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# Improvement in Upstream Oil and Gas Production Trough Flare Gas Recovery using Ejector System

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ABSTRACT

*Flare gas is a significant source of energy loss and air pollution in the oil and gas industries. In recent years, it has become a major concern, prompting various countries and industries to commit to "zero routine flaring" by 2030. Energy recovery from flare gas can be achieved through the use of a compressor, which is quite expensive. Therefore, this study aimed to analyze and study ejector system technically and economically. To achieve this, ejector geometries with different motive pressures were modeled and simulated using Ansys software. Subsequently, the amount of energy recoverable from flare gas was modeled and simulated with multi-unit processes integrated through Aspen Hysys software. The results showed that ejector recovered energy from flare gas on the XYZ platform by 226,879 mmbtu/year and reduced $CO_2$ emissions by 13,284 tons/year. Economically, the use of this device had a net present value of 3,720,478 USD and a payback period (PBP) of 6 months, underscoring its economic viability.*

## 1. INTRODUCTION

The use of oil and gas resources is crucial in global energy production but has environmental consequences, such as the burning of excess gas in flare stack, commonly referred to as flare gas [1]. This arises when gas, for economic or technical reasons, cannot be utilized for use or sale and is instead incinerated in a controlled manner [2]. In the process, large amounts of toxic materials is released into the environment, such as carbon dioxide ($CO_2$), and methane ($CH_4$), as well as acid gases such as hydrogen sulfide ($H_2S$), sulfur dioxide ($SO_2$), and nitrogen oxides ($NO_X$). These cause various environmental problems such as global warming and acid rain [3]. Based on a report from the World Bank released in April 2021, global flare tower emissions in 2020 were 142 billion cubic meters (BCM), or equivalent to a quarter of the total gas consumption in Europe [4]. This quantity, when converted into electrical energy, could produce 800 billion kWh, roughly equivalent to the annual consumption of the entire African continent [4].

Given the impact, various countries and industries have committed to achieving "zero routine flare" by 2030. In addition, several technologies have been explored for flare gas recovery, with compressors being the most prevalent [5]. It is used to pressurize low-pressure flare gas which is then subjected to several processes before being used for fuel, gas lift, or sale [5]. Studies have been performed to recover flare gas using a compressor. Comodi *et al.* [6] investigated the reuse in an oil refinery system utilizing a liquid ring compressor (LRC). The results showed that the LRC with a mass flow rate of 400 kg/s was the most suitable option, with an estimated annual recoverable energy of 2900 tons of oil equivalent (TOE) and a payback period (PBP) of about 2.5 years. Evbuomwan *et al.* [7] analyzed flare gas recovery containing acidic compounds using both a liquid ring and a reciprocating compressor. As a result, the LRC showed a payback period of 4.3 years, indicating better performance.

The use of compressors to recover low-pressure flare gas has proven to be effective but expensive [8]. Therefore, several studies have proposed its replacement with ejector system which offers advantages such as absence of moving parts, simple designs, low investment and maintenance costs, fast installation, and extended service life [9]. Leagas *et al.* [10] present the results of studies on 2 ejector projects, one of which is located offshore and adopted a gas-motive. Due to the requisite high compression ratio, a multi-stage ejector was chosen. However, this report did not analyze the economic and technical aspects of the stratified ejector on flare gas recovery process.

As mentioned above, several studies related to flare gas recovery have been conducted, but little has been discussed regarding the use of ejector systems. Therefore, this study aimed to analyze energy recovery from flare gas using ejector system, with a specific focus on the technical and economic aspects. The investigation concentrates on offshore oil and gas production

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facilities, providing a systematic investigation of the device for the recovery processes. The geometry of the new ejector was presented using various motive pressures to obtain the most optimal energy recovery and $CO_2$ emission reduction. Furthermore, an economic review is essential in determining the viability of implementing the device.

## 2. SYSTEM DESCRIPTION

Flare gas system is a familiar feature in oil and gas production facilities, serving as a safe and reliable method of burning gas during emergency [11]. Its systems are divided into 2 main categories, namely associated and non-associated gas. Associated gas originates directly from the well, often in 2 or 3 phases at formation pressure, and is intentionally burned during the production process due to a decrease in pressure or the pressure to atmospheric level (low-pressure flare). Meanwhile, non-associated gas is produced during abnormal situations such as start-up, shutdown, or emergency (high-pressure flare). Due to its small quantity, this type of flare gas has a negligible environmental impact [12].

