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INVESTIGATE TECHNO-ECONOMICAL ASPECTS OF PRESSURE BOOSTING STATIONS TO ENHANCE OIL EXTRACTION IN GACHSARAN

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Abstract

The purpose of this study is to consider strategies and options for improving the efficiency of the pressure boosting station No. 4 in Gachsaran oil reserve (which is located in south-western of Iran). In order to achieve these objectives, the four rational options from technical and operational views were proposed and then these options went through an economic assessment. Next, by considering the other important criteria based on technical conditions (due to the necessity of evaluating other criteria beside economic criterion), decision-making techniques were employed. The results of economic evaluation show that the present value of the costs of option 1 is lower than other options and option 2 provides poorer economic status and is ranked last among the recommended options. Therefore, option 1 is 30.5 percent better than option 2. In addition, employing MCDM Technique allocated maximum weight (0.320) to economic evaluation criterion and again option 1 -with the highest weight (0.354)- was the best possible option. Regards to purpose of this study, using techno-economical approach leads practitioners to decide based on technical and economic facts simultaneously.

Keywords: Oil reservoirs, Stabilize pressure, Pressure boosting, Multi criteria decision making.

1. Introduction

Nowadays, there are many methods for increasing oil recovery from underground oil reservoirs in the world which differ based on the characteristics of each oil reservoir. In Iran, considering the present conditions, injecting gas into the oil

Nomenclatures

Mmscfd	Million metric standard cubic (Fig. 1), feet per day
Mtbf	Mean time between failures, hour
Rpm	Revolutions per minute (Fig. 1), *rev/min, r/min*
Scfd	Standard cubic (Fig. 1), feet per day

Abbreviations

AHP	Analytical Hierarchy Process
CHP	Combined Heat and Power
CSs	Compressor Stations
DCF	Discounted Cash Flow
EGT	Exhausted Gas Temperature
HP	High Pressure Compressor (Fig. 1)
HSE	Health, Safety, & Environment
IRR	Internal Rate of Return
LCA	Life Cycle Assessment
LP	Low Pressure Compressor (Fig. 1)
MCDM	Multi criteria Decision Making
MV	Medium voltage switchgear
NPV	Net Present Value
PBP	Pay Back Period
RTO	Real Time Optimization
SAGD	Steam Assisted Gravity Drainage
TCs	Turbo-Compressors
VFD	Variable Frequency Drive

reservoirs for oil recovery is considered suitable for the majority of reservoirs in the country.

The oil extracted from the oil fields generally contains a huge amount of light hydrocarbons which are termed associated gases. These gases can be separated from oil under room temperature and pressure conditions and if they are not separated, they can lead to multiple complications in the transfer lines and pipes, tanks, oil tankers and oil refineries. The task of separating associated gases is first carried out in multiple steps on well-based separators and utilization units and then these gases are collected in a large grid and directed into pressure boosting stations so that their pressure can be increased. In these stations, the input gases are transferred to the gas injection station after pressure boost and from there they go through another stage of pressure boosting and then the gases will be injected to the wells. These stations help stabilize the pressure of oil reservoirs by reinjection of the associated gases into the reservoirs, collecting associated gases and preventing their burn out and environmental pollution as well as the production and utilization of gaseous condensates.

In this regard, Derakhshan [1] indicates that by injecting around 2.6 trillion cubic meters of natural gas over a period of 30 years into those oil reserves in Iran that are suitable for injection, by pressure boosting the oil reservoirs we can reach a 70-billion-barrel increase in oil extraction and keep four million barrels a day continuous extraction for 50 years after the total pressure boosting of these reservoirs. Kurz et al. [2] carried out an economic investigation of a gas pressure boosting station in Texas, the U.S. and argued that the economic success of a gas compressing operation was significantly influences by the utilization of the gas compressor as well as important criteria such as operational cost and greenhouse emissions, which are considered in an economic evaluation of such projects. However, Ohanian and Kurz [3] showed that a sequence of a series of identical compressor sets can provide a better outcome compared to the parallel installation. It is worth mentioning that in this regard, operational flexibility is very important since demand varied under different conditions. Furthermore, the power of the gas turbine depends on the common conditions [4]. Moreover, Santos [5] identified a wide range of operational conditions that should be covered by the compressor station.

