Technical performance assessment of large scale process concepts for the recycling of end-of-life photovoltaic panels

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Introduction

Photovoltaic power systems have emerged as one of the most promising alternatives to reduce the impact of the energy sector on climate change and to improve the energy security of countries all over the world [1]. Although photovoltaic panels (PhVP) have much larger useful lifespan than the majority of electronic and electrical equipment they still become waste products after approximately 30 years.

According to literature data there are estimates for the accumulation of 1.7–8 million tons by 2030 and 60–78 million tons by 2050 of end-of-life PhVP (EOL PV) [2-4]. To manage such a large quantity of waste material goes beyond just enforcing policies, it needs a massive research and innovation effort to ensure the development and large scale deployment of ground-breaking, cost effective and eco-friendly EOL PV recycling technologies.

In attempt to provide a useful contribution to the field of EOL PV recycling, the current study presents novel large scale process concepts for the comprehensive treatment of EOL PV.

Results @ Discussions

The process of recycling the EOL PhVP is divided into the following subsystems (the PFDs developed in CHEMCAD are in Fig. 1):

1 - Processing and mechanical separation
2 - The processing of the coarse fraction
3 - Ag and Si release by pyrolysis
4 - Dissolution and purification
5 - Silver recovery by reducing AgCl to Ag considering two cases:
  - Case 1 - the reducing system is glucose + NaOH + Na_2CO_3
  - Case 2 - the reducing agent is Al.

The mathematical models developed and presented in Fig.1 for the recovery process of metals from EOL PhVP were simulated in order to find the optimal technological option. For both cases, three different thermal integrations were considered: (I) - no thermal integration; (II a) - thermal integration only for the recycling process and (II b) - thermal integration include also the CO_2 caption process.

The obtained results are presented in Tables 1-6.

