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Techno-Economic Evaluation of a Molecular Sieve-Based Dehydration Unit

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---***ABSTRACT***---
Adsorption dehydration of natural gas is a critical operation in the processing of oil and gas reservoir fluids as it reduces the potential for pipelines and equipment to corrode, get plugged by hydrates, or cause other operational issues. This study technically evaluates the impact of temperature and pressure on the performance of an adsorption unit that uses zeolite molecular sieve beds for dehydration. Process simulation with the proprietary aspen adsorption at varying operation pressures and temperatures in wet natural gas, indicated that, although dehydration for both base and optimal cases are met, pressure and temperature elevation penalizes the dehydration performance such that efficiency drops by 44 percent. The dynamic process simulation results show that profiles of mole fractions of methane in the bed indicated a drop in product composition at the elevated pressures and temperatures. Results from the economic evaluation in terms of cost effectiveness and return on investment (ROI) are shown with consideration of a product stream comprising 90% methane, 5% each of ethane and propane and 0% water.at a temperature and pressure of 25^0C *and 3.3 Bar. The time taken for the product stream to emerge from the simulation is 2400 seconds and the basis of the evaluation is the amount of dry natural gas available following adsorption. We considered two scenarios: (i) dehydrated natural gas immediately sold to buyers; or (ii) dehydrated natural gas fed into an LNG plant. Revenue from either scenario was computed, including both CAPEX and OPEX. Finally, the profitability of both scenarios based on cash flow analysis is investigated using instruments such as payback time, net present value and internal rate of return, and findings indicate a profitable venture for both scenarios with greater profitability registered by the LNG route.*

KEYWORDS;- *Techno-Economic Evaluation, Natural Gas(NG) Adsorption Dehydration, Molecular Sieve*

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I. INTRODUCTION

Field processing of natural gas and the liquefaction of natural gas involve a crucial step which is the dehydration process. The process of dehydration aims to control the moisture content of natural gas and to ensure the compliance of the fluid to pipeline and pretreatment specifications. Meeting the specifications safeguard downstream equipment and maintains process efficiency and safety. For cryogenic processes and other applications, hydrate control is necessary in order to prevent blockages and associated hazards within the facility such as corrosion prevention, maintenance costs reduction and plant lifespan extension. Several processes are available for absorption and adsorption dehydrating of natural gas (Abam and Umer, 2018; Kinigoma and Ani, 2016; Naresh et al, 2019; Kemper et al, 2014; Santos et al, 2017; Santo et al, 2021). Kinigoma and Ani (2016) carried out comparison of gas dehydration methods based on energy consumption where they compare three conventional methods of associated natural gas dehydration on the basis of energy requirement. The methods are triethylene glycol (TEG) absorption, solid desiccant adsorption and condensation with their results showing that energy required for all three processes decreases with increase in pressure, but condensation dehydration requires the least energy at high pressures. The adsorption dehydration component of their work did not include economics of the process which can provide a clue on the benefits and cost savings in deploying such a process (Kinigoma and Ani, 2016).

Adsorption dehydration can involve temperature swing adsorption (TSA) and/or pressure swing adsorption (PSA). In either case, mass transfer of adsorbates on adsorbent occurs in the adsorption column where a fixed bed allows the continuous flow of fluids through the bed of adsorbent, and where the adsorbate is retained until adsorbent saturation. At saturation point, adsorption is no longer possible and regeneration of the beds becomes necessary at this point which is achieved through a desorption process.

Solid desiccants used for adsorption are porous solid materials that have the ability to selectively separate compounds in a mixture – the so-called molecular sieves. Molecular sieves are of different types but most are characterized by a porous, hydrophilic crystalline structure of aluminosilicates, even though the process of dealumination makes the structure hydrophobic. The water molecule has a diameter small enough to get it adsorbed. Thus, the objective of this work was to emphasize the importance of the adsorption separation technology in field and gas plant processes, and to discuss the influence of pressure and temperature on performance, and to implement the process on a proprietary simulator, taking into account the adsorption process in molecular sieve for the separation of water from natural gas and this problem has received less attention in open literature.

II. MATERIALS AND METHODS

Process Description

An adsorption simulation on zeolite molecular sieves was performed using the proprietary Aspen Adsorption (Sirawich and, Chantaraporn, 2022). Figure 1 shows a typical flowsheet of the process simulation (S. Gupta, 2012). The water in the wet gas passing through the molecular sieves is selectively adsorbed. Regeneration of the beds follows, upon saturation of the bed with water, in order to recover their adsorption capacity. The process involving a TSA process comes into play, and allows the heating of the bed by a hot gas up to a point where the adsorbed water molecules get desorbed onto the surface of the bed. The desorbed water vapour is then purged off the system. The regeneration gas is cooled and separated upon full regeneration, and the cycle repeated when necessary. Figure 1 shows a Free Water Knock Out Tank (FWKO) for free water removal before it got fed into the adsorber of 2.4meter height and 0.35m diameter, containing activated carbon of density 1420 kg/m^3.

