SLURRY HYDROCRACKER PROJECT

Appendix A - Mass & Energy Balance

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A.1 SUMMARY

Appendix A contains detailed lists of mass and energy balances for the overall process, as well as for the bubble column reactor. Specific balances are provided for the reactor to ensure correct operation given that the reactor is not modelled in the simulation.

Included in the supplementary files are two Excel spreadsheets with detailed calculations for mass balances, energy balances, and product distribution, as well as an Excel copy of the stream table.

A.2 MASS BALANCE

A.2.1 Overall Process Mass Balance

Table A1 shows the mass balance for the entire process. The total difference was found to be 0.24 kg/h, or 0.00003%.

Table A1. Overall process mass balance.

In			Out		
Stream Description	Stream Number	m (kg/h)	Stream Description	Stream Number	m (kg/h)
Bitumen Feed	S1	665,516	Final Product	S60	602,327
Steam	S26	139,000	Residue Product	S45	14,424
Methane	S27	39,845	SMR Liquid	SMR-S09	1,085
Stripper Steam	S41	4,500	Claus Plant	CP-S01	23,797
Fresh Catalyst	S7	6,655	PSA Purge	S32	207,918
Combustion Air	-	1065	Waste-Water	S46	7,029
Total:		**856,581**	**Total:**		**856,581**

A.2.2 Reactor Mass Balance

Table A2 shows the combined mass balance around the slurry bubble column reactors (with specific product composition).

Table A2. Reactor Mass Balance.

In		Out	
Stream Description	m (kg/h)	Stream Description	m (kg/h)
Bitumen Feed	665,516	Product Gas	91,369
(Fresh) Catalyst	6,655	Naphtha	128,937
Fresh H_2	40,176	LGO	242,047
Recycle Gas	140,052	VGO	215,123
		Residue	14,716
		(Spent) Catalyst	6,655
		Unreacted H_2	13,500
		Recycle Gas	140,052
Total:	**852,400**	**Total:**	**852,399**

A.3 ENERGY BALANCE

A.3.1 Overall Energy Balance

A summary table for the overall process energy balance is presented in the following table. It was assumed that all reactors operate isothermally. Stream enthalpies were taken directly from VMG Symmetry and can appear positive or negative based on the arbitrary enthalpy baseline set by VMG.

Table A4. Overall process energy balance.

Stream Description	Stream Number	Electricity Input (kW)	Heat In (kW)	Heat Out (kW)	Energy In (kW)	Energy Out (kW)
Bitumen Feed	S3	-	-	-	-11,814	
Steam	S33	-	-	-	39,592	
Methane	S34	-	-	-	10,800	
Stripper Steam	S44	-	-	-	862	
Final Product	S60	-	-	-		3,165
Residue Product	S45	-	-	-		430
SMR Liquid	SMR-S09	-	-	-		506
Acid Gas	S30	-	-	-		712
PSA Purge	S35	-	-	-		30,559
Waste-Water	S52	-	-	-		3,282
Equipment Description	**Equipment Number**	**Electricity Input (kW)**	**Heat In (kW)**	**Heat Out (kW)**	**Energy In (kW)**	**Energy Out (kW)**
Slurry Bubble Column Reactor(s)	R-01 – R-04	-	93,536	-	93,536	
Conversion Reactor	R-05	-	-	8,151		8,151
Pump Feed Train	P-01	4,965	-	-	4,965	
Final Product Pump	P-02	1	-	-	1	
Compressor Train Compressors	CT-CP01 / CT-CP02	54,734	-	-	54,734	
Compressor Train Cooler	CT-C01	-	-	26,753		26,753
Product Gas Expander	EX-01	-	-	-		4,642
Product Overheads Cooler	C-01	-	-	211,564		211,564
Product Bottoms Cooler	C-02	-	-	1,030		1,030
Stripper Cooler	C-03	-	-	4,559		4,559
3-Phase Separator Cooler	C-04	-	-	41,843		41,843
Bitumen Feed Furnace	F-01	-	57,014	-	57,014	
Internal Recycle Gas Furnace	F-02	-	56,431	-	56,431	
Bitumen Feed Pre-heater	E-01	-	64,949	-		
Hydrogen Pre-Heater	E-02	-	15,038	-		
Internal Recycle Gas Compressor	CP-01	480	-	-	480	
Stripping Unit Overheads Compressor	CP-02	9,581	-	-	9,581	
SMR/PSA	-	-	-	-	12,924	
Amine Unit	AU	-	-	-		3,115
				Total:	**329,105**	**331,310**
				Difference:	**-2,204**	**1%**

A.3.2 Reactor Energy Balance

Table A5 shows the overall energy balance for the (combined) slurry bubble column reactors. The table shows that the overall difference is only ~1%, and is therefore acceptable.