This study investigates the potential for energy recovery from flare gas on the XYZ platform using ejector. The production system of the XYZ platform is shown in Figure 1, while Tables 1 and 2 present the average properties and composition of flare gas. The output of ejector or discharge is then directed to the compressor suction drum inlet to serve as a feed gas for purposes such as gas lift or for sales. Table 3 shows the property values of flare gas recovery in conjunction with compressor suction drum inlet specifications.

**Table 1. Properties of flare gas at the XYZ Platform.**

| Parameter | Value | unit |
|---|---|---|
| Pressure | 20 | Psig |
| Temperature | 90 | °F |
| Gas flow rate | 500 | mscfd |
| Molecular weight | 24.2 | g/mol |
| Concentration of $H_2S$ | 0.00 | % |

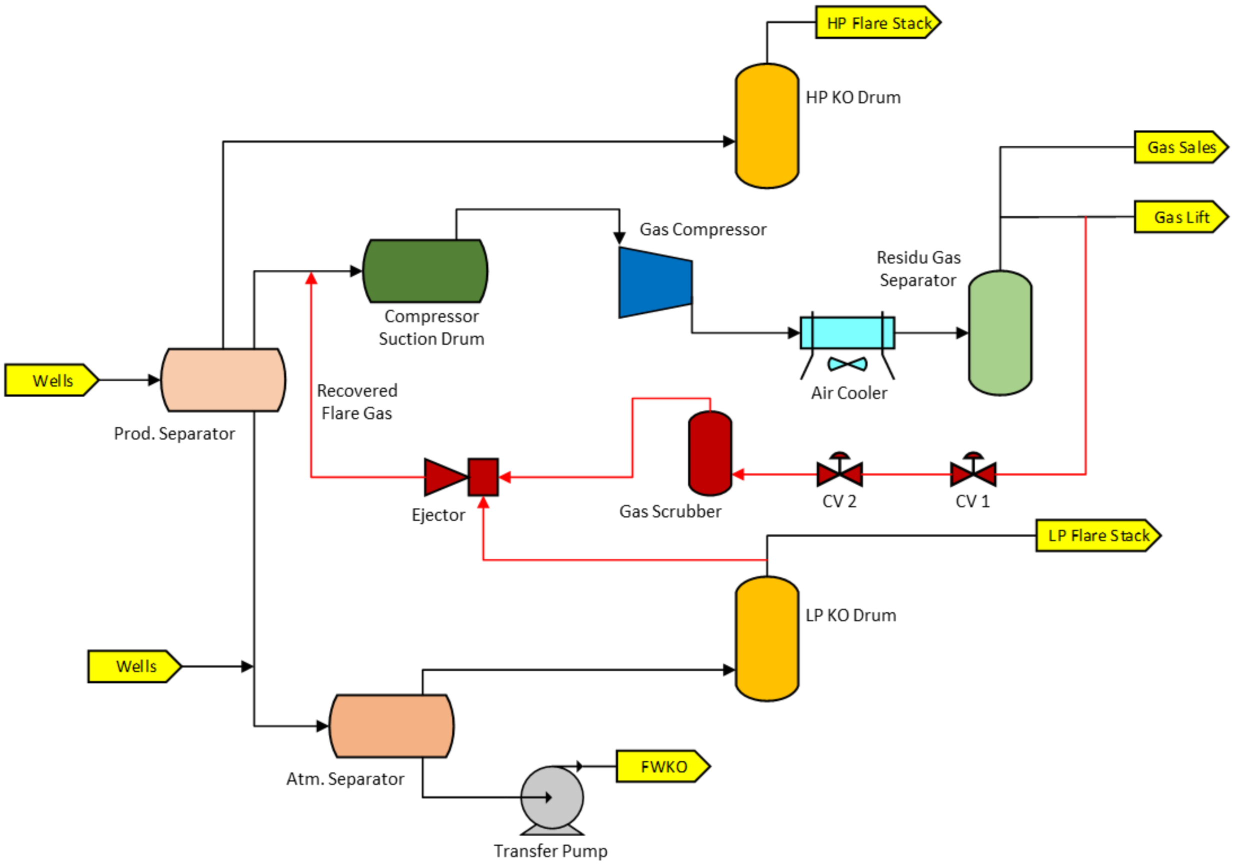


**Fig. 1. Schematic of the process at XYZ platform.**

## 3. PROPOSED GAS RECOVERY SYSTEM

### *3.1 Gas Ejector Modeling*

Ejector, also known as a jet pump, eductor, or venturi, is a robust and reliable tool for pumping fluids or increasing fluid pressure. It operates on Bernoulli principle, where it was stated that in a flowing frictionless fluid, the total energy (the sum of potential, kinetic, and pressure energies) remains constant along the path. Consequently, an increase in velocity (kinetic energy) leads to a decrease in pressure, and vice versa [13].