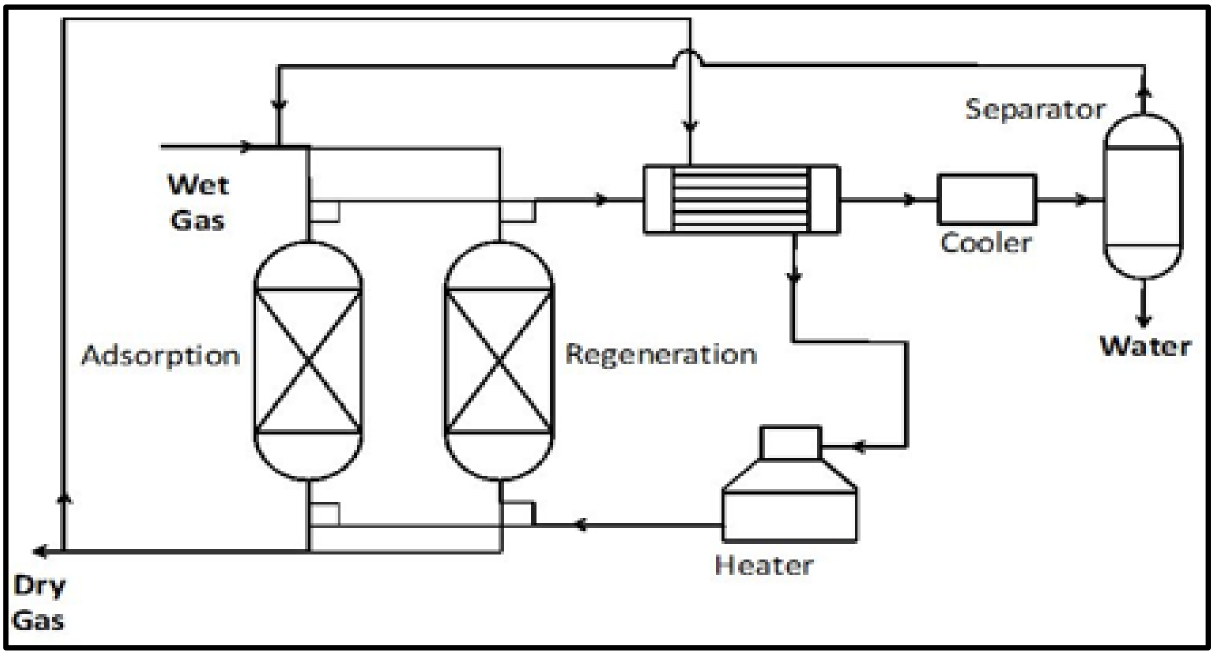

Figure 1: Typical flowsheet of the dehydration process (S. Gupta, 2012))

The wet gas is assumed 100% dried with dried gas reaching methane composition of 90% and 5% each of ethane and propane. The simulation time is 2400 seconds with the desorption process achieved at a pressure and temperature of 3.5 bar and 35^{0}C, respectively. The feed gas contains 3% mole of water and at the onset of adsorption, three zones are generated in the bed: the equilibrium zone with a saturation front. A moving profile just ahead of the saturation front is called the mass transfer zone (MTZ) and the MTZ is followed by an active zone which is yet to be contacted by the wet gas. Breakthrough occurs when the MTZ reaches the end of the bed, with a water content above specification.

Process Economics

Economic evaluation of the adsorption dehydration process was carried out to determine profitability in terms of return on investment (ROI), payback time and net cash flow with considerations of the capital costs, operating costs, revenue generation, cost-benefit analysis, and other financial metrics. Table 1 and 2 show the effect of high

Table 1: Base Case

FEED STREAM			PRODUCT STREAM		
	Value	Units		Value	Units
Flowrate	1000	Kmol/h	Flowrate	1000	Kmol/h
Methane	70.0	Mol %	Methane	50.0	Mol %
Ethane	15.0	Mol %	Ethane	25.0	Mol %
Propane	12.0	Mol %	Propane	25.0	Mol %
Water	3.0	Mol %	water	0.0	Mol %
Temperature	35	^{0}C	Temperature	45	^{0}C
Pressure	45	Bar	Pressure	42	Bar