Table A5. Slurry bubble column reactor energy balance.

Stream Description	Stream Number	Electricity Input (kW)	Heat In (kW)	Heat Out (kW)	Energy In (kW)	Energy Out (kW)
Reactor Product	"	-	-	-	324,341	
Vapour Overheads	S11	-	-	-		419,438
Liquid Bottoms	S10	-	-	-		640
Equipment Description	Equipment Number	Electricity Input (kW)	Heat In (kW)	Heat Out (kW)	Energy In (kW)	Energy Out (kW)
Slurry Bubble Column Reactor(s)	R-01 – R-04	-	93,536	-	93,536	
				Total:	**417,877**	**420,077**
				Difference:	**2200**	**1%**
				Equipment Total:	**93,536**	**0**
				Difference:	**93,536**	**-**

A.4 PRODUCT DISTRIBUTION

Data here is provided to show a comparative analysis between different liquid products produced, and to compare final product composition with (Athabasca bitumen) feedstock.

A.4.1 Liquid Product Distribution

Table A3 shows a comparative component yield analysis for three liquid hydrocarbon products; the original reactor liquid (before being treated in the stripping process), the final (saleable) product, as well as the catalyst-containing residue product. Data includes stream composition both with and without spent catalyst.

Table A3. Component distribution for various liquid products.

Boiling Cut / Component	Cut Temperature	Weight % (w/o Catalyst)	Weight % (w/ Catalyst)
Original Reactor Liquid			
Lights	IBP - 50	0.0	0.0
Naphtha	50-170	21.5	21.2
Light Gas Oil	170-350	40.3	39.8
Heavy Gas Oil	350-550	35.8	35.4
Residue	550 - EBP	2.4	2.4
Spent Catalyst	N/A	-	1.1
Final Product			
Lights	IBP - 50	2.9	2.9
Naphtha	50-170	20.1	20.1
Light Gas Oil	170-350	40.2	40.2
Heavy Gas Oil	350-550	35.6	35.6
Residue	550 - EBP	1.2	1.2
Residue Product			
Lights	IBP - 50	0	0.0
Naphtha	50-170	0	0.0
Light Gas Oil	170-350	0	0.0
Heavy Gas Oil	350-550	5.5	3.0
Residue	550 - EBP	94.5	50.9
Spent Catalyst	N/A	-	46.1

A.4.2 Final Product-Feedstock Comparisons

Figure A1 displays a distillation curve of the final product compared with the distillation curve of pure bitumen from Gray (2015).

