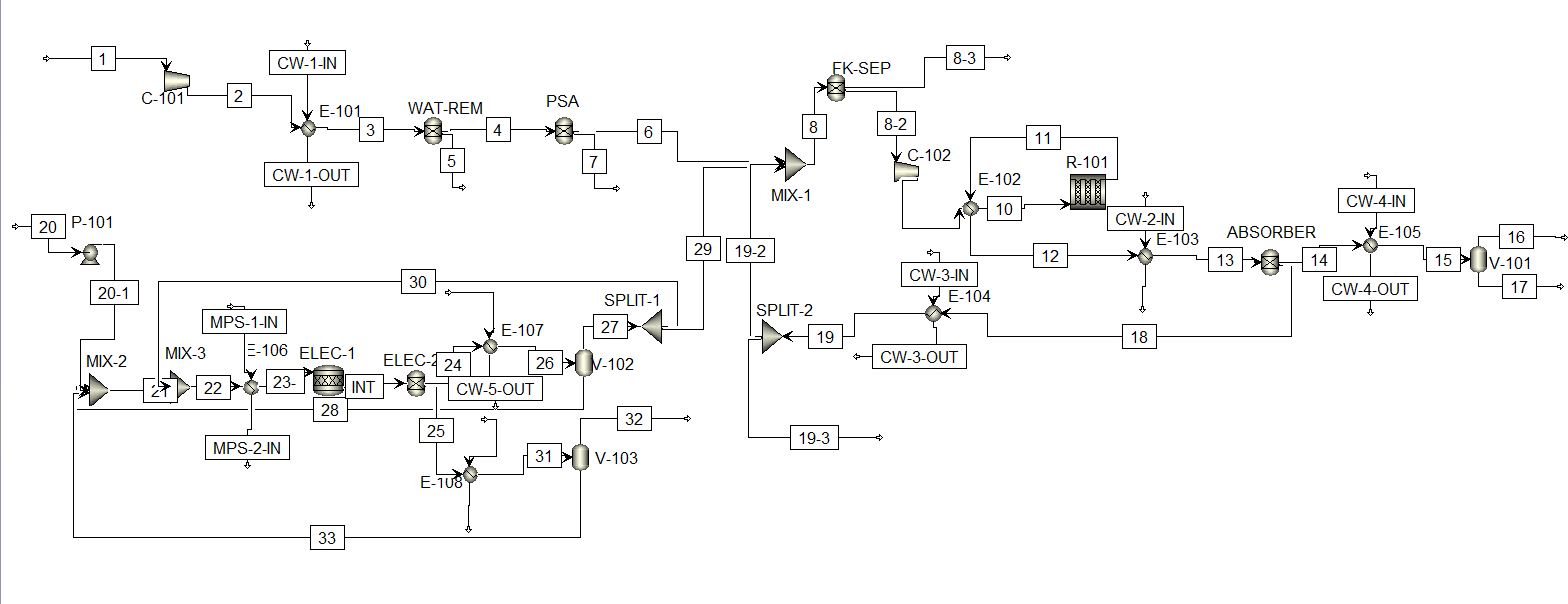
**Aspen Simulation**

Note\*: The stream numbers in aspen does not match the PFD and stream table. That’s why we provided separate stream tables for each.

Overall flowsheet:

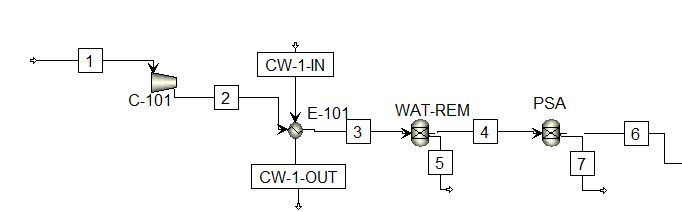


Downstream flowsheet:

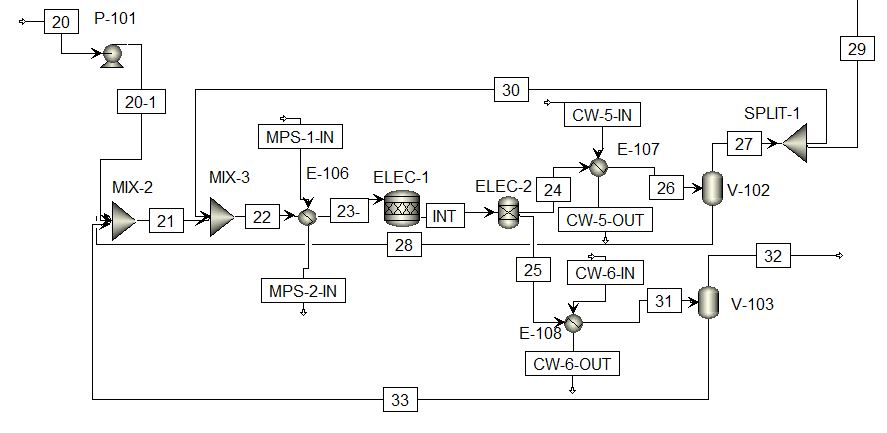
![A close up of a map

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAkACQAAD/4RDmRXhpZgAATU0AKgAAAAgABAE7AAIAAAAJAAAISodpAAQAAAABAAAIVJydAAEAAAASAAAQzOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFRvcmEgR2FvAAAABZADAAIAAAAUAAAQopAEAAIAAAAUAAAQtpKRAAIAAAADMDYAAJKSAAIAAAADMDYAAOocAAcAAAgMAAAIlgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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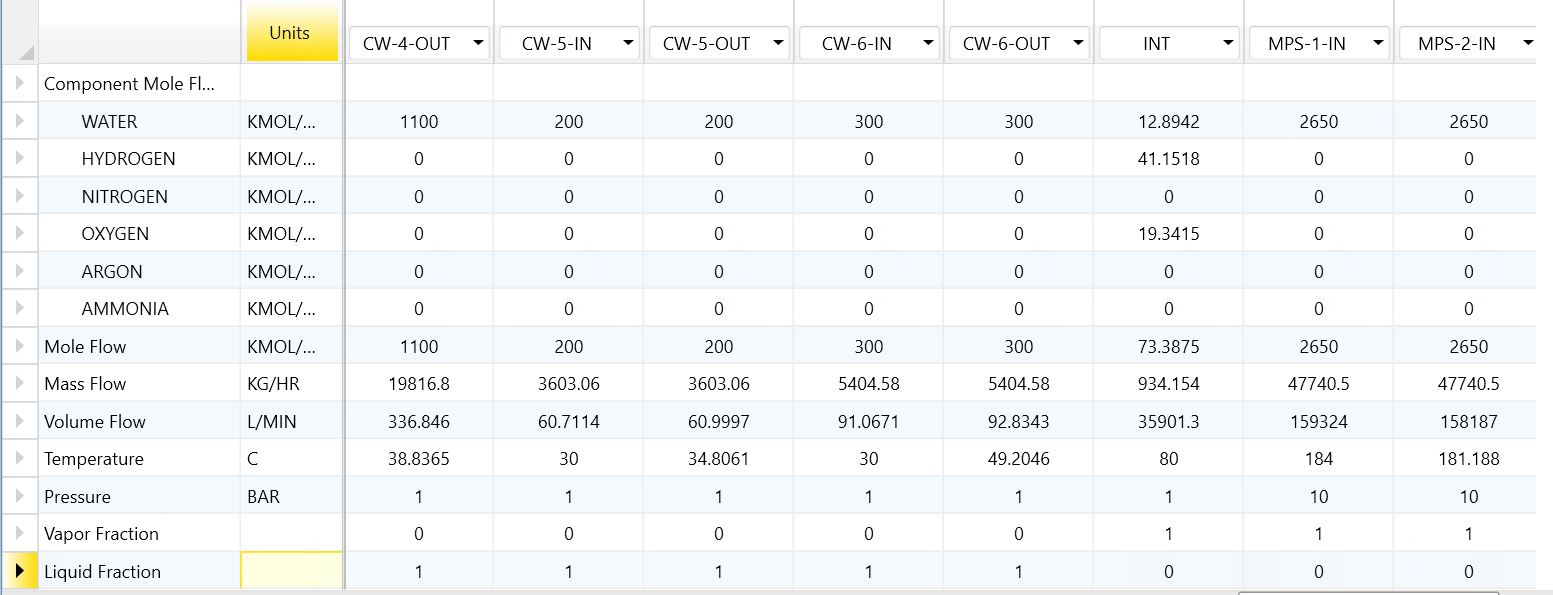
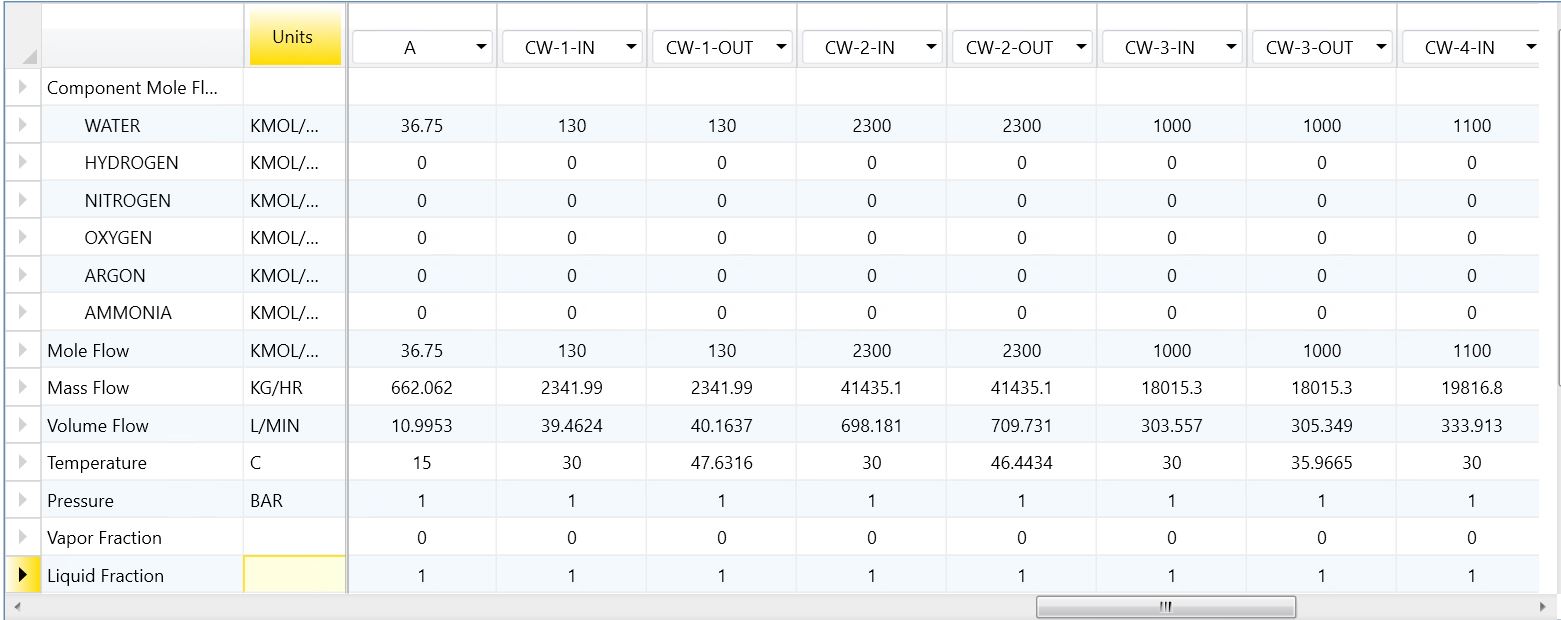
