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	Initials	**Print Name**	**Date**
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7. Purpose

The objective of this study was to simulate/evaluate removal of contaminants, dimethyl carbonate (DMC), acetaldehyde, and Hydrofluoric acid (HF), from the vent gas system stream coming from the shredding lines avoiding the use of a thermal oxidizer as a final environmental control element.

Initially, the scope of the study included:

- The simulation of the system with Aspen Plus, including a condenser, a separator, and a carbon adsorption system.
- A Process Flow Diagram
- Preliminary datasheets for the condenser, the separator, and the carbon bed absorption system.
- A final report.

Hargrove completed this study, and the report (Rev A) with the deliverables indicated in the scope was submitted to Ecobat on October 20, 022. The level of contaminants at the outlet of the condenser was not adequate to be fed to the carbon adsorption system since the time to saturation was less than one day. A scrubber was added to the system to reduce the level of contaminants to less than 1000 ppm. This updated report provides revised system design parameters for the carbon bed adsorption system based on using a scrubber for removal of contaminants. It also includes datasheets for new equipment and updates to the previous attachments.

8. Method and Process Model Description

- Aspen Plus V12 software package modeling software was used to simulate the process. Inputs to the model were from vent stream chemistry and a block flow diagram of the vent system which were supplied by Ecobat.

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9. Assumptions/Premises

- Atmospheric pressure was 1 atm and ambient temperature was 40 °C
- Water supplied to the scrubber was at 25 °C
- Use of 50% propylene glycol as refrigerant, which is more environmentally friendly than ethylene glycol and 2(for the initial study – Rev A).
- Streams 001 and 002 are available at 0.7 barg.
- Control valve outlet pressure (inlet to carbon adsorption system) was set at 0.098 atm (0.1 barg)
- VOC composition was based on Gas Chromatography-Mass Spectrometry; since the weight percent was not defined, 100 % acetaldehyde was assumed.

The block flow diagram shown below, Figure 1, was the basis for the study.

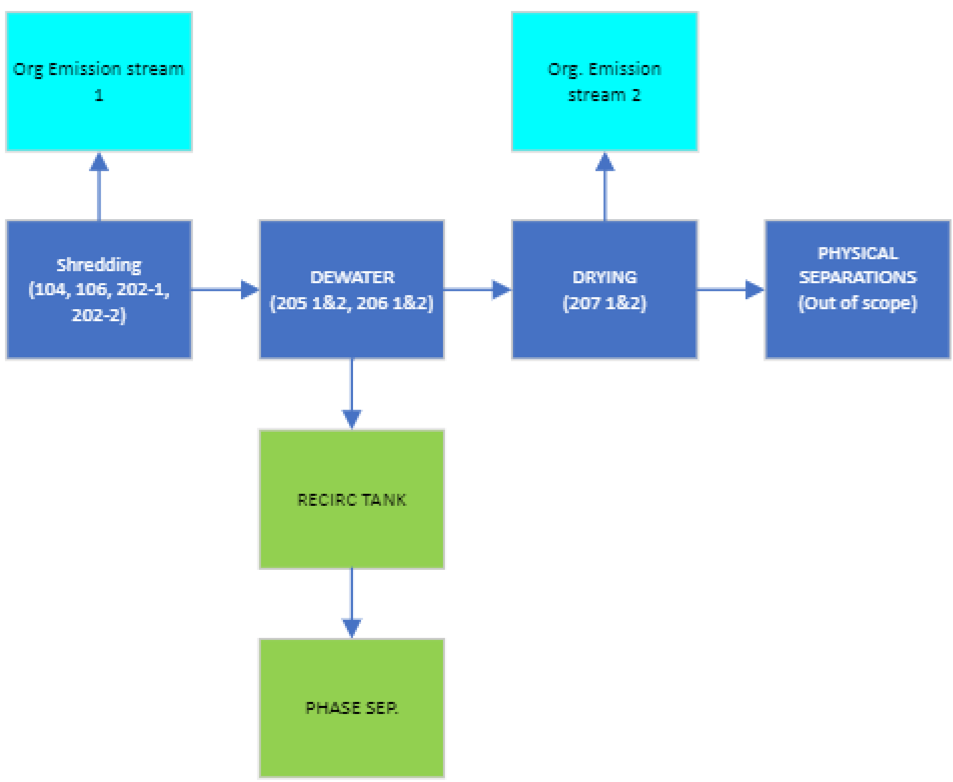

Figure 1. Schematic of sources of streams to be treated

Revised composition and flow rates of the two vent gas streams, for the scrubber study, were provided by Ecobat.

