50	18%	
	Duct from B	**27**				**0.37**	**41749**	**0.57**	**1.13**		
Bed 2	Nozzle C	Elliptical	34	34		0.59	35889	0.66	0.39	13%	Ratio must be < 20%
	Nozzle C	Rectangular	18	48		0.56	35889	0.66	0.43	15%	Ratio must be < 20%
	Duct to C	**27**				**0.37**	**35889**	**0.66**	**0.97**		
	Nozzle D	Elliptical	24	48		0.58	39856	0.60	0.43	15%	
	Nozzle D	Rectangular	18	48		0.56	39856	0.60	0.47	16%	
	Duct from D	**27**				**0.37**	**39856**	**0.60**	**1.08**		
Bed 3	Nozzle E	Elliptical	34	34		0.59	34972	0.68	0.38	12%	Ratio must be < 20%
	Nozzle E	Rectangular	18	48		0.56	34972	0.68	0.42	13%	Ratio must be < 20%
	Duct to E	**27**				**0.37**	**34972**	**0.68**	**0.95**		
	Nozzle F	Elliptical	24	48		0.58	36856	0.65	0.40	13%	
	Nozzle F	Rectangular	18	48		0.56	36856	0.65	0.44	14%	
	Duct from F	**27**				**0.37**	**36856**	**0.65**	**1.00**		
Bed4	Nozzle G	Elliptical	34	34		0.59	34931	0.52	0.28	8%	Ratio must be < 20%
	Nozzle G	Rectangular	18	48		0.56	34931	0.52	0.31	8%	Ratio must be < 20%
	Duct to G	**27**				**0.37**	**34931**	**0.52**	**0.71**		
	Nozzle H	Elliptical	24	48		0.58	36673	0.49	0.30	8%	
	Nozzle H	Rectangular	21	48		0.65	36673	0.49	0.24	7%	
	Duct from H	**27**				**0.37**	**36673**	**0.49**	**0.75**		
	Total additional converter height [in]				**0**						

Custom-built Process Simulation



Case 1: Design Rate, Stream 7 Composition

SO2	14.0%
O2	13.8%
CO2	0.6%
N2	71.4%

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Pressure	In WC	−14	−14	2	−14	−14	−26	190	177	166	169	158	168	169	146	146
Temperature	F	112	70	81	160	88	122	230	540	734	1 178	1 178	1 178	1 178	784	797
SO2	NCFM	18 600	0	0	106	19 600	19 555	18 555	19 555	19 565	7 235	3 705	27	3 678	3 679	3 705
SO3	NCFM	0	0	0	0	0	0	0	0	0	12 320	6 309	45	6 263	6 263	6 309
H2O_vap	NCFM	7 154	2 584	313	0	9 738	0	0	0	0	0	0	0	0	0	0
O2	NCFM	2 152	17 208	2 086	2 086	19 380	18 380	16 360	19 380	18 380	13 200	6 780	49	6 711	6 711	6 780
CO2	NCFM	1 080	0	0	0	1 080	1 080	1 080	1 080	1 080	1 080	553	4	549	549	553
N2 & Ar	NCFM	34 853	65 347	7 820	7 920	100 000	100 000	100 000	100 000	100 000	100 000	51 206	366	50 840	50 640	51 206
Flow	NCFM	64 638	65 139	10 318	10 111	149 778	138 885	138 885	139 885	138 885	133 835	68 535	483	68 042	68 042	68 535
Enthalpy	BTU/lbmol	30 012	551	626	1 625	13 332	13 018	13 615	16 192	17 727	18 543	18 543	18 543	18 543	15 162	15 186
	MMBTU/hr	324.19	7.83	1.08	2.78	333.69	304.06	323.21	378.81	414.72	414.72	212.37	1.63	210.84	172.40	173.93