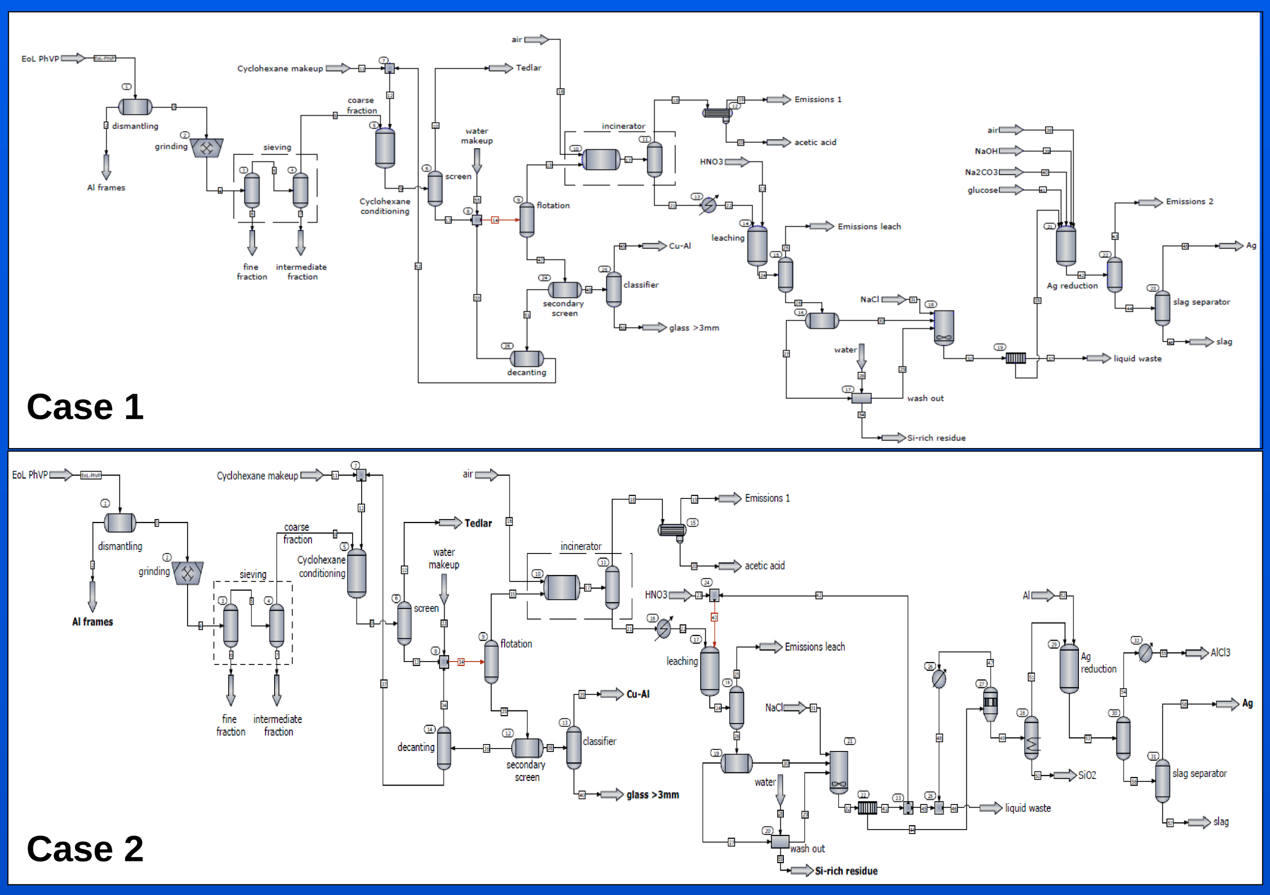

Fig. 1. Process flow diagrams of the EOL PhVP recycling plant.

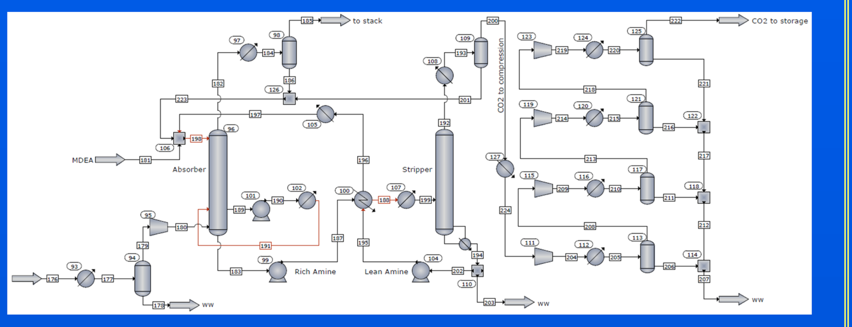

Fig. 2. PFD for the CO_2 capture process.

Considering the importance of CO_2 capture in the industrial sector, the recycling plant of EOL PhVP was coupled with a post-combustion CO_2 capture based on amine absorption process (the PFD developed in CHEMCAD is presented in Fig. 2).

Table 1. Production rate and recovery yield for the main products of the end-of-life PhVP recycling process.

Process type	Product	Glass	Tedlar	Si	Ag	Al	Cu
	Production rate, (kg/h)	6950	430	330.20	4.45	1000	108
Case 1 and Case 2	Recovery yield, (%)	97	98	89.23	89.01	98.83	99.99

Table 2. Specific consumption of raw materials in kg/kg PhVP to obtain the main products of the recycling process of end-of-life PhVP.

Process type	Raw material		H_2O	HNO_3	NaCl	NaOH	Na_2CO_3	$C_6H_{12}O_6$	aer	C_6H_{12}	TOTAL
Case 1	Consumption	kg/h	919	1713	26.39	2.42	1.17	1.12	16004	203.1	-
		kg/kg PhVP	0.09	0.17	~ 0				2.75	0.02	3.03
Case 2	Consumption	kg/h	919	210	2.5	-	-	-	16000	203.1	-
		kg/kg PhVP	0.09	0.02	~ 0	-	-	-	2.75	0.02	2.88

Table 3. Specific consumption of raw materials in kg/kg product for different subsystems of the spent PhVP recycling process.

Process type	Subsystem	1	2	3	4	5	TOTAL
Case 1	TOTAL, (kg/h)	10203	266	16000	2392	9.6	
	W, (kg/kg)	2.91	0.05	0.91	4.81	0.52	9.2
Case2	TOTAL, (kg/h)	10203	266.1	16000	864.9	0.38	
	W, (kg/kg)	2.91	0.05	0.91	1.74	0.06	5.67

Table 4. Thermal energy balance for different subsystems of the end-of-life PhVP recycling process for the two non-thermally integrated case studies.