Kurz et al. [6] carried out an economic assessment study using NPV for high pressure gas transfer lines and considered the conditions of the compressors and the driver selection and its impacts on the higher pressure on the compressors. Gipson et al. [7] investigated a gas turbine CHP system and three economic cases were considered and applied to a case study and the most economical situation was determined. Xenos et al. [8] presented a method for optimizing the operation of compressors in parallel in process industries. The paper demonstrates the application of the RTO to a network of parallel industrial multi-stage centrifugal compressors. Moreover, Kashani et al. [9] presented a thermodynamic modelling of natural gas through the main elements of the network i.e. pipelines and compressor stations (CSs) to find optimum operating condition of natural gas network. For this purpose, a multi-objective approach was performed and optimized several decision variables. In this regard, Xenos et al. [10] present a framework which integrates maintenance and optimal operation of multiple compressors. Kurz et al. [11] argued the impact of the type and arrangement of turbo machinery equipment used in compressor stations. In addition, Gibson et al. [12] presented a method to compare the economic feasibility of fuel cell-based CHP systems with more alternative prime movers (micro turbine and gas turbine).

Kostowski et al. [13] have been analysed three alternative improvement strategies in aspect of energy and exergy performance as well as their economic feasibility. Gibson et al. [14] examined three economic cases to ensure a comprehensive analysis was conducted. Martín-Aragón [15] developed a method to determine the economic cost of gas turbine compressor fouling and applied this method to a real gas turbine. Giacchetta et al. [16] present an economic-environmental model for SAGD technology optimization (as an extraction technique of oil from oil sands reservoir) and carry out DCF analysis and LCA by considering NPV, IRR and PBP. Jiehui et al. [17] present a systematic review and examination of the technical and economic evaluation techniques for the development of shale gas to provide an overview of their current status. Jiehui et al. [18] develop a comprehensive DCF model and incorporate in to a technical and economic evaluation to explore the profitability of shale gas development.

The majority of oil fields located in the dry regions of Iran are in the second half of their life cycles and their pressure has significantly decreased. Therefore, necessary investments should be set aside for raising the pressure of these reservoirs immediately so that their recovery can be maximized. Injecting gas into oil reservoirs is the main link for oil and gas policies. This study tries to use a composite approach based on operational and financial assessment techniques and also decision-making analyses to identify suitable strategies for adjustment and improvement of the compressors and turbines in mentioned station. Hence, considering the analyses carried out and the close examination of the equipment, four rational strategies and options including (a) adjusting the equipment for the compression operation, (b) increasing the efficiency of the compressor and replacing the current gas turbine with an electrical engine, (c) increasing the efficiency of the compressor and replacing the current gas turbine with a gas engine, and (d) increasing the efficiency of the compressor and replacing the current gas turbine with a new gas turbine are proposed and analysed. Moreover, in order to accomplish this, the technical criteria for efficiency and effectiveness of these stations are identified and based on these criteria, the proposed options will be evaluated and ranked benchmarked using a MCDM process.

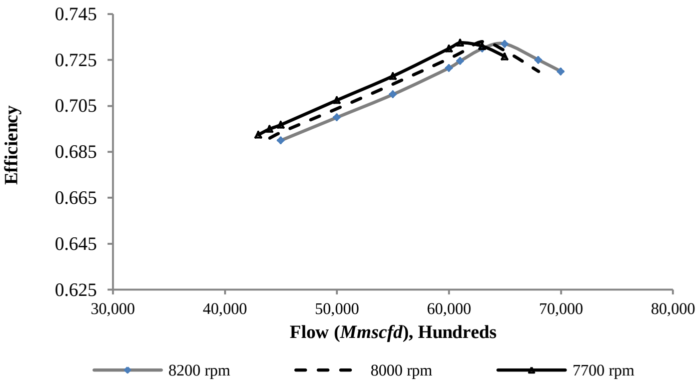
Therefore, by regarding the recent literature, the novelty and importance of this study is demonstrated in several aspects: Being considered the scope of study in recent literature, the practicality of the subject in increasing the oil reservoirs recovery, employing techno-economical approach simultaneously, using a composite approach based on financial and decision-making techniques.