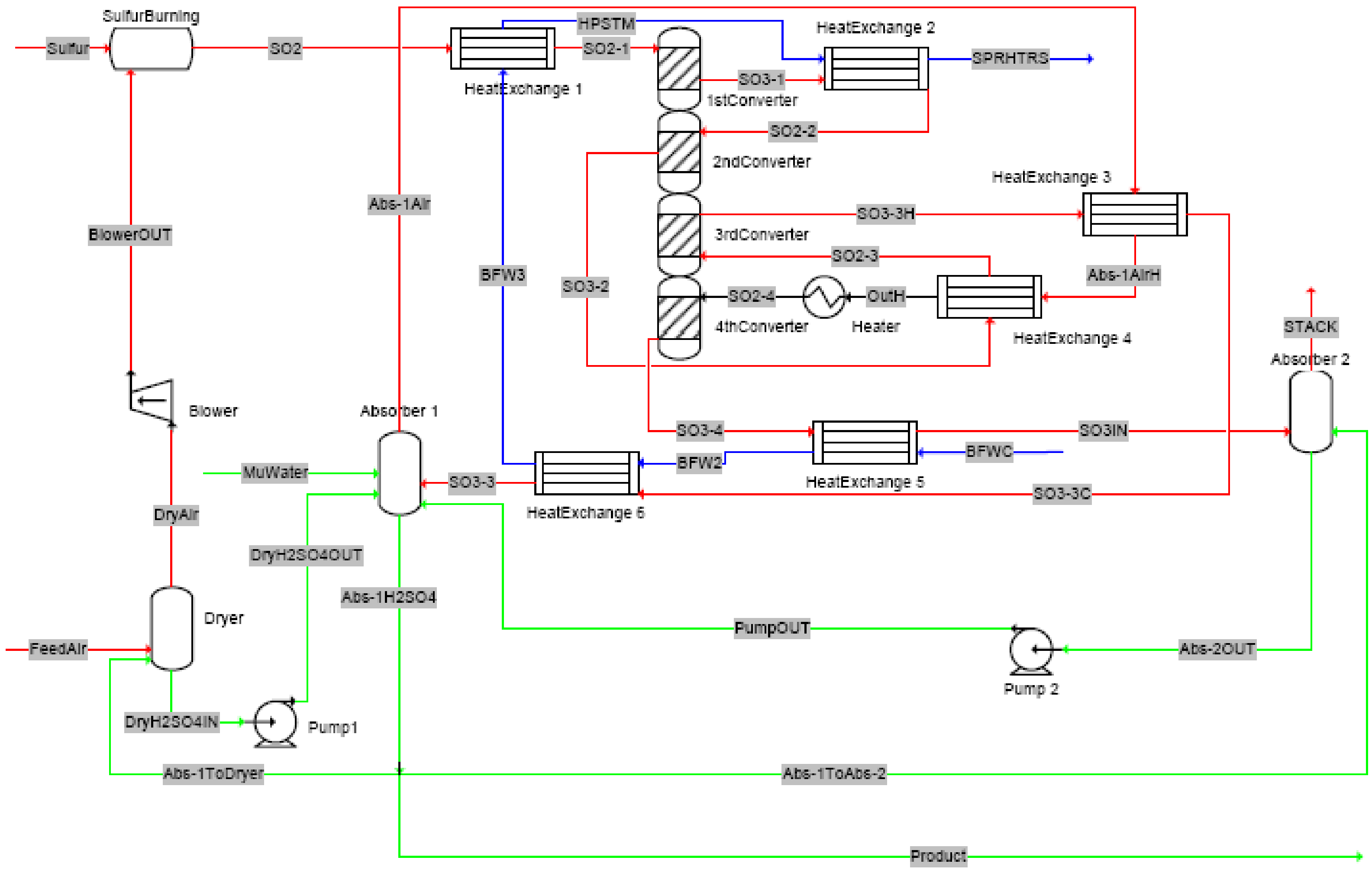
		16	17	18	19	20	21	22	23	24	25	26	27	28	29
Pressure	in WC	158	145	145	138	123	110	104	94	69	61	50	36	26	0
Temperature	F	1 178	787	797	982	787	850	830	450	180	472	734	788	350	180
SO2	NCFM	3 530	3 530	7 235	2 092	2 092	645	645	645	690	690	690	8	8	8
SO3	NCFM	6 011	6 011	12 320	17 463	17 463	18 910	18 910	18 910	95	95	95	777	777	0
O2	NCFM	6 441	6 441	13 200	10 628	10 629	9 905	9 905	9 905	9 905	9 905	9 905	9 584	9 564	9 584
CO2	NCFM	627	527	1 080	1 080	1 080	1 080	1 080	1 080	1 080	1 080	1 080	1 080	1 080	1 080
N2 & Ar	NCFM	48 792	48 792	100 000	100 000	100 000	100 000	100 000	100 000	100 000	100 000	100 000	100 000	100 000	100 000
Flow	NCFM	65 301	65 301	133 835	131 264	131 264	130 540	130 540	130 540	111 770	111 770	111 770	111 428	111 428	110 652
Enthalpy	BTU/lbmol	18 643	15 186	15 186	15 484	13 829	13 906	11 974	10 443	−390	1 822	3 727	3 738	691	−1 069
	MMBTU/hr	202.35	165.72	339.65	339.65	303.35	303.35	261.22	227.82	−7.28	34.03	69.61	69.61	12.87	−19.77