Table 2: Optimal Case

FEED STREAM			PRODUCT STREAM		
	Value	Units		Value	Units
Flowrate	23.478	Kmol/h	Flowrate	22.9885	Kmol/h
Methane	70.0	Mol %	Methane	90.0	Mol %
Ethane	15.0	Mol %	Ethane	5.0	Mol %
Propane	12.0	Mol %	Propane	5.0	Mol %
Water	3.0	Mol %	water	0.0	Mol %
Temperature	25	^{0}C	Temperature	25	^{0}C
Pressure	3	Bar	Pressure	3.3	Bar

temperature and pressure on molecular sieve adsorbent unit on two cases: base case and optimal case. Results on these two cases suggest that the higher the temperature and pressure, the less efficient the separation (adsorption) process is (see tables 1 and 2)

III. RESULTS AND DISCUSSION

This study aims to techno-economically evaluate adsorption dehydration process using a base case and an optimal case of the process. The dehydration plant treats 23.47 kmol/hr of wet gas with composition and conditions shown in table 1 and 2. The adsorption simulation results suggest that dehydration performance is strongly dependent on the temperature and pressure of the wet natural gas (NG) feed (see Figures 2 and 3). In the real dehydration process, before the gas enters the bed, certain pre-conditioning operations are necessary: It is worth noting that for conventional NG scenarios higher operation pressure and temperature of the plant decreases the performance of the dehydration unit. However, at relatively lower temperatures and pressures, adsorption performance increases. In other words, dehydration unit is being penalized by the higher flowrate and the reduction of the adsorption phase duration. Thus, effects on temperature and pressure elevation on the adsorbed water showed that the mole fraction of methane in product stream decreased by 44%. For both simulation cases, dehydration was 100 %, which indicates that the product stream does not retain water molecules. On the other hand, with a higher flow rate, breakthrough time decreases, as the bed saturates more quickly.

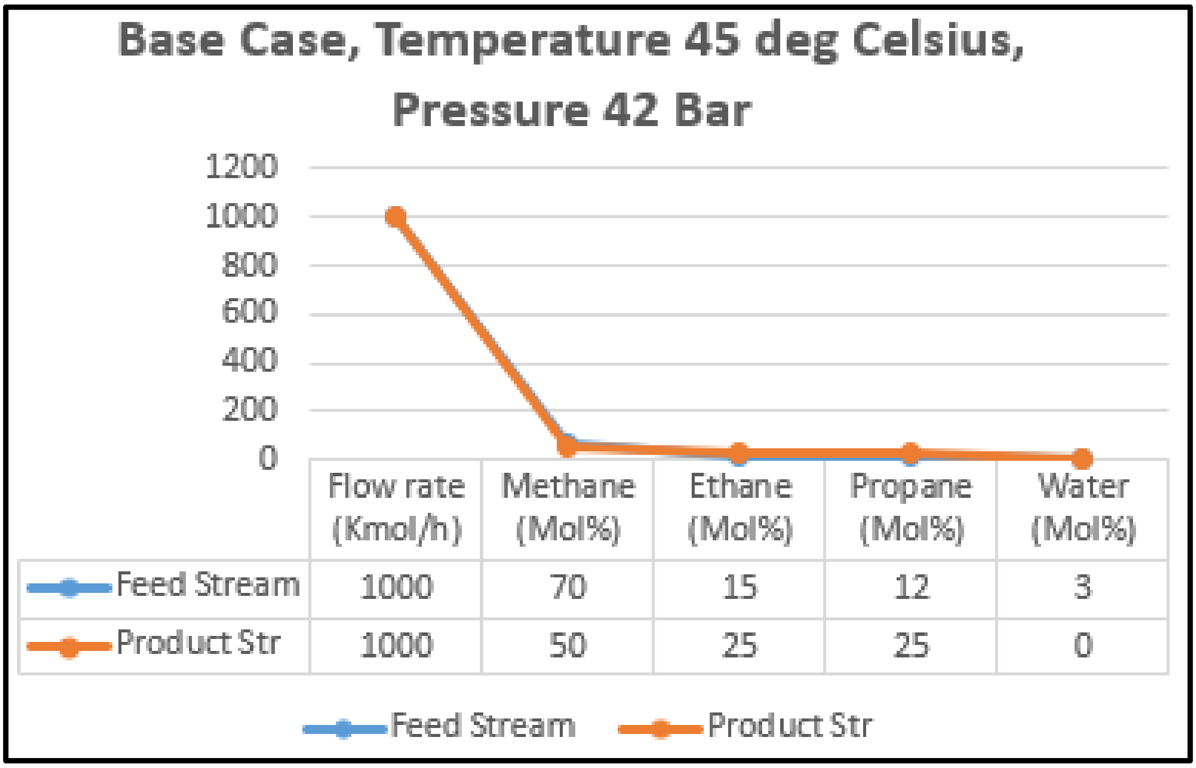

Figure 2: Base case results at relatively higher temperature and pressure.