2. Experimental Section

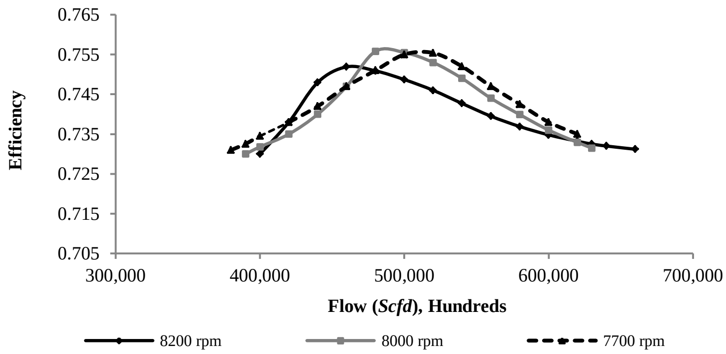
One of these important stations is station NO.4 in Gachsaran. In this oil field, the separated gas enters pressure boosting and injection stations and this process is carried out in three stages by the Turbo Compressors (TCs). Generally, compressors are designed under certain conditions and often the design conditions are not the same as the operational conditions. During the compression stages multiple variables including pressure, temperature, volume and the combinations of gases affect the efficiency, performance, life cycle, productivity and effectiveness of compressors. Considering the fact that the preliminary studies and the design process for this pressure boosting station were carried out years ago, many variations have happened regarding the above-mentioned variables. These variations along with long down times due to failure, have led to a decrease in the efficiency and performance of the compressors and these have increased the maintenance costs, which has led to an increased gas-burning volume.

In station No. 4 of Gachsaran, two density arrays; namely C-403 and C-405, have been placed parallel to each other and each row consists of a gas turbine as well as a pressure boosting compressor. The availability of them based on the accessible documents (information forms related to the causes of downtime and functioning times of these devices during the time period between 2009 and 2012) for the C-403 turbo compressor is 88.3% and for the C-405, it is 65.1%. These values indicate that by considering 15% time frame for the predicted maintenance tasks, in the most optimistic scenario, the C-403 and the C-405 will be unavailable in 26.7% and 49.9% of the time in a year, respectively. Hence, ignoring the necessary adjustments will lead to a huge gas burn out cost over the following years.

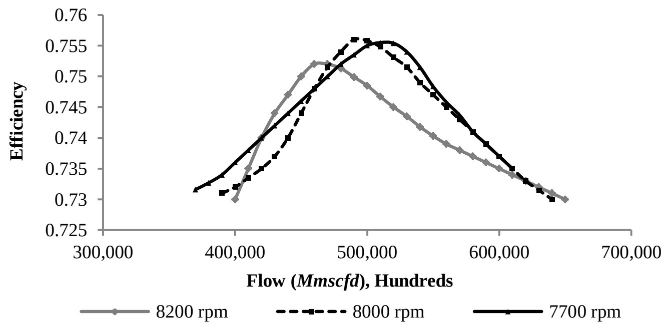
According to the results of a survey conducted by Engineering and Exploitation Department of Gachsaran Oil and Gas Production Company, analysis of the operational status of the compressors (A and B) and calculation of the extent of power consumption and also the efficiency of the compression stages showed that in first stage of compression, the polytrophic efficiency of compressor A -under the best possible conditions- reached 73%, in second stage, this value reached 75.5% in compressor B and the value of this compressor in third stage of compression reached 75% (as shown in Fig. 1). In order to analyse the data obtained from testing the performance of the gas turbine, it is necessary to calculate the generated power as well as the performance efficiency of the generator and the turbine.



(a) Operational curve of LP compressor A (First stage of compression)



(b) Operational curve of HP1 compressor B (Second stage of compression)



(c) Operational curve of HP2 compressor B (Third stage of compression)

Fig. 1. Operational curve of compressors.

Considering the fact that the three compression stages in the two different compressors on the same axis are connected to the outlet axis of the power turbine through a gear box and these three stages have different power consumption and efficiency, the data obtained from testing the performance of the compressor and the gas turbine show that the efficiency of the gas turbine in 8200 Rpm reaches the maximum of 24.7%. Accordingly, the average efficiency of the gas turbine set is approximately 22.5%. Hence, the low efficiency of the equipment not only leads to a high cost, but also it decreases the feasibility of the facilities and leads to environmental pollution. By considering the importance of the smooth operation of mentioned station as well as the close examinations carried out on this station, it was found that the efficiency and productivity of the machinery and equipment in this station were far from the optimal level, the maintenance and repair costs were very high and the gas burn out cost due to multiple interruptions was very significant.

3. Technical and Economical Investigation and MCDM

The analysis and its results show that considering the average availability of the equipment in the compression arrays of this station (C-403= 88.3% and C-405= 65.1%) as well as the efficiency of the compression arrays in that station, the comprehensive repair of the compressors and the gas turbines or their replacement is required. Hence, the following options are investigated based on technical and operational conditions as well as economic and financial feasibility.