In gas ejector applications, an essential parameter is the entrainment ratio, defined by Equation 1:

$$\text{Entrainment ratio: } \omega = \dot{m}_s / \dot{m}_p \qquad (1)$$

As previously explained, optimal energy recovery from flare gas is highly desirable. This means that the ideal operation of ejector should be characterized by the optimum entrainment ratio. Furthermore, the numerical modeling focused on examining the effects of motive pressure on the entrainment ratio.

**Table 2. Composition of gas (flare and gas lift for motive ejector) at the XYZ Platform.**

| Composition | | Mole fraction (%) | |
|---|---|---|---|
| | | Flare Gas | Gas Lift |
| C1 | Methane | 69.91 | 76.11 |
| C2 | Ethane | 7.13 | 4.94 |
| C3 | Propane | 9.33 | 7.08 |
| iC4 | i-Butane | 1.68 | 1.52 |
| nC4 | n-Butane | 2.03 | 1.66 |
| iC5 | i-Pentane | 0.56 | 0.57 |
| nC5 | n-Pentane | 1.15 | 0.28 |
| C6+ | n-Hexane | 1.13 | 0.46 |
| $H_2S$ | Hydrogen Sulphide | 0.00 | 0.00 |
| $CO_2$ | Carbon dioxide | 4.78 | 5.00 |
| $N_2$ | Nitrogen | 2.25 | 2.33 |
| Total | | 100 | 100 |

In this present study, numerical simulations were performed using Ansys Fluent. The geometry of ejector used is shown in Figure 2. The device is modeled in a two-dimensional axisymmetric geometry constructed with Ansys Design Modeler, using a structured mesh and quadrilateral element types, totaling 38,398 elements. The K-ε model was selected to simulate the turbulent flow due to its superior accuracy in predicting ejector performance than the other models [14]. Shear stress transport (SST) is taken into consideration to predict any adverse pressure gradient and separation occurrence inside ejector. The boundary conditions of the primary and secondary flow inlets were set as the "pressure inlet" conditions. Meanwhile, ejector outlet was adopted as the "pressure outlet" condition, as shown in the Ansys model setup summary in Table 4. To determine the amount of energy that was recovered from flare gas, ejector was modeled and simulated with multi-unit integrated processes using Aspen Hysys software. Finally, the Peng-Robinson fluid package was used in the simulation process.

**Table 3. Properties of flare gas**

| Parameter | Value | unit |
|---|---|---|
| Pressure | 50 | Psig |
| Liquid separation | > 98 | % |

**Table 4. Ansys setup summary**

| Mesh | |
|---|---|
| Mesh Type | Structured |
| Element type | Quadrilaterals |
| Number of elements | 38.398 |
| Numerical Setup | |
| Turbulence model | K-ε-sst |
| Solver | Pressure based |
| Method of initialization | Hybrid |
| Discretization scheme | Second order upwind |
| Fluid density | Ideal gas |
| Convergence criteria | Residuals $<10^{-6}$ |
| Boundary Conditions | |
| Discharge flow outlet | Pressure outlet |
| Secondary flow inlet | Pressure inlet |
| Primary flow inlet | Pressure inlet |

### *3.2 Economic Modeling*

Economic analysis is used as a basis for estimating the initial or procurement costs (capital costs), operating costs, and economic indicators which include Net Present Value (NPV) and Payback period. The Costing Module is considered one of the most accurate approaches to estimating the investment costs of an industrial unit. Furthermore, it includes all the main equipment in the process, such as pumps, turbines, compressors, as well as heat and exchangers [15]. The total capital cost, which consisted of fabrication and installation was estimated using Equation 2 [15]:

$$C_{TM} = 1.18 \sum_{i=1}^{n} C_{BM,i} \tag{2}$$

Where $C_{TM}$ is the capital cost (total module) of the plant, n is the total number of individual units, and $C_{BM}$ is the bare module equipment cost, which is the cost for each component including direct and indirect costs. Direct costs comprised of cost of materials and labor required for installation while the indirect counterpart comprising shipping costs, designer contractors, taxes, and insurance, was calculated using Equation 3 [15]:

$$C_{BM} = C_{Ej} \,.\, F_{BM} = C_{Ej} \,.\, (B_1 + B_2 F_P F_M) \tag{3}$$

Where $C_{Ej}$ is the purchased cost for base conditions, usually made of carbon steel and ambient operating pressure, $F_{BM}$ is the bare module cost factor, or multiplication factor which accounts for the item alongside the specific materials of construction and operating pressure. B1 and B2 are the correction coefficients for material type, $F_P$ is the operating pressure factor, and $F_M$ is the material factor [15].