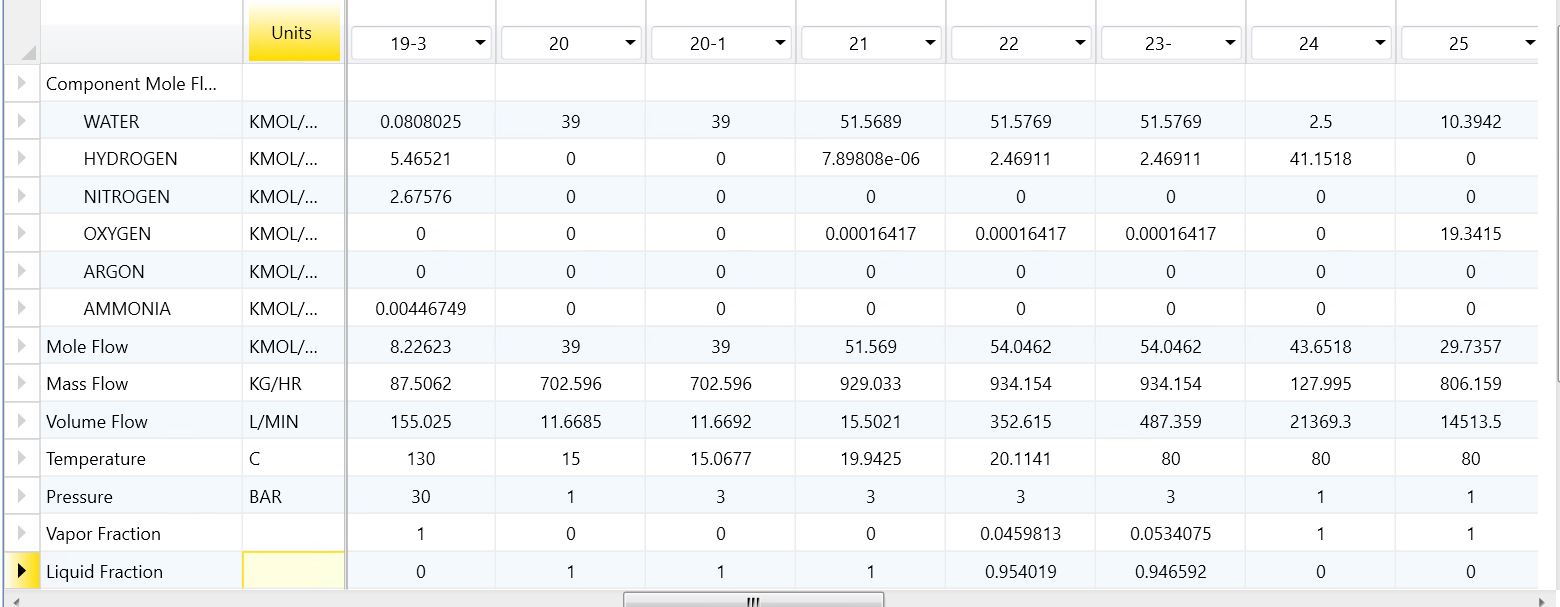
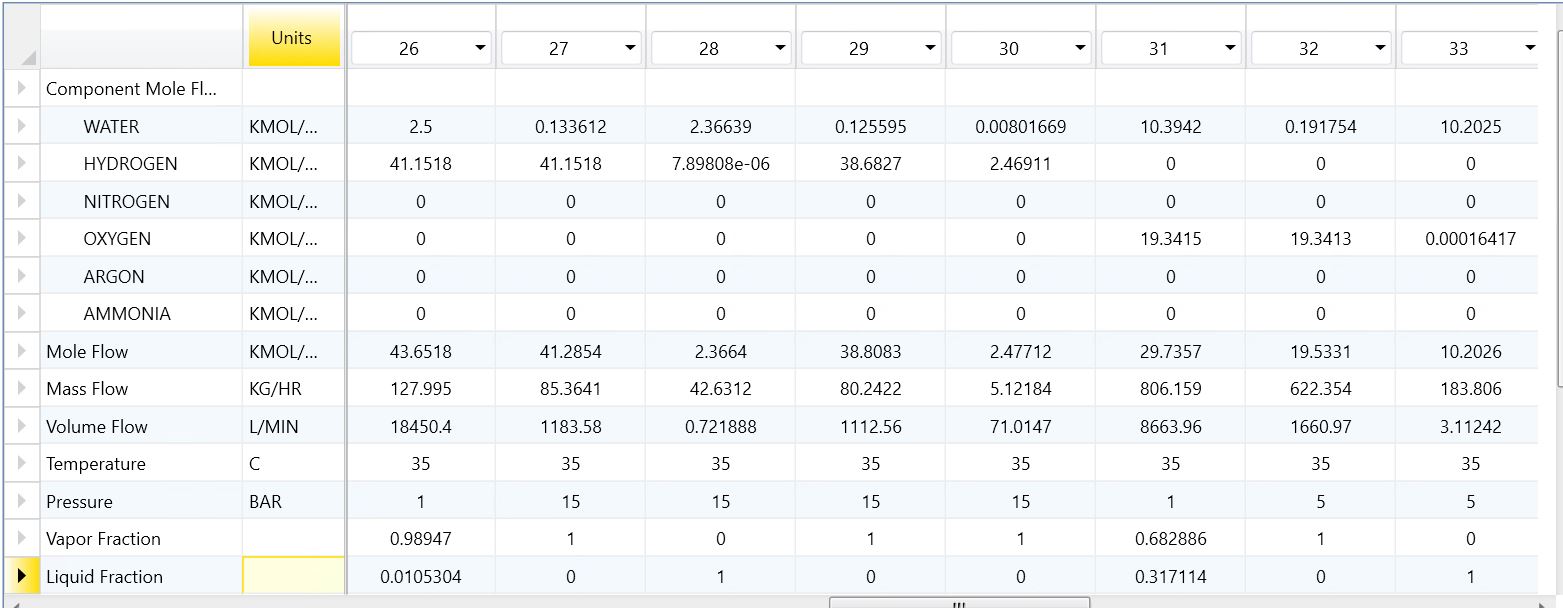
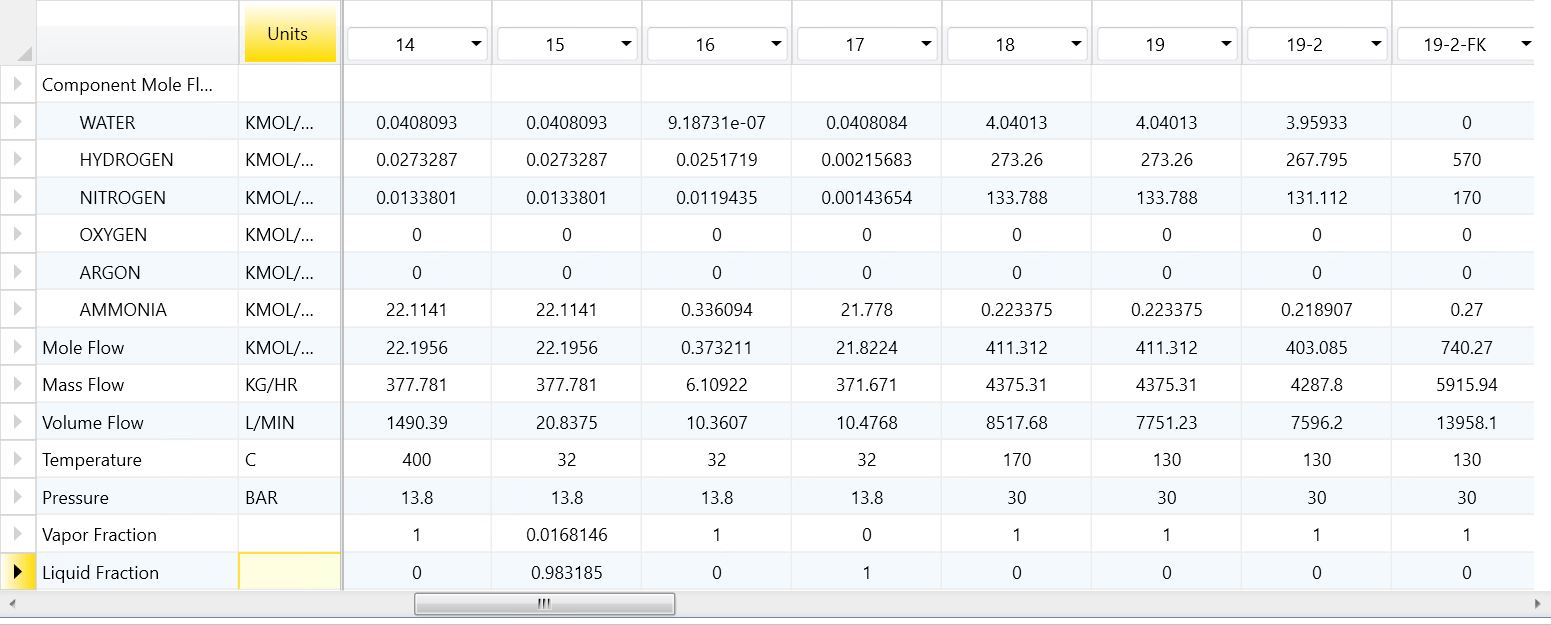
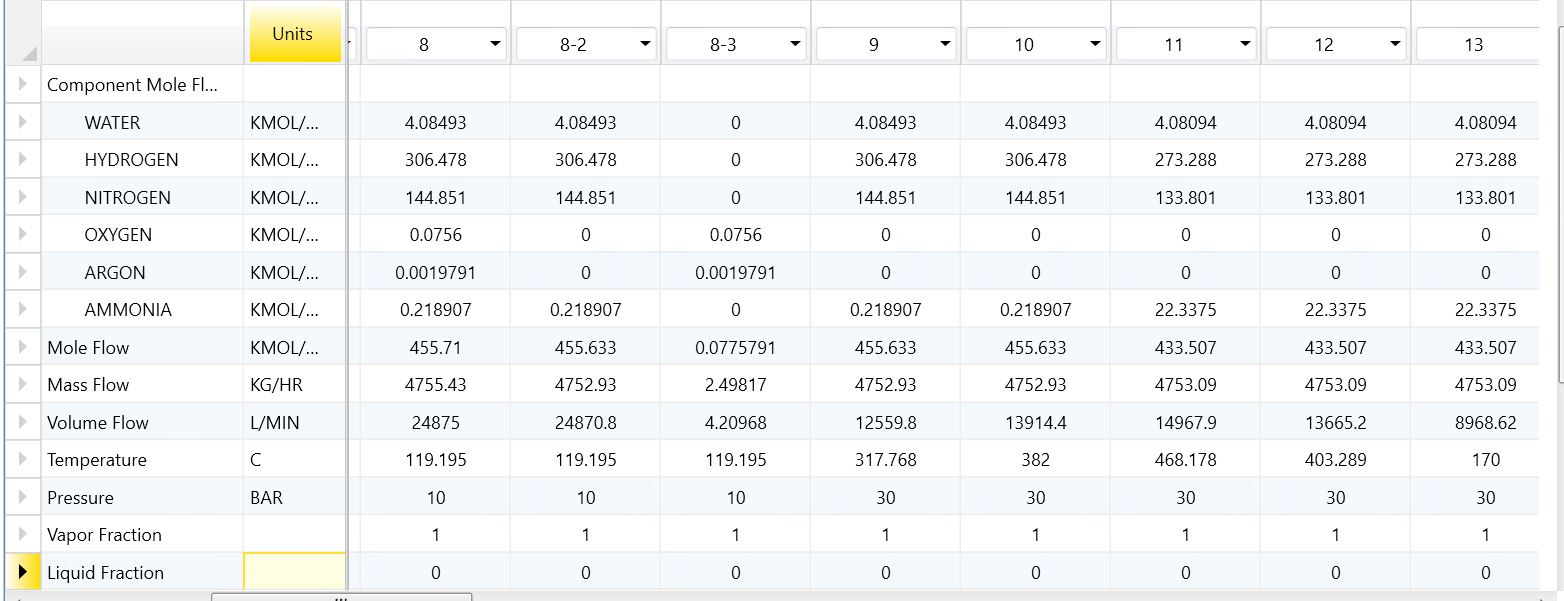
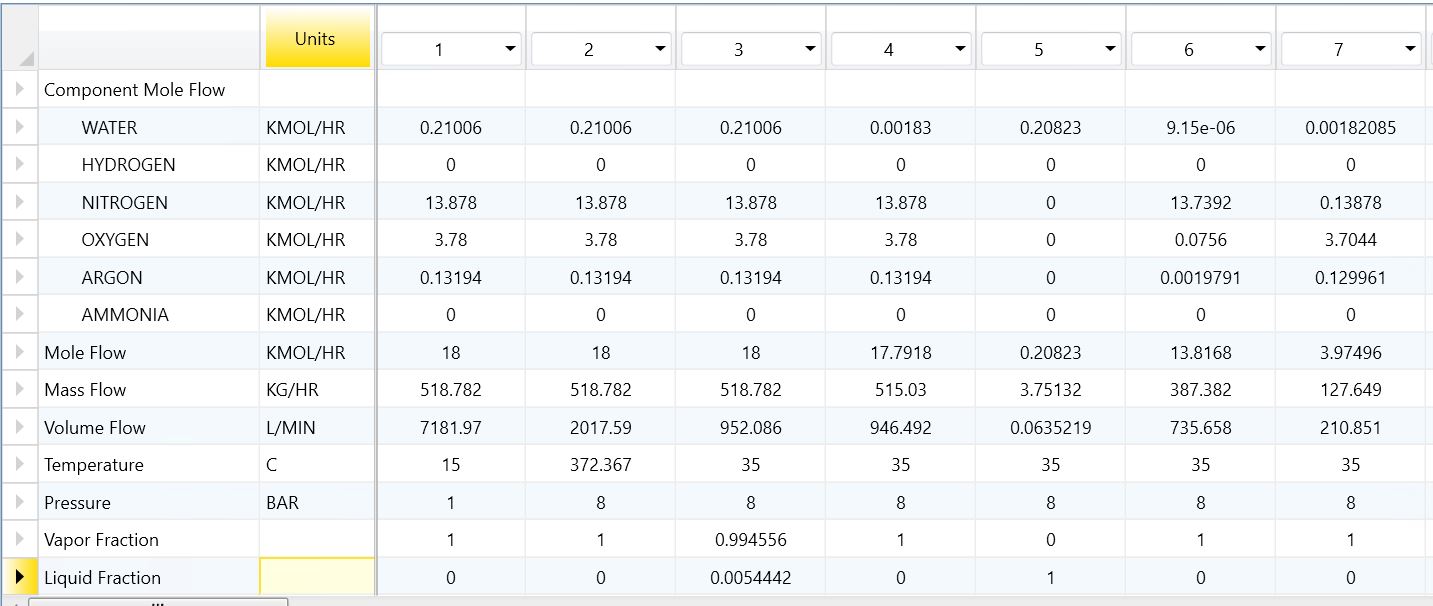
Upstream – pressure swing adsorption flowsheet:



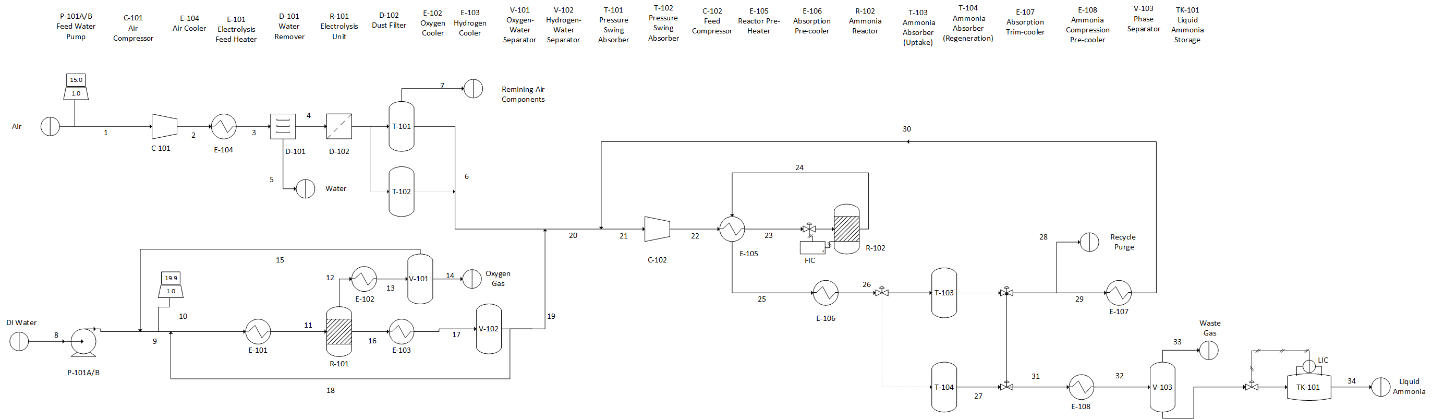
Upstream – electrolysis flowsheet:



Stream Table Screen Shot:



**PFD**



**Stream Table**

**Table 1.1** Stream 1-7 for PFD

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Stream #** | **Unit** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| Water | Kmol/hr | 0.53 | 0.53 | 0.53 | 0.53 | 0.52 | 0.0 | 0.0 |
| Hydrogen Gas | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nitrogen Gas | Kmol/hr | 34.7 | 34.7 | 34.7 | 34.7 | 0.0 | 13.7 | 20.96 |
| Oxygen Gas | Kmol/hr | 9.45 | 9.45 | 9.45 | 9.45 | 0.0 | 0.1 | 9.37 |
| Argon | Kmol/hr | 0.33 | 0.33 | 0.33 | 0.33 | 0.0 | 0.0 | 0.33 |
| Ammonia | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Flow | Kmol/hr | 45.0 | 45.0 | 45.0 | 45.0 | 0.52 | 13.8 | 30.66 |
| Total Flow | Kg/hr | 1297 | 1297 | 1297 | 1297 | 9.43 | 387.4 | 900.1 |
| Total Flow | L/min | 17955.0 | 17955.0 | 17955.0 | 17955.0 | 0.16 | 735.7 | 1630.4 |
| Temperature | C° | 15.0 | 332.5 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 |
| Pressure | Bar | 1.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| Vapor Frac |  | 1.00 | 1.00 | 0.99 | 1.00 | 0.00 | 1.00 | 1.00 |

**Table 1.2** Stream 8-14 for PFD

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Stream #** | **Unit** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| Water | Kmol/hr | 39.0 | 51.6 | 51.6 | 51.6 | 10.4 | 10.4 | 0.2 |
| Hydrogen Gas | Kmol/hr | 0.0 | 0.0 | 2.5 | 2.5 | 0.0 | 0.0 | 0.0 |
| Nitrogen Gas | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oxygen Gas | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 19.3 | 19.3 | 19.3 |
| Argon | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ammonia | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Total Flow | Kmol/hr | 39.0 | 51.6 | 54.0 | 54.0 | 29.7 | 29.7 | 19.5 |
| Total Flow | Kg/hr | 702.6 | 929.0 | 934.2 | 934.2 | 806.2 | 806.2 | 622.4 |
| Total Flow | L/min | 11.7 | 15.5 | 1037.1 | 2140.2 | 14513.5 | 8664.0 | 1661.0 |
| Temperature | C° | 15.0 | 19.9 | 19.7 | 80.0 | 80.0 | 35.0 | 35.0 |
| Pressure | Bar | 1.0 | 3.0 | 3.0 | 3.0 | 1.0 | 1.0 | 5.0 |
| Vapor Frac |  | 0.00 | 0.00 | 0.05 | 0.08 | 1.00 | 0.68 | 1.00 |

**Table 1.3** Stream 15-21 for PFD

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Stream #** | **Unit** | **15** | **16** | **17** | **18-1** | **19** | **20** | **21** |
| Water | Kmol/hr | 10.2 | 2.5 | 2.5 | 0.0 | 0.1 | 14.5 | 4.1 |
| Hydrogen Gas | Kmol/hr | 0.0 | 41.2 | 41.2 | 2.5 | 38.7 | 273.3 | 306.5 |
| Nitrogen Gas | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 133.8 | 144.9 |
| Oxygen Gas | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 19.3 | 0.1 |
| Argon | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ammonia | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 22.3 | 0.2 |
| Total Flow | Kmol/hr | 10.2 | 43.7 | 43.7 | 2.5 | 38.8 | 463.2 | 455.7 |
| Total Flow | Kg/hr | 183.8 | 128.0 | 128.0 | 5.1 | 80.2 | 5559.2 | 4755.4 |
| Total Flow | L/min | 3.1 | 21369.3 | 18450.4 | 71.0 | 1112.6 | 23482.2 | 24875.0 |
| Temperature | C° | 35.0 | 80.0 | 35.0 | 35.0 | 35.0 | 119.2 | 119.2 |
| Pressure | Bar | 5.0 | 1.0 | 1.0 | 15.0 | 15.0 | 10.0 | 10.0 |
| Vapor Frac |  | 0.00 | 1.00 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 |

**Table 1.4** Stream 22-28 for PFD

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Stream #** | **Unit** | **22** | **23** | **24** | **25** | **26** | **27** | **28** |
| Water | Kmol/hr | 4.1 | 4.1 | 4.1 | 4.1 | 0.0 | 0.0 | 0.1 |
| Hydrogen Gas | Kmol/hr | 306.5 | 273.3 | 273.3 | 273.3 | 0.0 | 0.0 | 5.5 |
| Nitrogen Gas | Kmol/hr | 144.9 | 133.8 | 133.8 | 133.8 | 0.0 | 0.0 | 2.7 |
| Oxygen Gas | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Argon | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ammonia | Kmol/hr | 0.2 | 22.3 | 22.3 | 22.3 | 22.1 | 22.1 | 0.0 |
| Total Flow | Kmol/hr | 455.6 | 433.5 | 433.5 | 433.5 | 22.2 | 22.2 | 8.2 |
| Total Flow | Kg/hr | 4752.9 | 4753.1 | 4753.1 | 4753.1 | 377.8 | 377.8 | 87.5 |
| Total Flow | L/min | 12559.8 | 14967.9 | 13665.2 | 8968.6 | 1490.4 | 1490.4 | 155.0 |
| Temperature | C° | 317.8 | 468.2 | 403.3 | 170.0 | 400.0 | 400.0 | 170.0 |
| Pressure | Bar | 30.0 | 30.0 | 30.0 | 30.0 | 13.8 | 13.8 | 30.0 |
| Vapor Frac |  | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

**Table 1.5** Stream 29-34 for PFD

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Stream #** | **Unit** | **29** | **30** | **31** | **32** | **33** | **34** |
| Water | Kmol/hr | 4.0 | 4.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Hydrogen Gas | Kmol/hr | 267.8 | 267.8 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nitrogen Gas | Kmol/hr | 131.1 | 131.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oxygen Gas | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Argon | Kmol/hr | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ammonia | Kmol/hr | 0.2 | 0.2 | 22.1 | 22.1 | 0.3 | 21.8 |
| Total Flow | Kmol/hr | 403.1 | 403.1 | 22.2 | 22.2 | 0.4 | 21.8 |
| Total Flow | Kg/hr | 4287.8 | 4287.8 | 377.8 | 377.8 | 6.1 | 371.7 |
| Total Flow | L/min | 7596.2 | 7596.2 | 20.8 | 20.8 | 10.4 | 10.5 |
| Temperature | C° | 170.0 | 130.0 | 400.0 | 32.0 | 32.0 | 32.0 |
| Pressure | Bar | 30.0 | 30.0 | 13.8 | 13.8 | 13.8 | 13.8 |
| Vapor Frac |  | 1.00 | 1.00 | 1.00 | 0.02 | 1.00 | 0.00 |