Organic stream 001 is discharged the shredders at ambient pressure and temperature and the addition of air dehumidified the liquid fraction in the stream. Organic stream 002 is discharged from the drying auger at 100 – 120 °C. Tables 1a and 1b indicate the composition of both streams in the two studies (Rev A-condenser and Rev B-scrubber). All stream compositions were given by Ecobat. The composition of streams 1 and 2 were updated by Ecobat for Rev B.

Table 1a. Stream 001 composition

Stream 001 Components	Flowrate (kg/hr) Rev A – Condenser Study	Flowrate (kg/hr) Rev B – Scrubber Study
Dimethyl carbonate (DMC)	125-235	88
VOCs - Acetaldehyde	55	13
Hydrofluoric acid (HF)	0	0
Water	0	0
Nitrogen	0	604
Air	2100 m^3/hr	90 kg/hr

Table 1b. Stream 002 composition

Stream 002 Components	Flowrate (kg/hr) Rev A – Condenser Study	Flowrate (kg/hr) Rev B – Scrubber Study
Dimethyl carbonate (DMC)	32	42
VOCs - Acetaldehyde	0	0
Hydrofluoric acid (HF)	11	3
Water	227	278
Nitrogen	0	115
Air	1000 m^3/hr	17 kg/hr

Ecobat provided the average DMC solvent composition based on their academic review and the following was utilized in the Rev A condenser simulation:

Dimethyl carbonate: 60%
Ethyl methyl carbonate: 39%
Diethyl carbonate: 1%

Ecobat recommended using 100% DMC in the Rev B scrubber study.

Ecobat's model indicated that at ambient conditions, substantial DMC solvent would be pushed into the water and removed during the dewatering stage. It was estimated that 76-186 kg/h of DMC would report to the water recycle loop.