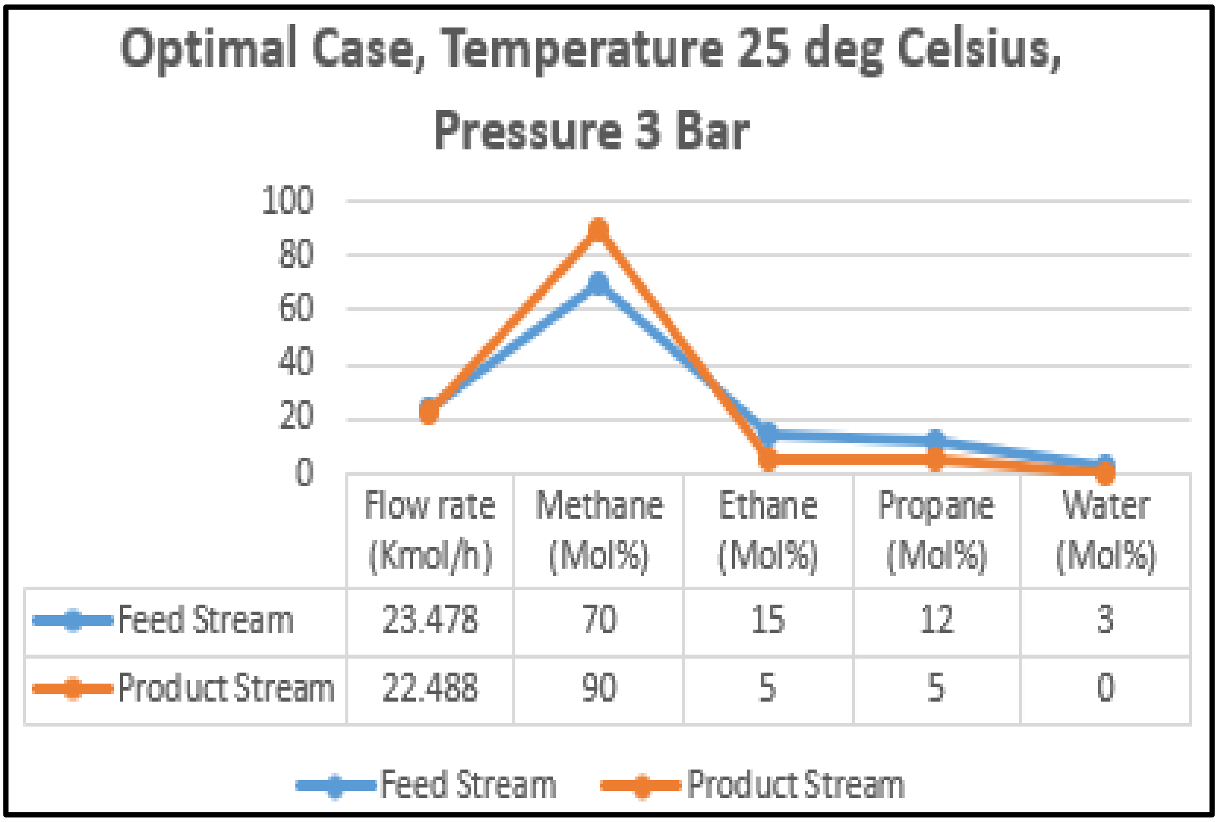

Figure 3: Base case results at relatively lower temperature and pressure.

Process breakthrough occurs at 2400 seconds after the start of simulation. Initially we tried to simulate the process with a temperature of 35ºC and a pressure of 45 Bar, even though the water was totally removed from the product stream, the amount of C1 (methane) dropped to 50mol% from 70mol%. On the other hand, when the temperature and pressure were reduced to 25ºC and 3.3 bar, respectively, the product stream had a C1 (methane) mol% of 90. This means that the molecular sieve unit is very sensitive to changes in feed temperature and pressure, and in order to get the best of this unit, it is to introduce pressure control valves, pressure alarms, temperature gauges, temperature control valves and alarms must be placed at the inlet to the molecular sieve to detect and rectify any process parameter that will limit its efficiency.