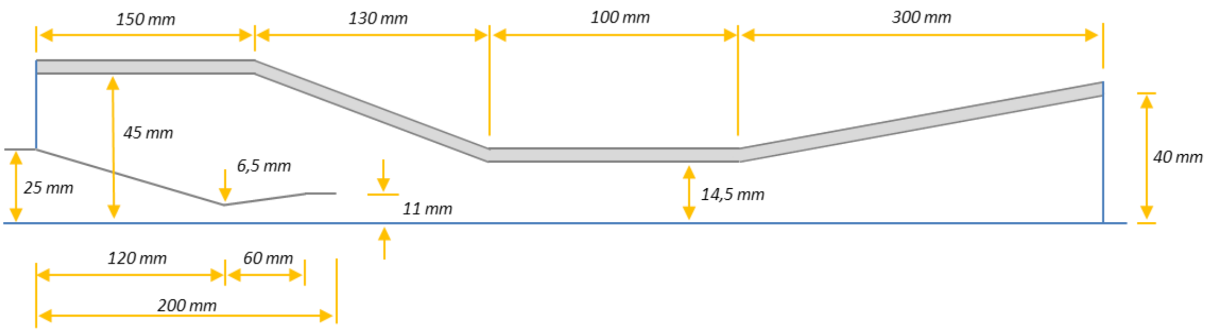


**Fig. 2. Geometrical configuration.**

For ejector, the estimated cost for base conditions can be determined using Equation 4 [16]:

$$C_{Ej} = 1000 \cdot 16{,}14 \cdot 0{,}989 \cdot \dot{M}_S \left[\frac{T_p}{P_p}\right]^{0{,}05} P_S^{-0{,}75} \quad (4)$$

Where $M_S$ is the mass flow rate in kg/s, $T_p$ is the temperature primary flow in K, while $P_p$ and $P_s$ are pressure primary and secondary or entrained flows, respectively in Mpa [16].

Operational-related costs should be estimated before assessing the feasibility of a proposed process. Estimated annual operating costs or cost of manufacturing excluding depreciation ($COM_d$) can be calculated using Equation 5 [15]:

$$COM_d = 0{,}18C_{TM} + 2{,}75C_{OL} + 1{,}23\,(C_{UT} + C_{WT} + C_{RM}) \quad (5)$$

Where $C_{OL}$, $C_{UT}$, $C_{WT,}$ and $C_{RM}$ are the operating labor, utility, waste treatment, and raw material costs, respectively [15].

When industries build and operate chemical process equipment, it is important to acknowledge that such material has a limited lifetime, hence, the value decreases with time. Several approaches exist in determining yearly depreciation, but in this case, the Double Declining Balance (DDB) method was adopted, which can be referenced using Equation 6 [15]:

$$d_k^{DDB} = \frac{2}{n}\left[C_{TM} - \sum_{j=1}^{j=k-1} d_j\right] \quad (6)$$

Where $d_k$ is declining in the kth year, n is the lifetime of equipment in years [15].

The annual net profit commonly known as cash flow can be determined by Equation 7 [15]:

$$CF = (R - COM_d - d)(1 - t) + d \quad (7)$$

Where t and d are annual tax and depreciation, while R is revenue from flare gas recovery [15].

In evaluating the profitability of a project, the several methods used were Net Present Value (Equation 8) and payback period (Equation 9) [15]:

$$NPV = \sum_{n=1}^{N} \frac{CF_n}{(1+i)^n} + \sum_{r=1}^{T} \frac{SV_r}{(1+i)^N} - C_{TM} \quad (8)$$

Where $CF_n$ is cash flow in the nth year, T is the total of equipment, i is the discount rate and SV is salvage value [15].

$$\sum_{n=1}^{B} \frac{CF_n}{(1+i)^n} + \sum_{r=1}^{T} \frac{SV_r}{(1+i)^N} - C_{TM} = 0 \quad (9)$$

## 4. RESULTS

### *4.1 Gas Ejector Modeling*

To validate Ansys simulation processes, ref. [17] was used. In this study, a test was conducted using working fluid R141b at operating conditions of motive or generator pressure (Pg) ranging from 0.4 – 0.604 MPa, an evaporator pressure (Pe) between 0.04 and 0.047 MPa, as well as a condenser pressure (Pc) of 0.06 MPa. Based on the simulation results in Figure 3, the biggest error of an entrainment ratio between simulation and experimental was 8.3%. Therefore, it was concluded that the modeling and simulation were following the test results.