10. Equipment Design Considerations

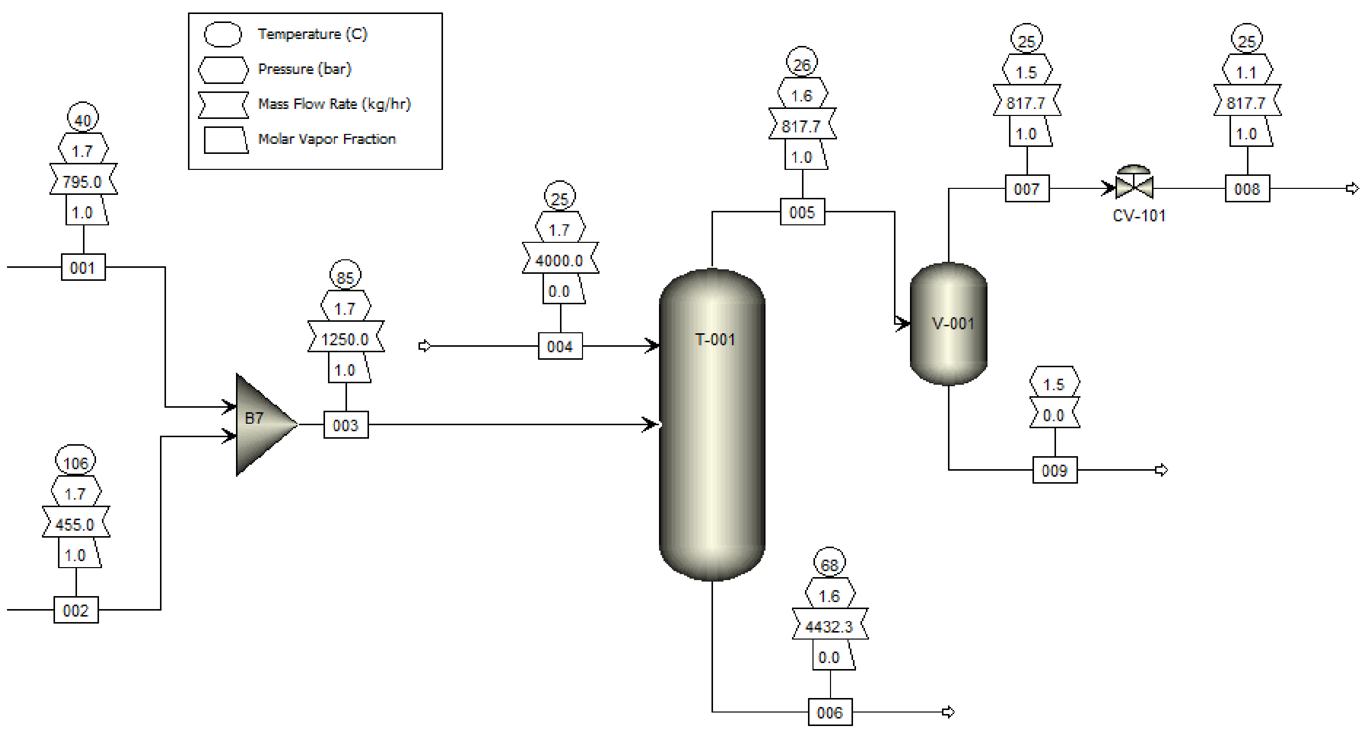

Figure 2. Flowsheet involving a scrubber system to treat contaminants present in Table 1b (Rev B)

<u>Blower</u>

- System design required an increase of pressure of organic streams 001 and 002 from atmospheric pressure to 0.7 barg.) The blowers or ejectors required for this compression service was not in the scope of this study.

<u>Vent Gas Scrubber (T-001)</u>

- Multi-stage (2, 4, 6, and 8) scrubber configuration was used to evaluate the removal of the components present in streams 001 and 002. Dimethyl carbonate and hydrofluoric acid were significantly reduced using the scrubber; percent removal was a function of water flowrate and number of stages. Preliminary runs were carried out at various water flowrates using 2, 4, 6, and 8 theoretical stages. The concentration profiles of the various components at the outlet of the scrubber are shown Figures 3a-3c.
- Sieve trays with a separation of 40, 30 and 25 cm were used for the simulations. The separation of 25 cm is adequate. For the detail design, packed towers maybe considered.