Contaminants in the gas may also reduce the effectiveness of the molecular sieve dehydration unit by increasing fouling of the adsorbent material in the unit, and this can increase the cost of setting up the unit because further pre-treatment is needed to make the gas suitable for the unit. If no pre-treatment is available for the contaminated gas, there will be constant fouling in the unit and this will lead to regular replacement of the adsorbent material thus raising the operational cost of the unit. Also, the gas in the product stream will not be properly dehydrated which defeats the purpose of setting up the unit. Therefore, constant monitoring of the feed gas is crucial to ensuring that the adsorbent material in the dehydration unit is effective in removing the water vapors from the wet gas

Economic Evaluation

The economic evaluation of the adsorption process using a cash flow model, which evaluated the capital costs of setting up the molecular sieve dehydration unit, the operational cost of running the adsorption unit and also the revenue derived from the unit. We considered two revenue paths for the dried gas exiting the molecular sieve dehydration unit. The first was to send the dried gas to an LNG plant for liquefaction, the second was to sell the dry natural gas directly to buyers. Both paths in Figure 5 and 6 generated massive revenues which can be viewed on the cash flow analysis tables.

The Internal Rate of Return (IRR) calculated from both product scenarios indicates that the adsorption process is a highly profitable one when compared with the initial investments. Cash flow tables 3 and 4 provides a structured overview of the cash flow from two project with the revenue section representing the cash inflows generated from both project routes (NG or LNG). Tables 3 and 4 is presented with an interest rate of 10% for LNG with corresponding net present value (NPV) and IRR showing $204,229,534.59 and 2663%, respectively while for NG, NPV was $45,748,781.41 and its IRR was 61% meaning that the outcome should be accepted since both where profitable.

The total revenue is computed from the product gas volume energy (in MMBTU) and gas price per MMBTU. The capital expenses (CAPEX) encompasses the cash outflows related to engineering and design costs, purchasing costs, installation costs and mobilization cost of the mol sieve unit and other associated units. It also includes expenditures for acquiring or leasing equipment, constructing production facilities, expanding infrastructure, and other major capital investments aimed at increasing gas production capacity.

Depreciation accounts for the systematic allocation of the costs associated with acquiring and developing product assets over their useful life and is the quotient of CAPEX and Useful Life (say in 5 years). The pretax is relevant since it helps in income tax computations usually determined from the difference between revenue and operating expenditure (OPEX). Taxable income represents the income after various deductions, exemptions, and adjustments have been taken into account in the project.

We take note of the Post-Tax Net Cash Flow which provides a more accurate representation of the cash available for distribution, reinvestment, or other purposes and it is a function of Revenue, OPEX , CAPEX and Tax**.** With payout time or payback period, we are able to determine the length of time required for an investment or project to recover its initial investment or breakeven and it is the quotient of Initial Investment and Net Cash Flow per Period.

With net present value, we can evaluate the profitability of both NG and LNG projects since it determines the present value of expected cash flows by discounting them to the present time and then subtracts the initial investment. The NPV is quite different from the internat rate of return (IRR) as the later measures the profitability and potential return of the project. It represents the discount rate at which the net present value (NPV) of the cash flows becomes zero.

Table 3: Cash Flow LNG option

YEAR ⟶	2024	2025	2026	2027	2028	2029
CAPEX ($)	2043121.73	0	0	0	0	0
OPEX ($)	0	5275444.096	5275444.096	5275444.096	5275444.096	5275444.096
GAS TREATED DAILY (MMSCF)	0	13.843	13.843	13.843	13.843	13.843
ANNUAL GAS TREATED (MMSCF)	0	5052.695	5052.695	5052.695	5052.695	5052.695
ENERGY FROM LNG PRODUCTION (MMBtu)	0	5041629.598	5041629.598	5041629.598	5041629.598	5041629.598
COST OF LNG ($/MMBTU)	0	15.41	15.41	15.41	15.41	15.41
REVENUE ($)	0	77691512.11	77691512.11	77691512.11	77691512.11	77691512.11
DEPRECIATION ($)		408624.346	408624.346	408624.346	408624.346	408624.346
PRE-TAX ($)		72416068.01	72416068.01	72416068.01	72416068.01	72416068.01
TAXABLE INCOME ($)		72007443.66	72007443.66	72007443.66	72007443.66	72007443.66
TAX ($)		18001860.92	18001860.92	18001860.92	18001860.92	18001860.92
POST TAX NCF ($)	-2043121.73	54414207.09	54414207.09	54414207.09	54414207.09	54414207.09
PAYOUT TIME	-2043121.73	52371085.36	106785292.5	161199499.6	215613706.6	270027913.7

Table 4: Cash Flow for dehydrated natural gas (NG) sale.