To validate Aspen Hysys simulation processes, ref. [7] was employed. This study was conducted at a refinery process located in Nigeria, where the energy recovery system from flare gas incorporates a single LRC and associated sweetening process due to the presence of $H_2S$ and $CO_2$ in the gas composition as shown in Figure 4. In the associated sweetening process, monoethanolamine (MEA), serves as an amine solvent. The energy recovery system from flare gas was modeled and simulated on Aspen Hysys software using the Peng-Robinson fluid package for the compression system and the Acid-Gas fluid package for the associated sweetening process or amine treatment.

The results of the comparison of simulated processes with reference [7] were shown in Fig. 4, where the parameters and a mole fraction of each gas component were discovered to be almost the same. The biggest difference is the mole fraction of methane which is only 0.09%. Therefore, the simulation was performed accurately.

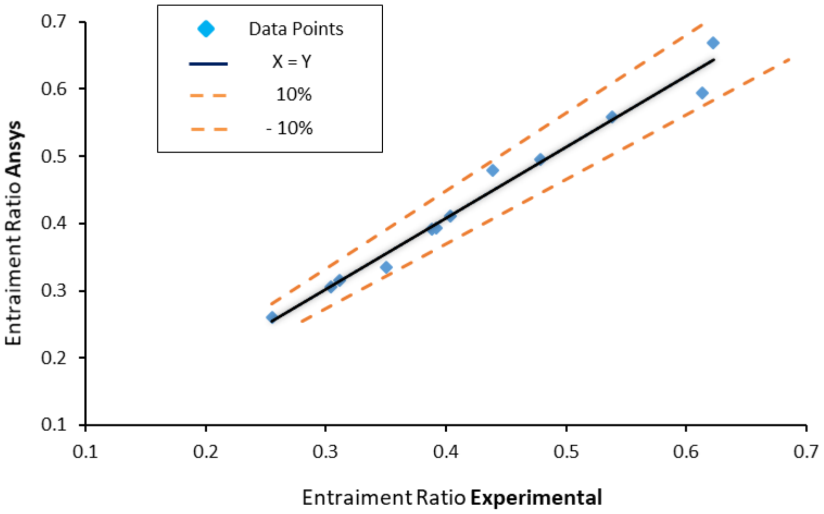


**Fig. 3. Comparison of entrainment ratio this simulation and experimental results.**

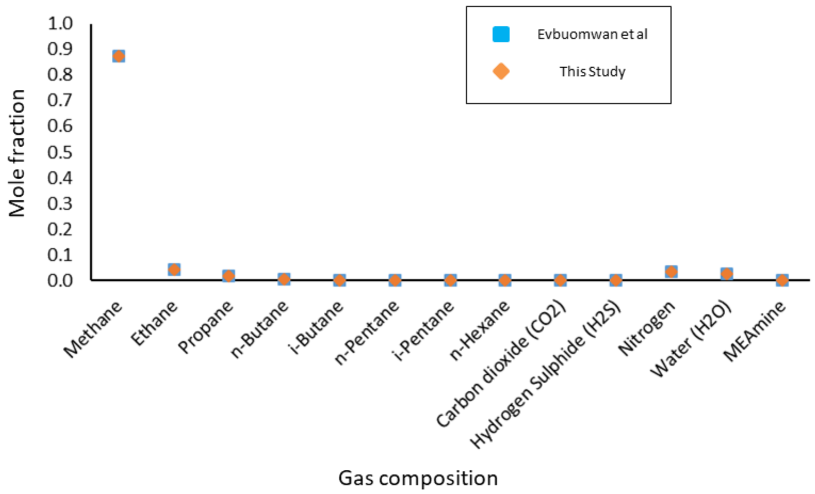


**Fig. 4. Comparison of recovered gas from reference and this simulation results.**

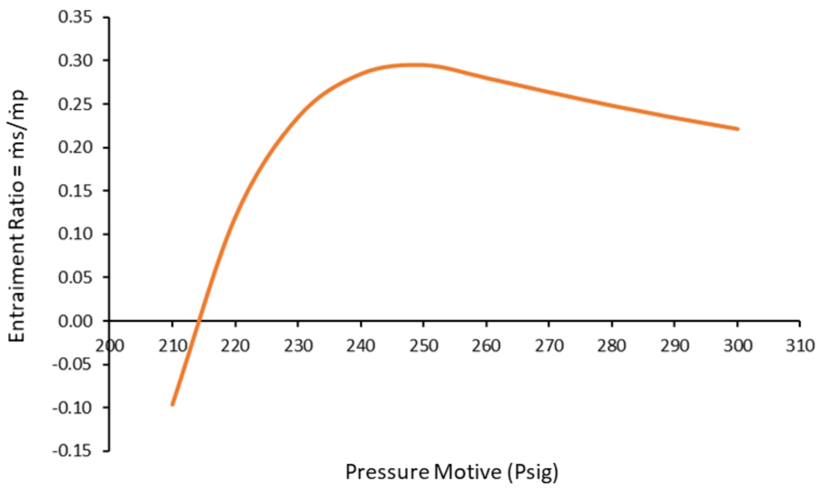


**Fig. 5. Variation of entrainment ratio with motive gas pressure.**

### *4.2 Ejector Modeling Results*

In the operation of natural gas ejector, the back pressure is determined by the constant pressure of the transportation pipeline, which in this study was established at 50 psig. To achieve maximum recovery from flare gas, the eject should operate at a maximum entrainment ratio. The investigation presents the performance of ejector at variated motive pressure. The result simulations are shown in Figure 5. It indicated that a motive gas pressure of 210 Psig does not produce a siphon or suction effect from flare gas. For ejector to effectively draw in flare gas, a motive pressure above 220 Psig was necessary, yielding an entrainment ratio of 0.1. The device achieves its highest entrainment ratio at a motive pressure of 250 Psig, with a value of 0.29.

Figure 6 shows the flow distribution inside ejector. Turbulent flow is characterized by high levels of fluctuating vorticity, a disorder in the movement of fluid particles, an overall irreproducible behavior, and the manifestation of multiple space and time scales. The shear stress and pressure drop will be sharper in turbulent flow due to its very thin viscous sublayer. The simulation results show that there are no signs of this flow in the secondary inlet area, hence, performance is being reduced. Figure 7 shows the axial pressure distribution inside ejector. With a motive flow of 250 Psig, the lowest vacuum value inside ejector measures 7.5 Psig. This condition is observed around the throat/mixing tube area of primary-secondary flow. Consequently, a post-shock-wave region extends beyond 50% of the diffuser area.