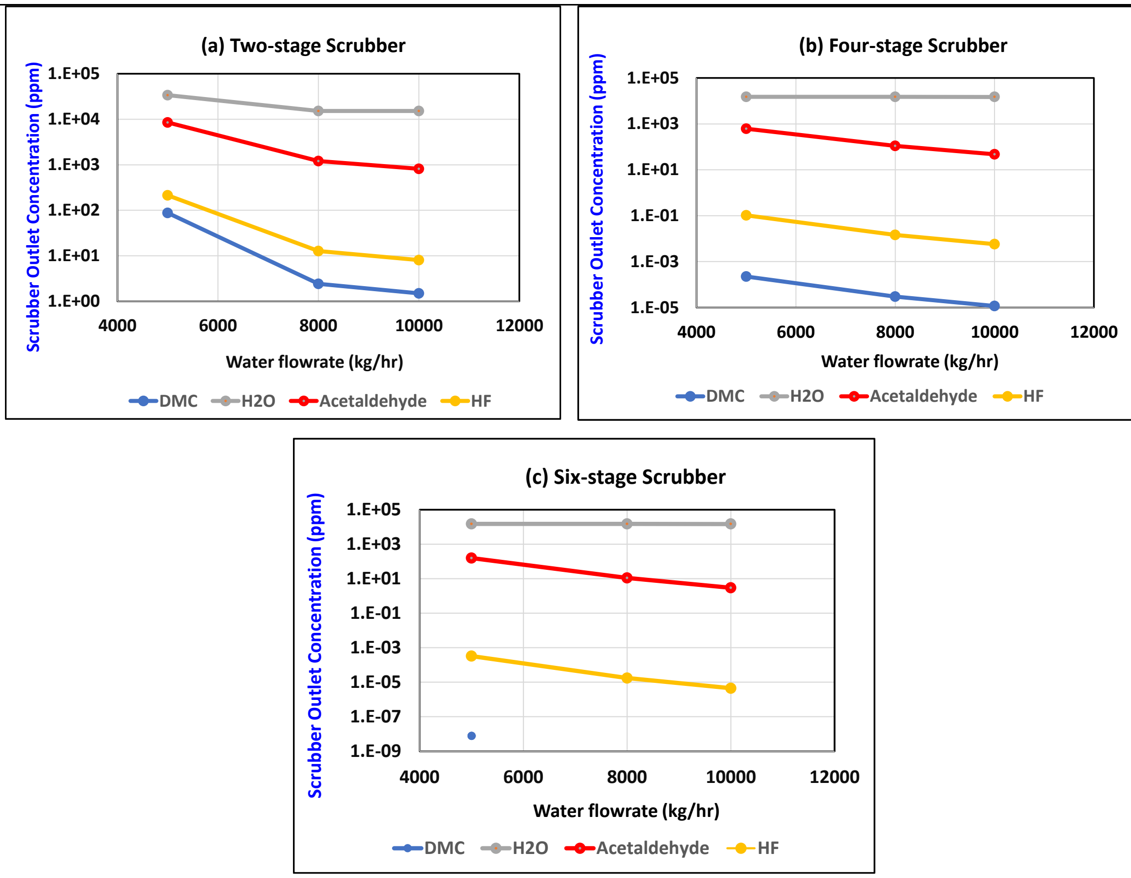

Figure 3. Effect of water flowrate on scrubber outlet concentrations at (a) two stage (b) four stage (c) six stage

Figures 3a-3c illustrate that higher removal is achieved at higher flow rates and higher number of theoretical stages. The next directive from Ecobat was to further increase the number of stages to eight and restrict the once-through water usage as much as possible. Figures 4a – 4d illustrate the effect of water flowrate on days to saturation for removal of acetaldehyde using a carbon filter downstream of the scrubber at a chosen number of stages. Days to saturation depends on the concentration of the components exiting the scrubber and bed size. The curves were obtained for acetaldehyde, since DMC and HF were significantly reduced, and acetaldehyde was the only critical component at the scrubber outlet. **Please note that saturation days are only estimated based on assumed carbon bed size for study purpose. The days to saturation need to be confirmed with vendor once final filter media beds type and size have been selected.** The figures demonstrate that at higher number of stages, a small increase in flowrate of water can yield an exponentially higher advantage of days to saturation. Additionally, we did a preliminary analysis to evaluate the use of recirculation and recycle of water, but it resulted in poor removal efficiency and did not offer a superior advantage of reduced flowrate.