YEAR ⟶	2024	2025	2026	2027	2028	2029
CAPEX	2043121.73	0	0	0	0	0
OPEX	0	50783.699	50783.699	50783.699	50783.699	50783.699
GAS TREATED DAILY (MMSCF)	0	13.843	13.843	13.843	13.843	13.843
ANNUAL GAS TREATED (MMSCF)	0	5052.695	5052.695	5052.695	5052.695	5052.695
ENERGY FROM NG PRODUCTION (MMBtu)	0	5052695	5052695	5052695	5052695	5052695
COST OF LNG ($/MMBTU)	0	3.31	3.31	3.31	3.31	3.31
REVENUE ($)	0	16724420.45	16724420.45	16724420.45	16724420.45	16724420.45
DEPRECIATION ($)		408624.346	408624.346	408624.346	408624.346	408624.346
PRE-TAX ($)		16673636.75	16673636.75	16673636.75	16673636.75	16673636.75
TAXABLE INCOME ($)		16265012.41	16265012.41	16265012.41	16265012.41	16265012.41
TAX ($)		4066253.101	4066253.101	4066253.101	4066253.101	4066253.101
POST TAX NCF	-2043121.73	12607383.65	12607383.65	12607383.65	12607383.65	12607383.65
PAYOUT TIME	-2043121.73	10564261.92	23171645.57	35779029.22	48386412.87	60993796.52

Figure 4 shows a plot of Capital Expenditure (CAPEX) against Year where you observe project investment on the investment year (2024) reaching USD2,043,121.73. The CAPEX covers costs lile engineering design, construction costs, equipment purchase, installation costs, infrastructure modifications and commissioning. Observe that it is largely a one-off expenditure (non-recurrent) in 2024 that subsequent years attracted negligible CAPEX.

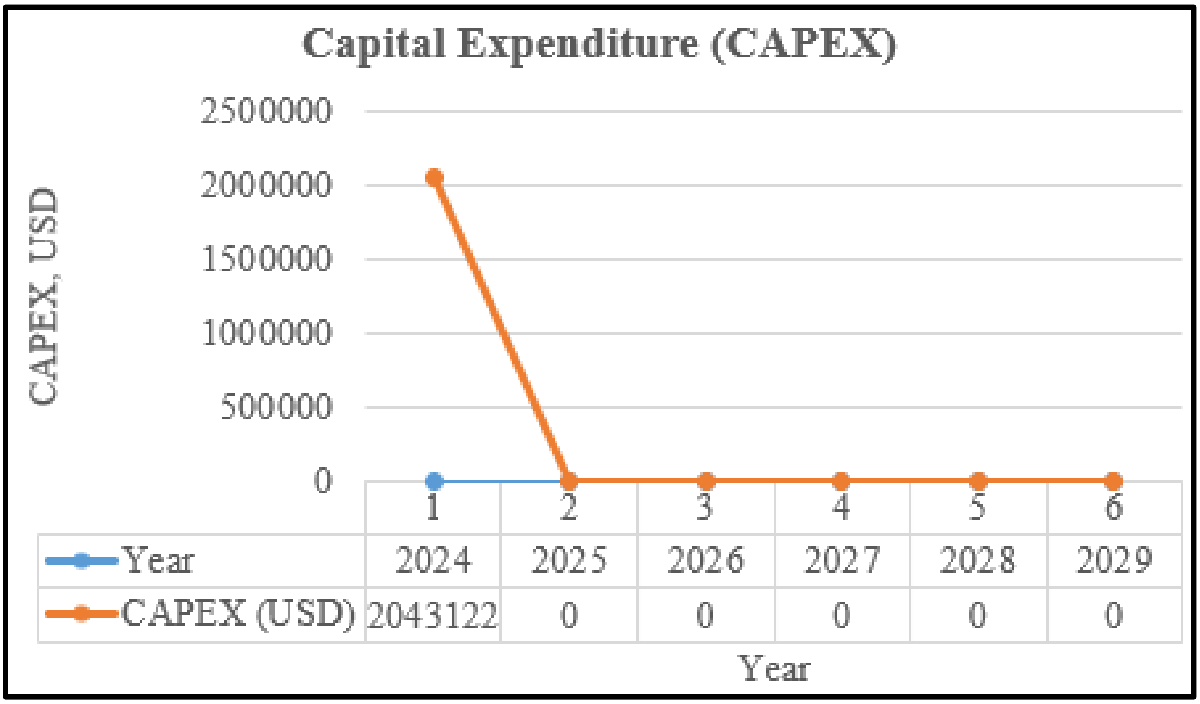

Figure 4: Capital Expenditure (CAPEX) versus Year.