Process type	Subsystem	Parameters of energy flows	Thermal energy				TOTAL consumption, MJ/h	Specific consumption, kJ/kg	Equivalent consumption, kg CH_4/h
			Generated			Consumed			
			1	2	3	1			
Case 1	1	T, °C				35			
		Q, MJ/h				68	68	6.80	1.36
	2	T, °C				34			
		Q, MJ/h				61	61	12.05	1.21
	3	T, °C	400	400	400				
		Q, MJ/h	-4900	-51581	-89				
	4	T, °C	0			60			
		Q, MJ/h	0			204	204	411	4.08
	5	T, °C	600						
		Q, MJ/h	-1.40						
Case 2	1	T, °C				35			
		Q, MJ/h				39	39	3.90	0.78
	2	T, °C				34			
		Q, MJ/h				61	61	12.04	1.21
	3	T, °C	400	400	400				
		Q, MJ/h	-4900	-53120	-89				
	4	T, °C	40			60			
		Q, MJ/h	-491			532	532	1070	10.64
	5	T, °C	500						
		Q, MJ/h	-7						

Table 5. Overall thermal energy balance for the recycling process of end-of-life PhVP.

Process type		Parameters	Thermal energy				Equivalent CH_4, kg CH_4/h	
			Generated, MJ/h			Consumed, MJ/h	Generated	Consumed
Case 1	I	T, °C	600	400	600	60		
		Q, MJ/h	-1.4	-56570	-1	333	1131	6.66
	II a	T, °C		400				
		Q, MJ/h		-56365			1127	
	II b	T, °C		400				
		Q, MJ/h		-46487			930	
Case 2	I	T, °C	40	400	500	60		
		Q, MJ/h	-491	-58109	-7	631	1162	12.63
	II a	T, °C		400				
		Q, MJ/h		-57577			1152	
	II b	T, °C		400				
		Q, MJ/h		-47699			954	

Table 6. Total and specific CO_2 emissions, respectivelly energy consumption of the CO_2 capture process for the recycling of end-of-life PhVP.

Process type		No capture		With capture		Capture energy consumption CO_2, (GJ/h)
		Total, (kg CO_2/h)	kg CO_2/t PhVP	Total, (kg CO_2/h)	kg CO_2/t PhVP	
Case 1	I	2989	298.92	149	14.95	9.94
	IIa	2971	297.09	149	14.85	9.88
Case 2	I	3006	300.55	150	15.03	9.99
	IIa	2971	297.07	149	14.85	9.88

Conclusions

► It was found that in the best operating conditions the average recovery rate of critical materials is over 89 % and the purity of the obtained compounds was more than 99 % which makes them suitable for new PhVP production.

► The results proved that in both case studies the pyrolysis and combustion of organic materials provides the necessary amount of energy for the thermal integration of the process.

► As an overall conclusion it can be stated that both case studies remain net thermal energy producers with the capacity to provide an equivalent of over 900 kg CH_4/h even in this situation with CO_2 capture.

References

1. Mahmoudi, S., Huda, N., Behnia, M., 2020. *Environmental impacts and economic feasibility of end of life photovoltaic panels in Australia: A comprehensive assessment*. Journal of Cleaner Production 260, 120996.
2. Mahmoudi, S., Huda, N., Behnia, M., 2021. *Multi-levels of photovoltaic waste management: A holistic framework*. Journal of Cleaner Production 294, 126252.
3. Rubino, A., Granata, G., Moscardini, E., Baldassari, L., Altimari, P., Toro, L., Pagnanelli, F., 2020. *Development and techno-economic analysis of an advanced recycling process for photovoltaic panels enabling polymer separation and recovery of Ag and Si*. Energies 13(24), 6690.
4. Wang, X., Tian, X., Chen, X., Ren, L., Geng, C., 2022. *A review of end-of-life crystalline silicon solar photovoltaic panel recycling technology*. Solar Energy Materials and Solar Cells 248, 111976.

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