**Equipment Summary:**

**Table 1.1** Compressors

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Equipment # / Title** | **C-101** | **C-102** | **C-103** | **C-104** |
| **MOC** | CS | SS | CS | CS |
| **Driver Rate (kW)** | 52.4 | 268 | 67.3 | 992.4 |
| **Efficiency (%)** | 90 | 90 | 72 | 72 |

**Table 2.1** Pumps

|  |  |
| --- | --- |
| **Equipment # / Title** | **P-101 A/B** |
| **Type** | Centrifugal |
| **Efficiency (%)** | 90 |
| **Driver Rate(kW)** | 0.097 |
| **MOC** | CS |
| **Pressure at Discharge (Barg)** | 3 |

**Table 2.2** Heat Exchanger

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Equipment ID / Title** | **E-101** | **E-102** | **E-103** | **E-104** | **E-105** | **E-106** | **E-107** | **E-108** |
| **Type** | S/T Floating Head | S/T Floating Head | S/T Floating Head | S/T Floating Head | S/T Floating Head | S/T Floating Head | S/T Floating Head | S/T Floating Head |
| **Tube/Shell Side MOC** | CS/CS | SS/CS | CS/CS | CS/CS | CS/SS | SS/CS | CS/CS | SS/CS |
| **Heat Transfer Area(m2)** | 77.60 | 24.72 | 36.39 | 18.71 | 124.98 | 174.53 | 125.80 | 2.69 |
| **Duty(kW)** | 94 | 246.7 | 207.7 | 114.38 | 242 | 865 | 135 | 220 |

**Table 2.3** Electrolysis Unit

|  |  |
| --- | --- |
| **Equipment # / Title** | **R-101** |
| **Type** | Alkaline electrolyzer |
| **Cell voltage (V)** | 3.75 |
| **Current Density (A/)** | 0.5 |
| **Current per electrolyzer (kA)** | 30.9 |
| **Operating Electricity [kW]** | 2201 |
| **Number of stacks** | 19 |

**Table 2.4** Reactor

|  |  |
| --- | --- |
| **Equipment # / Title** | **R-102** |
| **Type** | Plug-flow reactor |
| **MOC** | SS |
| **Bed Void Fraction** | 0.4 |
| **Max Operating Pressure (Barg)** | 30 |
| **Max Operating Temperature (C)** | 468 |
| **Volume ()** | 3.72 |
| **Length (m)** | 2.68 |
| **Diameter (m)** | 1.33 |

**Table 2.6** Absorbers

|  |  |  |
| --- | --- | --- |
| **Equipment # / Title** | **T-103** | **T-104** |
| **Bed void fraction:** | 0.32 | 0.32 |
| **MOC** | CS | CS |
| **Number of tubes:** | 29 | 29 |
| **Tube length (m):** | 1 | 1 |
| **Diameter length (m):** | 0.5 | 0.5 |

**Table 2.7** Vessels

|  |  |  |  |
| --- | --- | --- | --- |
| **Equipment # / Title** | **V-101** | **V-102** | **V-103** |
| **Type** | Vertical | Vertical | Vertical |
| **MOC** | CS | CS | CS |
| **Volume ()** | 184.5 | 86.7 | 0.208 |
| **Diameter (m)** | 4.28 | 3.33 | 0.45 |
| **Length (m)** | 12.84 | 9.98 | 1.34 |
| **Pressure (Barg)** | 15.2 | 16.5 | 5.5 |
| **Temperature (C)** | 35.2 | 38.5 | 38.5 |

**Table 2.8** Adsorption Towers

|  |  |  |
| --- | --- | --- |
| **Equipment # / Title** | **T-101** | **T-102** |
| **Bed void fraction:** | 0.615 | 0.615 |
| **MOC** | CS | CS |
| **Volume ()** | 3.9 | 3.9 |
| **Diameter (m)** | 0.82 | 0.82 |
| **Length (m)** | 7.38 | 7.38 |

**Problem Specifications**

We are currently producing 21.778 Kmol/hr of anhydrous ammonia at a purity of 99.6 weight percent per module unit. Assuming a stream factor of 0.95 and a total of six modules, this equates to:

.

Thus, we are meeting the problem specification of 50 Mtpd production with a purity over 99.5 weight percent.

**Mass Balance**

Values from stream tables:

Flowrate in = Flowrate out

**Heuristics**

Heat Exchanger:

For heat exchanger area, we have equation:

The results of simulated heat duties, stream temperatures and estimated U are listed below:

Heat exchanger provided information

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Unit #** | **E-101** | **E-102** | **E-103** | **E-104** | **E-105** | **E-106** | **E-107** | **E-108** |
| **q [W]** | 45753 | 242067 | 856100 | 135039 | 219997 | 93664 | 21756 | 130428 |
| **U [W/]** | 60 | 30 | 60 | 60 | 850 | 60 | 60 | 60 |
| **[** | 30.0 | 317.8 | 30.0 | 30.0 | 30.0 | 180.4 | 30.0 | 30.0 |
| **[** | 35.0 | 403.3 | 170.0 | 130.0 | 32.0 | 19.7 | 35.0 | 35.0 |
| **[** | 332.5 | 468.2 | 403.3 | 170.0 | 400.0 | 80.0 | 80.0 | 80.0 |
| **[** | 45.6 | 382.0 | 46.4 | 35.9 | 38.8 | 184.0 | 34.8 | 49.2 |

Assuming F=0.9, and the equation for finding is provided below:

Using the above equation and table to determine the log-mean temperatures of each exchangers and further to find out the area estimation:

Heat exchanger calculated values

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Unit #** | **E-101** | **E-102** | **E-103** | **E-104** | **E-105** | **E-106** | **E-107** | **E-108** |
| **[]** | 95.5 | 64.6 | 81.8 | 17.9 | 96.3 | 20.1 | 18.0 | 30.3 |
| **A []** | 8.0 | 125.0 | 174.5 | 125.8 | 2.7 | 77.6 | 20.2 | 71.8 |

Vessels:

The volumetric flow rates into each vessel is summarized in the table below:

Vessels provided information

|  |  |  |  |
| --- | --- | --- | --- |
| **Unit #** | **V-101** | **V-102** | **V-103** |
| **[]** | 0.0208 | 18.45 | 8.67 |
| **P [bar]** | 13.8 | 15 | 5 |
| **T [C]** | 32 | 35 | 35 |

Assuming we are controlling the level at half full of a hold up time of 5 minutes and L/D ratio of 3, we can estimate the volume and dimension for our vessels. We can also determine the design pressure and temperature of the vessels. The design pressure and temperature are typically 10% over the max operating values.

Vessels Calculated values

|  |  |  |  |
| --- | --- | --- | --- |
| **Unit #** | **V-101** | **V-102** | **V-103** |
| **V []** | 0.208 | 184.5 | 86.7 |
| **L [m]** | 1.34 | 12.84 | 9.98 |
| **D [m]** | 0.45 | 4.28 | 3.33 |
| **[bar]** | 15.2 | 16.5 | 5.5 |
| **[C]** | 35.2 | 38.5 | 38.5 |

Compressors:

Compressors provided information

|  |  |  |  |
| --- | --- | --- | --- |
| **Unit #** | **C-101** | **C-102** | |
| **[barg]** | 1 | 10 | |
| **[barg]** | 8 | 30 | |
| **T [C]** | 333 | 318 | |
| **Efficiency [%]** | 0.9 | 0.73 |

The compressor ratio for C-101 is 8 and for C102 is 3, It is suggested that the compressor ratio is around 6 for efficiency of 85% and 2 for 75%. Our compressors’ ratio roughly matches the heuristics.

**Additional Info for L1 blocks**

Pressure Swing Adsorption

Sources:

* Chinh, P. V., Hieu, N. T., Tien, V. D., Nguyen, T.-Y., Nguyen, H. N., Anh, N. T., & Thom, D. V. (2019). Simulation and Experimental Study of a Single Fixed-Bed Model of Nitrogen Gas Generator Working by Pressure Swing Adsorption*. Processes*, 7(10), 654. doi: 10.3390/pr7100654
* Patel, V. S., Patel, M. J. (2014). Separation of High Purity Nitrogen from Air by Pressure Swing Adsorption on Carbon Molecular Sieves. *International Journal of Engineering Research & Technology*, 3(3).
* Schulte-Schulze-Berndt, A., & Krabiell, K. (1993). Nitrogen generation by pressure swing adsorption based on carbon molecular sieves. *Gas Separation & Purification*, 7(4), 253–257. doi: 10.1016/0950-4214(93)80026-s

Sizing:

Size based on adsorption capacity and physical properties of CMS-240 adsorbent. This adsorbent can produce 240 L of nitrogen (at 99.5 % purity) per hour per kg of adsorbent (240 L NH3/(hr\*kgads) at around 8 bar. Using this value, along with the density, bed voidage, assumed saturation percentage, height/diameter ratio, and our nitrogen production rate, we can calculate that each tower will need to be 7.38m tall and have a diameter of 0.82 m (volume = 3.9m3).

Power:

Our size PSA can be estimated to use 0.46 kWh/m3 N2 produced

Electrolyzer

Sources:

* National Renewable Energy Laboratory. “Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis. <https://www.hydrogen.energy.gov/pdfs/46676.pdf>
* Rashid, M. M., Mesfer, M. K. A., Naseem, H., & Danish, M. (2015). Hydrogen Production by Water Electrolysis: A Review of Alkaline Water Electrolysis, PEM Water Electrolysis and High Temperature Water Electrolysis. Hydrogen Production by Water Electrolysis: A Review of Alkaline Water Electrolysis, PEM Water Electrolysis and High Temperature Water Electrolysis.

Power:

The operating electricity per mass basis of hydrogen provided by the paper is 53.5 kWh/kg of hydrogen gas. The production rate of hydrogen gas simulated in Aspen is 82.3 kg/hr. To find the operating electricity for our electrolysis unit, we multiply the two values together. The electricity requirement is 2202 kW per module.

Sizing:

The max production rate of a single electrolyzer unit is 4.5 kg/hr. The production rate required is 82.3 kg of hydrogen gas on an hour basis simulated in Aspen (for one module unit). For equipment dimension, the alkaline battery voltage paper provides the optimal voltage for operating electrolysis is 3.75V at around 80 degree Celsius and the current density is typically around 0.5 A/. Given our operating electricity is at around 2202 kW, we can determine the current needed for our electrolyzer. We will have 19 electrolyzers stacked in parallel to achieve 82.3 kg/hr of hydrogen gas production. We know power over voltage is equal to current. The current requirement is:

Using this result and known current density, we can determine the area of each electrolyzer, which is 61,800 for one side of the electrolyzer and 123,600 = 12.36 in total.

Absorber

Sources:

* Palys, M., Mccormick, A., Cussler, E., & Daoutidis, P. (2018). Modeling and Optimal Design of Absorbent Enhanced Ammonia Synthesis. *Processes*, 6(7), 91. doi: 10.3390/pr6070091
* Malmali, M., Wei, Y., Mccormick, A., & Cussler, E. L. (2016). Ammonia Synthesis at Reduced Pressure via Reactive Separation. *Industrial & Engineering Chemistry Research*, 55(33), 8922–8932. doi: 10.1021/acs.iecr.6b01880

Sizing:

Number of tubes – 29, tube length – 1m, tube diameter – 0.5m

Power:

~2.56 kWh/kg NH3 produced