Figure 5 depicts Operating Expenditure (OPEX) against year including expenses related to energy consumption, maintenance and repairs, replacement of adsorbents, wastes disposal, labour, and day-to-day operational activities. In 2024, no operating expenditure were made until later years that incurred annual expenses of approximately USD 5,275,444.096.

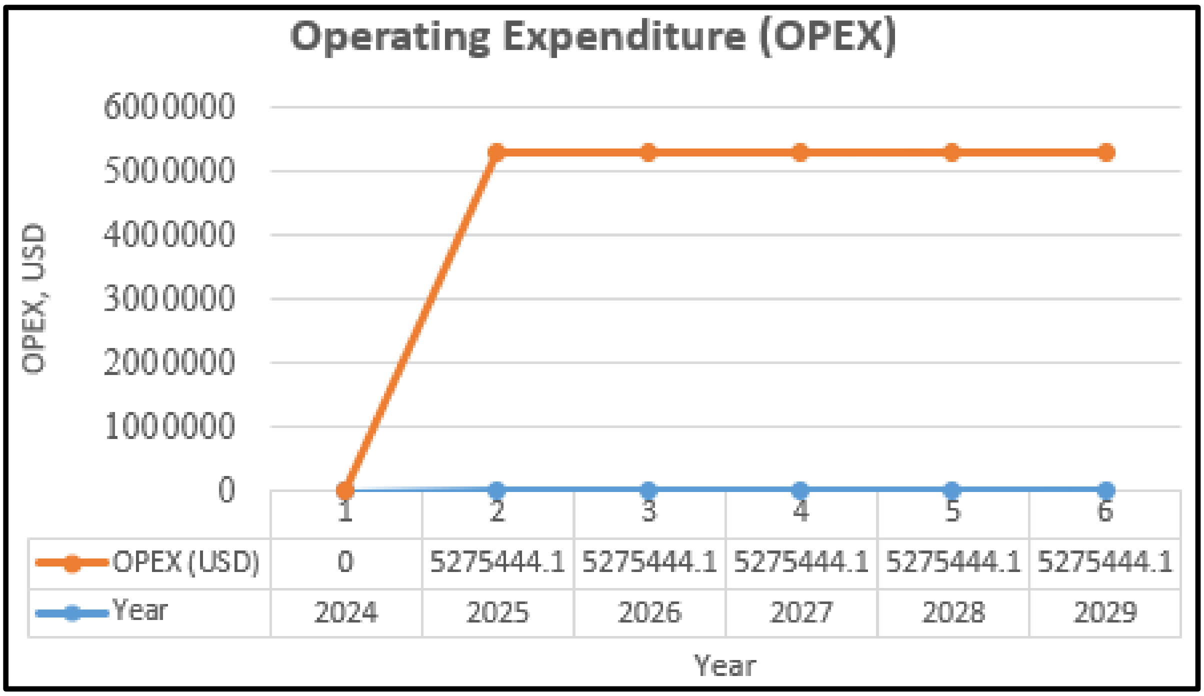

Figure 5: Operating Expenditure (OPEX) versus Year.

A similar profile to OPEX was observed relative to revenue (see Figure 6). Revenue is generated from the sale of the dehydrated gas and any monetizable by-products or co-products from the process. Obviously, no revenue was generated in 2024 but you can observe the massive revenue generated in later years, and annually to the tune of USD 77,691,512.11 between 2025 and 2029.