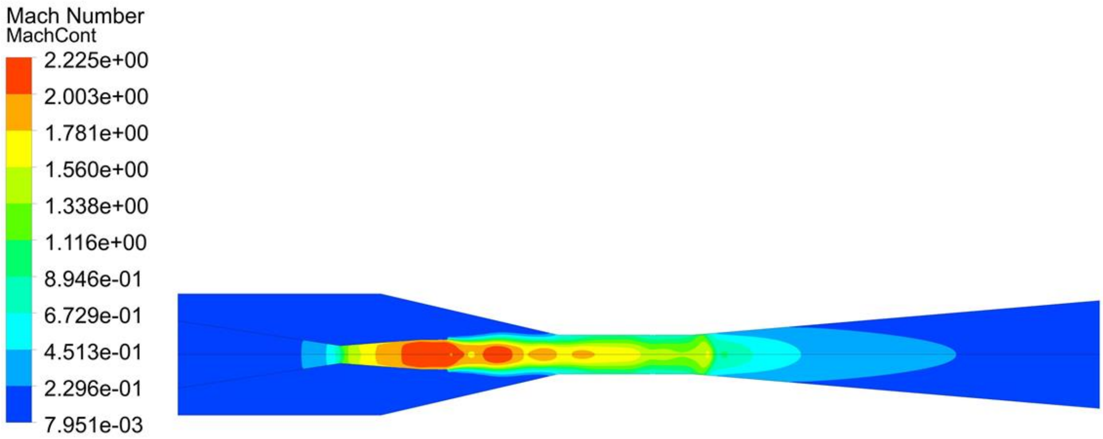


**Fig. 6. Flow distribution inside ejector.**

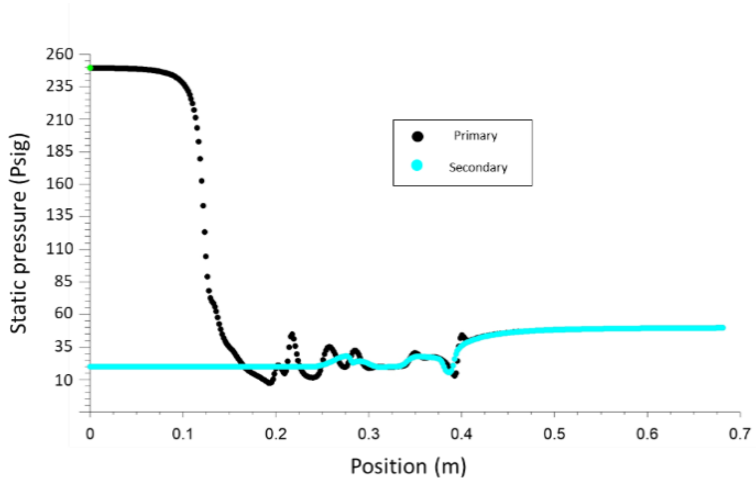


**Fig. 7. Static pressure distribution inside ejector.**

The results of Aspen Hysys simulation, shown in Figure 8, were based on ejector geometry in Figure 2, with a motive pressure set at 250 Psig. Due to the presence of high-pressure gas in the operational environment, a pressure of 700 Psig was available. This was regulated down to an optimal motive gas pressure of 250 psig, ensuring it meets the operational requirements for flare recovery. The reduction was achieved through 2 control valves, namely the first lowered the motive gas pressure from 700 Psig to 400 Psig, and the other decreased it to 250 Psig. To guarantee that the motive gas supplied to ejector was completely dry, it was directed to a separator or scrubber, as indicated in Fig. 8. Based on the results of the simulation, it was discovered that ejector had an entrainment