PRELIMINARY

NORAM

KENNECOTT UTAH COPPER CORPORATION

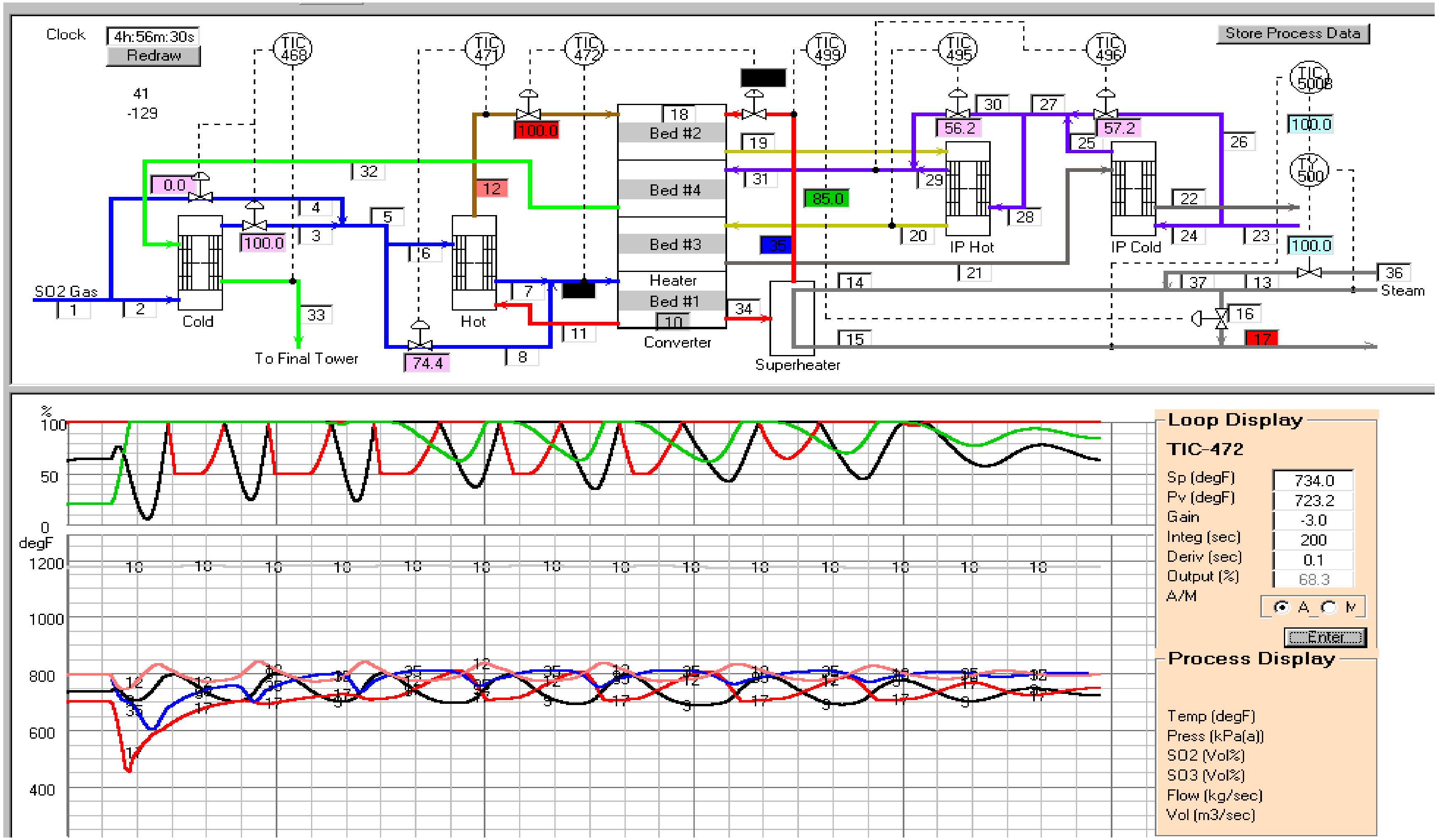
Commercial Simulation Process Flow Diagram