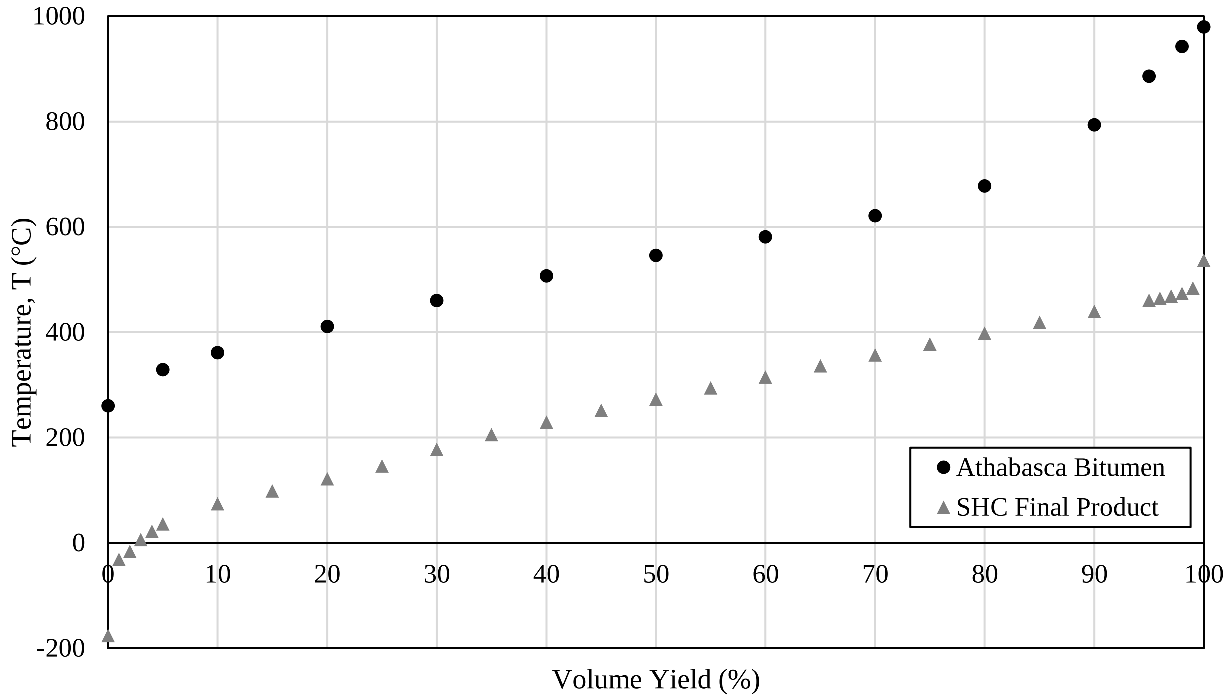

Figure A1. Distillation curves for Athabasca bitumen (feed) and SHC final product.

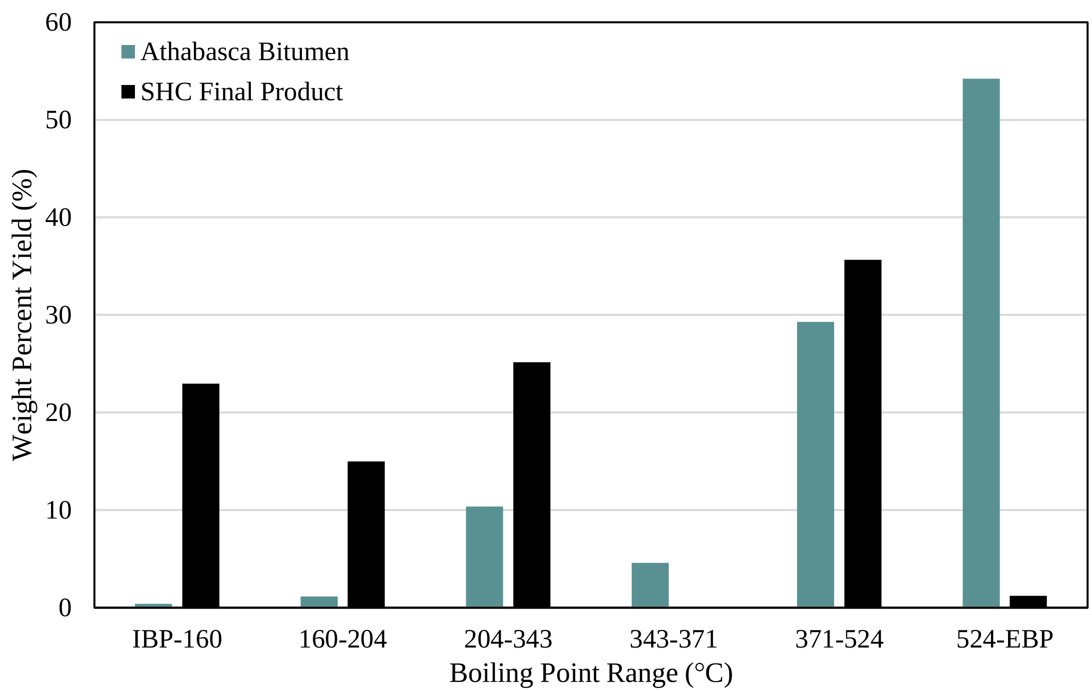

Figure A2. Composition of boiling fractions for Athabasca bitumen and SHC final product.

A.5 REFERENCES

Ghasemi, M. & Whitson, C. (2013). Modeling Steam-Assisted Gravity Drainage With a Black-Oil Proxy. *SPE Reservoir Evaluation & Engineering*. 16, 155-171. 10.2118/147072-PA.

Gray, M.R. (2015). “Upgrading oilsands bitumen and heavy oil”, 1st Ed., The University of Alberta Press.