ratio of 0.29, consistent with previous modeling and simulation using Ansys software. The simulation results showed that the device will be able to recover flare gas of 500 mscfd with a motive flow rate of 1,721 mscfd. With the gross heating value of flare gas at 1,296 scf/btu, the amount of energy that was recovered using ejector system was 226,879 mmbtu/year. The amount of $CO_2$ emissions from flares was based on an estimated 98% combustion efficiency [18]. Therefore, the emission reduction on platform XYZ was 13,284 tons/year.

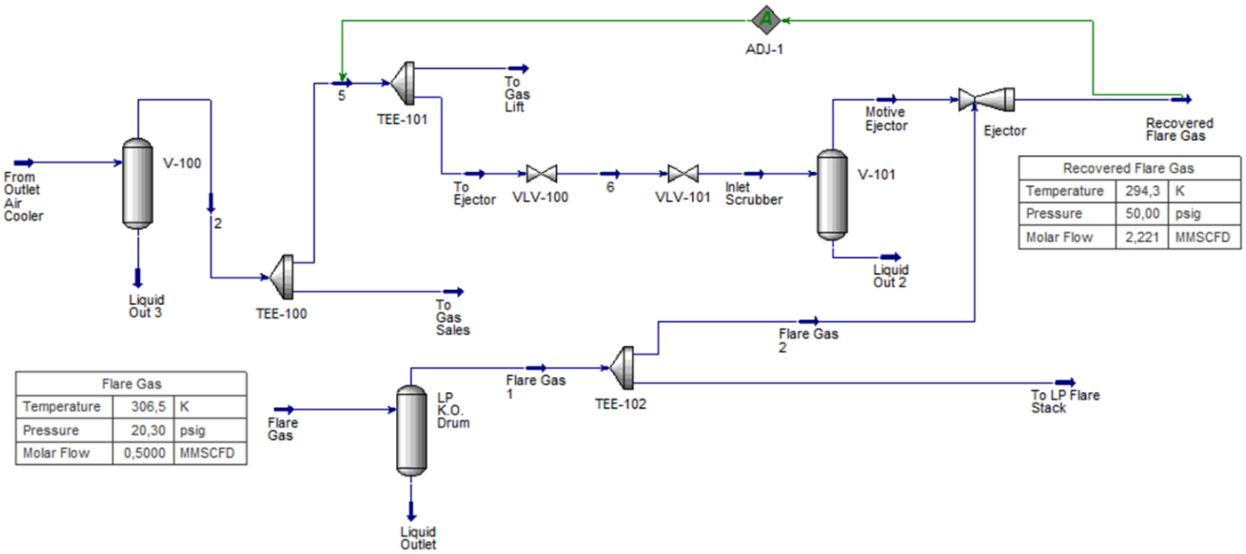


**Fig. 8. Aspen Hysys simulation results.**

**Table 5. Parameter values for economic assessment.**

| Parameter | Value | Unit |
|---|---|---|
| Taxation rate | 15 | % |
| Annual interest rate | 15 | % |
| Labor (operator/year) | 10,000 | $ |
| Gas sales price | 3.5 | $/mmbtu |
| Project lifetime | 20 | years |
| Annual Operating hours | 8400 | hours |
| Construction period | 1 | years |