Dynamic Modeling an Acid Plant

- Useful when conditions fluctuate
- Can help setup process controls
- Requires all the information for steady state simulation plus
  - Thermal mass
  - Residence time
  - Valve description
- Use commercial package or create your own

Custom Built Dynamic Process Simulation



Commercial Program for Dynamic Simulation

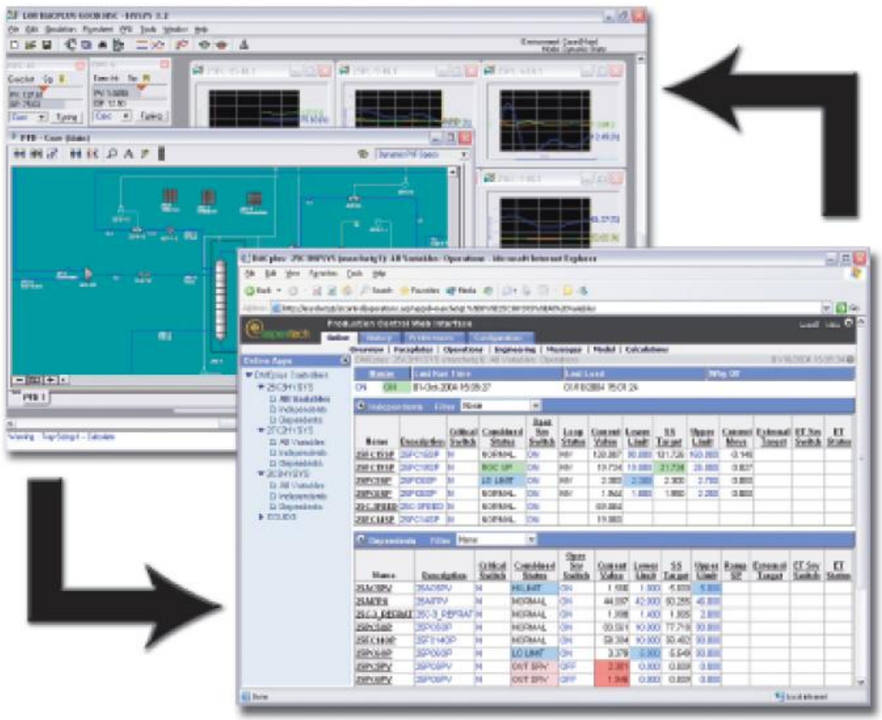


Figure 2a. Aspen HYSYS Controlled from DMCplus GUI