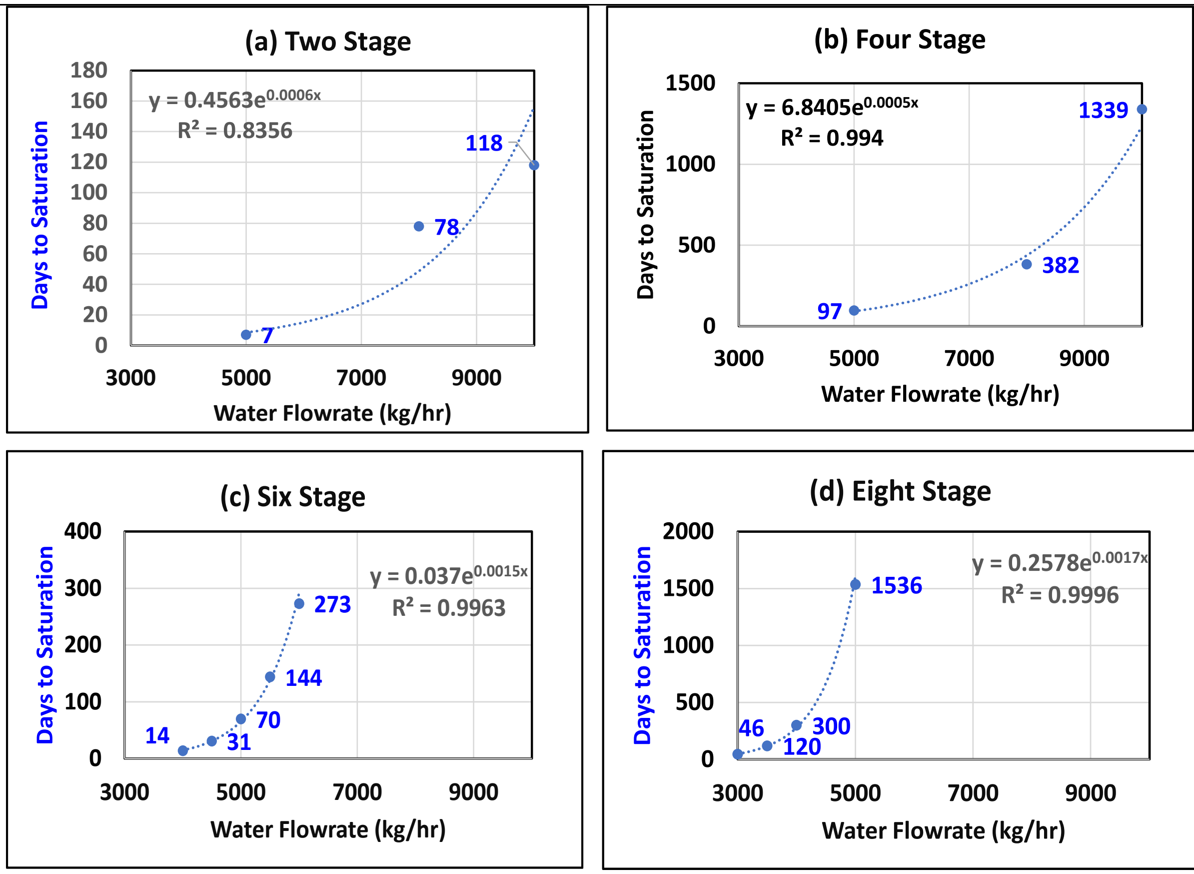

Figure 4. Effect of water flowrate on days to saturation of carbon filter downstream of scrubber (a) two stage (b) four stage (c) six stage (d) eight stage

Results were discussed with Ecobat and based on the discussion 8 stages and 4000 kg/hr of water was selected for the final simulation.

Vent Gas KO Drum (V-001)

- A 300-micron droplet size was taken as the basis. Credits were not taken for Demister installation.
- Minimum connection elevation: 200 mm from tangent line of the vessel.
- For vessel nozzle size. maximum ρv^2 in the inlet was 2500 and 3022 for the outlet. A minimum nozzle size of 2" was considered for the liquid outlet.
- Manholes, vents, steam out, and drain were considered with typical sizes.

Carbon Adsorption System (F-001)

The datasheet for the carbon adsorption system was submitted to several manufacturers as indicated below.

Table 2: Carbon filter details to treat effluent from scrubber

FILTER COMPANY	DESIGN PARAMETERS	CONTAMINANT VOC ACETALDEHYDE	 ORGANIC DMC	 Halogen HF
CONTINENTAL CARBON	**Bed**	CPIIZ	4X8S	STCL(initial HSCL)
	Bed size	2520 -3900 lbs	Not required since CPIIZ will remove trace amount of DMC	2520 lbs
	Time to Saturation	3-4 months		2-3 years
	Water handling	Use of condenser or mist eliminator in vessel		
	Additional Information	Proposed filter media works best in the range of 4 to 50		
DESOTEC	**Bed**	Aircon HC-XL with a microporous activated Carbon Organosob 10-CO		TDS Aircon 2000 PE with an impregnated activated carbon Airpel
	Bed size			
	Time to Saturation	1.5 months	Not required	1 year
	Water handling	Heating to 30 °C to less than 70 % relative humidity using tracing or heater.		
	Additional Information	They can operate as low as -30°F.		
RECO	**Bed**	Virgin carbon	AW Carbon	Impregnated Carbon
	Bed size			
	Time to Saturation			
	Water handling	Dehumidifier (KO drum with limestone fill)		
	Additional Information	Use plastic for vessels and equipment		

The following companies declined to provide system designs due to lack of expertise:

- SHELCO
- EGS Filtration
- Calgon filter (Kukaray)
- Dr M. (Dr. Mueller)
- Gore

11. Calculations

Calculations were done using ASPEN Plus V12

12. References

A) Block Flow Diagram supplied by Ecobat (Figure 1)