**Table 6. Capital cost of ejector system.**

| Equipment | Equipment ($) | Bare Module ($) | Total Module ($) |
|---|---|---|---|
| Ejector | 46,810 | 101,578 | 119,862 |
| Separator | 28,200 | 61,194 | 72,209 |
| CV 1 | 4,500 | 9,765 | 11,523 |
| CV 2 | 4,500 | 9,765 | 11,523 |
| Ball Valve | 3,200 | 6,944 | 8,194 |
| SDV | 4,600 | 9,982 | 11,779 |
| PSV | 3,000 | 6,510 | 7,682 |
| Flow meter | 4,000 | 8,680 | 10,242 |
| | Total | | 253,013 |

### *4.3 Economic Assessment*

Parameter values for economic analysis in the application of ejector system on the XYZ platform are presented in Table 5. Based on the technical analysis, several equipment were obtained for the installation of this system as shown in Table 6. With the bare module equipment cost of ejector and the purchased cost of other equipment, the capital cost (total module) of ejector system amounted to 253,013 USD. Considering an annual revenue of 794,075 USD/year from the gas sales, the cumulative cash flow projection for 20 years was 3,598,261 USD as shown in Figure 9.

Based on the calculations, it is discovered that the net present value (NPV) for ejector system in energy recovery from flare gas on the XYZ platform after operating for 20 years was 3,720,478 USD, with a payback period (PBP) of 6 months. This shows the feasibility of the project, the payback period is less than 5 years, in line with the recommendation provided by reference [19] for chemical process equipment.

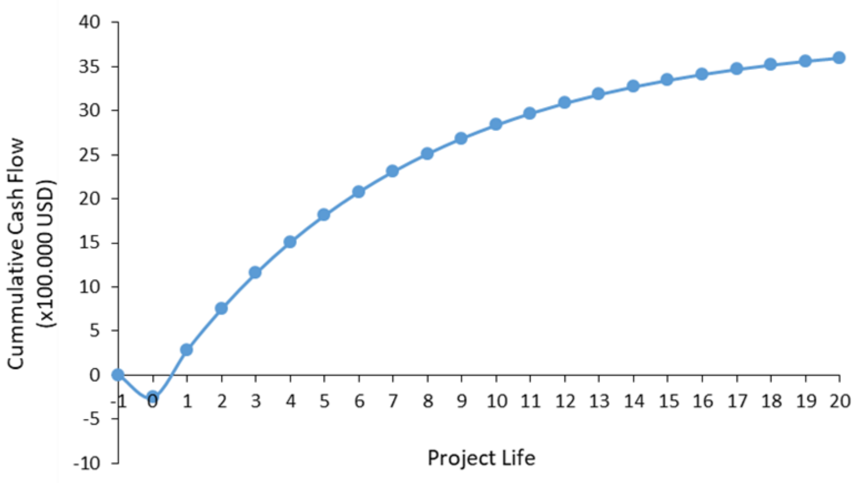


**Fig. 9. The cash flow projection.**

## 5. CONCLUSION

In conclusion, the analysis of ejector for energy recovery from flare gas showed the substantial potential in improving energy efficiency. The choice of different motive gas ejector pressures directly impacted energy recovery, along with investment and operational costs. After a thorough examination, the XYZ platform identified the most suitable ejector system with a motive gas pressure of 250 Psig. This configuration was projected to recover an impressive 226,879 mmbtu of energy annually from flare gas, resulting in a significant reduction of 13,284 tons of $CO_2$ emissions per year. From an economic perspective, the adoption of ejector system proved highly favorable, with a substantial net present value of 3,720,478 USD and an exceptionally short payback period of only 6 months. This underscored not only the environmental benefits but also the economic viability of this innovative system to energy recovery.

## NOMENCLATURE

Abbreviations

| | |
|---|---|
| BCM | Billion cubic meters |
| BTU | British thermal unit |
| CF | Cash flow |
| COM | Cost of manufacturing |
| DBB | Double declining balance |
| LRC | Liquid ring compressor |
| NPV | Net present value |
| PBP | Payback period |
| PSI | Pounds per square inch |
| SCF | Standard cubic feet |
| SST | Shear stress transport |
| SV | Salvage value |
| TOE | Tons of oil equivalent |

Symbols

| | |
|---|---|
| C | Cost |
| d | Declining |
| T | temperature |
| $\omega$ | entrainment ratio |
| $\dot{m}$ | mass flowrate, kg/s |
| P | pressure |

Subscripts

| | |
|---|---|
| BM | Bare module |
| c | Condenser |
| e | Evaporator |
| Ej | Ejector |
| g | Generator |
| M | Material |
| OL | Operating labor |
| p | Primary |
| RM | Raw material |
| s | Secondary |
| TM | Total module |
| UT | Utility |
| WT | Waste treatment |

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