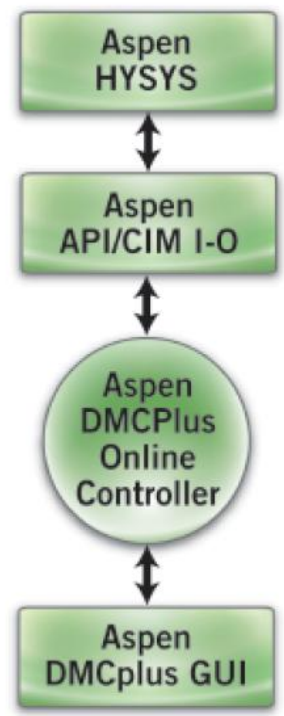
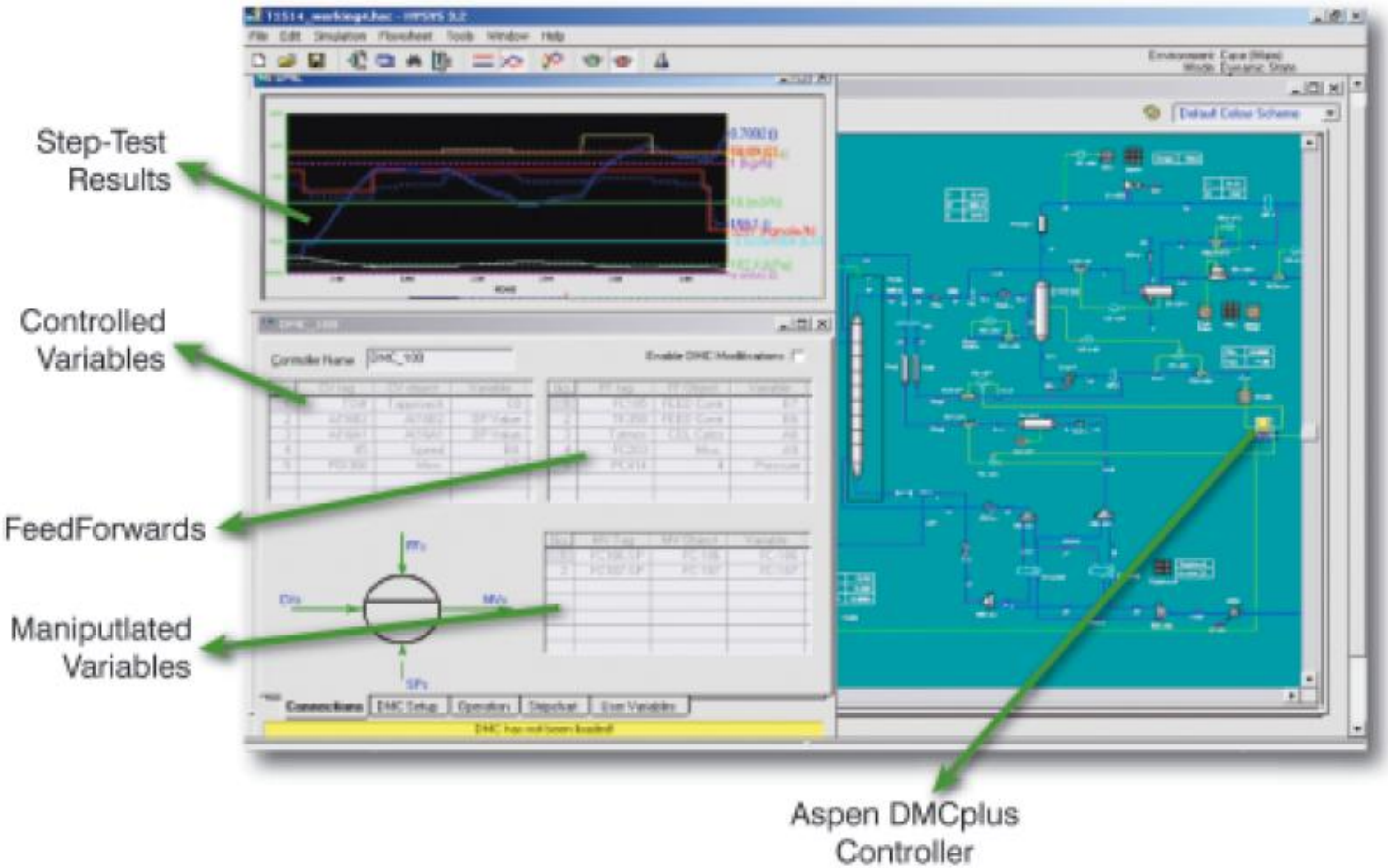


Figure 2b. Aspen HYSYS Acting like the Real Plant

Commercial Program for Dynamic Simulation



Summary

- Process simulation tools can be useful
- Require work for meaningful results
- Plants have several options for simulation
- May require consultant for assistance (unbiased promotion!)

Thank You
and Good Day