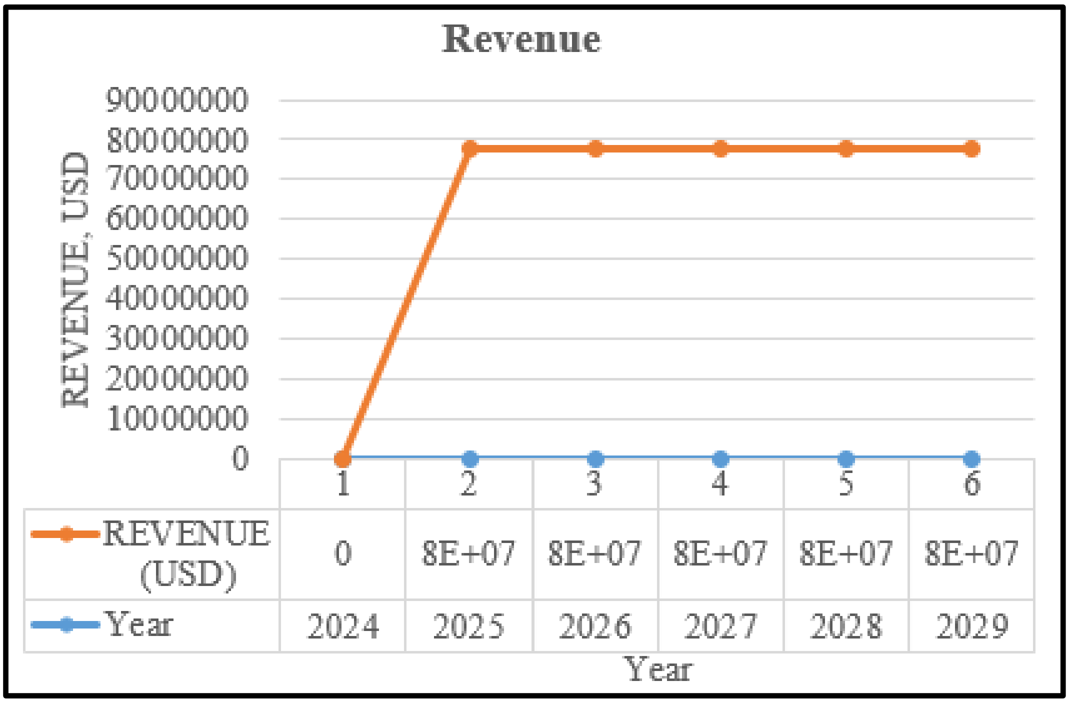

Figure 6:Annual Revenue Generation

Figure 7 shows the time taken to break even in the Project which is characterized by a change from negative values to positive values. Observed that the amount changed in 2024 the negative value of USD -2,043,121.73 to the positive one of USD 52,371,085.36 in 2025 and this increased steadily up to 2029. Thus, there is early profitability of the project over the 6-year investment.

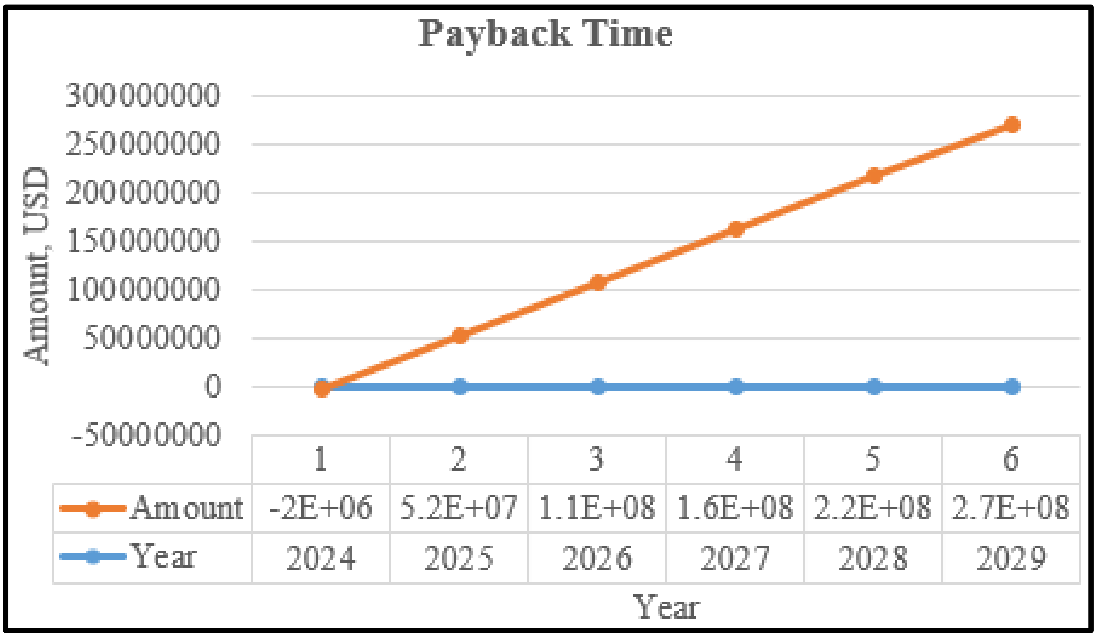

Figure 7:

IV. CONCLUSION

Å zeolite molecular sieve (MS) is used in the adsorption dehydration simulation of NG aided by an proprietary adsorption simulation tool. Results show, for example, that the adsorption increased 44 % when temperature and pressure decreased, indicating that relatively larger values of these parameters have negative impact on natural gas dehydration in the MS units. Moreover, the economic evaluation study has provided valuable insights into the financial viability and cost-effectiveness of this project in terms of two post dehydration options. A key finding have emerged suggesting the technical feasibility of the project and an economic evaluation further demonstrates that the implementation of molecular sieve technology for gas dehydration can offer significant long-term benefits in terms of profitability, operational efficiency, and product recovery and utilization.

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