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13. Results Summary

The two organic streams defined by Ecobat were combined and served as inlet to the scrubber. Simulation using Aspen Plus V12 included runs with a scrubber with 2, 4, 6, and 8 stages and water flowrates ranging from 3000 to 10000 kg/hr. In addition, as requested by Ecobat, simulations recirculating the wastewater to the tower were done and results were not satisfactory. Based on the preliminary results and discussion with Ecobat, the final simulation of a scrubber with 8 stages and using 4000 kg/hr water was shared with the downstream carbon filter vendors. The reduction of contaminants simulated in both studies – (a) using condenser – Rev A and (b) vent gas scrubber – Rev B is summarized in Tables 3a and 3b.

Table 3a: Composition and Flowrate of Condenser Inlet, Carbon Filter Inlet, WW Inlet, and % Removal (Rev A)

Component	Condenser Inlet (kg/hr)	Vapor to Carbon Filter Inlet (kg/hr)	Vapor to Carbon Filter Inlet (ppm)	Liquid to WW inlet (kg/hr)	% Removal
Dimethyl carbonate (DMC)	160.2	28.6	5084	131.6	82
Ethyl methyl carbonate	104.1	8.5	1511	95.6	92
Diethyl carbonate	2.7	0.1	14	2.6	97
VOCs - Acetaldehyde	55.0	50.5	8977	4.5	8
Hydrofluoric acid (HF)	11.0	7.8	1379	3.2	29
Water	227.0	16.2	2880	210.8	93
Nitrogen	0.0	0.0	-	0.0	
Air	5518.0	5513.7	-	4.3	
TOTAL	**6078.0**	**5625.5**		**452.5**	

Table 3b: Composition and Flowrate of Scrubber Inlet, Carbon Filter Inlet, WW Inlet, and % Removal using 8 theoretical stages and 4000 kg/hr water to scrubber (Rev B)

Component	Scrubber Inlet (kg/hr)	Scrubber Inlet (ppm)	Vapor to Carbon Filter Inlet (kg/hr)	Vapor to Carbon Filter Inlet (ppm)	Liquid to WW Inlet (kg/hr)	% Removal
Dimethyl carbonate (DMC)	130.0	104,000	0.00	0	130.0	100.0
VOCs - Acetaldehyde	13.0	10,400	0.76	933	12.2	94.1
Hydrofluoric acid (HF)	3.0	2400	2.62×10^{-08}	0.00003	2.99	99.9
Water	278	222,400	10.82	13,228	4267.2	96.0
Nitrogen	719.0	-	702.7	-	16.3	
Air	107.0	-	103.4	-	3.6	
TOTAL	**1250.0**		**817.7**		**4432.3**	

The level of contaminants at the outlet of the condenser system was higher than what could be fed to the carbon adsorption system and the time to saturation was estimated to be less than one day, which makes the condenser system design impractical. Use of scrubber to remove the components from streams 001 and 002 offers a promising route for significant removal of DMC, VOCs, and water before it is sent to the carbon filter system. The results of the scrubber system simulation were submitted to several Filtering System companies and all of them coincide that the removal of the contaminants was adequate, and the life of the filter media was more than 90 days for the component present at the highest concentration (acetaldehyde) at the scrubber outlet.

14. Conclusions & Recommendations:

- The addition of an 8-stage scrubber with a water flowrate of 4000 kg/hr will reduce the level of contaminants as indicated in Table 3b:
  - Dimethyl carbonate: 100.0 %
  - Acetaldehyde: 94.1 %
  - HF: 99.9 %
- The saturation days of filter media for acetaldehyde is estimated to be more than 90 days. Saturation days will depend on bed type, the size of the bed, and manufacturer, and it needs to be confirmed with the vendors.
- It is recommended to trace lines from the scrubber to the inlet of the filtering system to maintain the required relative humidity and avoid free water in the filtering system inlet.

Item	Attachments	Rev.	Pages
1	PFD	B	
2	Vent Gas Scrubber (T-001) datasheet	A	
3	Vent Gas KO Drum (V-001) datasheet	B	
4	Vent Gas Filter System (F-001) datasheet	B	