3.1. Option 1 (O1): adjusting the equipment for the compression operation

In this option, the comprehensive repair of the current gas compressors as well as the repairing of the current gas turbines (upgrading from model 1533 to model 1534 to provide the necessary power for carrying out the compression operation based on a 20-year required capacity) in the compression arrays of the station are considered. The comprehensive repair of the gas compressors is carried out by repairing the compressors and replacing the rotors of the gas compressors. Also, the repair process of the gas turbines is carried out through the comprehensive repair of the gas generator along with the secondary systems, the comprehensive repair of the power turbine by replacing the fixed and movable blades as well as the comprehensive repair of the gear boxes used. The time frame required for these repairs is estimated to be about two months and during this time frame, the station will be completely offline and the entire inlet gas will be directed toward the torch.

Considering the required operational conditions for creating the production capacity over the next twenty years, in case of using this option, the temperature of the output gas from the compression stages under the new conditions will be lower than the acceptable maximum temperature. It is worth mentioning that another advantage of this option is that without any special adjustments and only by using the current equipment after the comprehensive repairs, the gas compression operations can be carried out in the shortest time possible. However, a disadvantage of this method is that both compression arrays are used and in case one of them becomes out of service, the gas must be directed to the torch.

Based on the data obtained from this station, the fix costs related to the adjustments include the costs for the comprehensive repair of the compressors, changing the arrangement of the compressors, replacing the rotor, the comprehensive repair of the gas generator along with the secondary systems (besides upgrading to model 1534), the comprehensive repair of the power turbine with replacing the fixed and movable blades, the comprehensive repair of the gear box, replacing the air filtration system of the gas turbines and the recurring costs of gas burn out. It should be noted that the recurring costs also include the gas burn out and the consumption of gas fuel after the maintenance process. Table 1 presents the discounted costs and the present value.

3.2. Option 2 (O2): increasing the compressor efficiency and replacing the current gas turbine with an electrical engine

In this option, two operations of adjusting the gas compressors (similar to option one) and replacing the current gas turbine system with an electrical engine are carried out simultaneously. The current model 1533 gas turbine system in this station is completely removes and replaced by an electrical engine with the same capacity. Under such conditions, it is required that the current gear box in the compression arrays be removed and replaced with new gears. In order to realize this, two electrical engines with the output capacity of 10 MW, establishing a high voltage power line to the station with the inlet power of 20 MW, a VFD system for changing the rotation of the compressor as well as MV switchgear and gear box should be utilized. The time frame for these adjustments is estimated to be about five months and during this time frame, the station will be completely offline and the inlet gas to the station will be directed towards the torch.

The advantage of this method is that by implementing these adjustments, the gas compression operation based on the production capacity over the next twenty years can be pressure boosted using the two compression arrays in this station. Moreover, using an electrical engine will prevent complications leading to interruptions in compression process due to failure or the need for a gas turbine component and this option will as well relax the compression performance range (not expandable due to the limitations of the turbine’s EGT) and the compressor will be able to continue the compression operation in higher rotations under certain conditions where the gas is lighter or its flow rate increases. However, it should be noted that the disadvantage of this method compared to the first option is the high cost of the adjustment operations on the equipment as well as the greater time frame required. In this option, the fixed costs include implementing the comprehensive repairs on the gas compressors, changing the arrangement of the compressors, the replacement of the rotor, buying and installing the electrical engines (each with a 10 MW capacity along with the related gear boxes), the cost of power lines for the station with the input capacity of 20 MW, the VFD system for allowing the rotation alteration of the compressor, the cost of the MV switchgear as well as the fixed costs of gas burn out. It should be noted that the recurring costs include the cost of gas burn out and the gas fuel consumption after implementing the adjustments. Table 1 presents the discounted costs and the present value.

3.3. Option 3 (O3): increasing the efficiency of the compressor and replacing the current gas turbine with a gas engine

This option acts the same as the two previous options regarding the process of increasing the efficiency of the compressors; however, the current gas turbines in the compression arrays will be removed and replaces with gas engines. Moreover, the current gear box used in the compression arrays will be replaced by new gear boxes. The time frame required for implementing the adjustments in this method is around five months. The additional advantage of this method over the second option is that due to using a gas engine, the complications related to establish the power line is not present in this method. Meanwhile, besides the operational costs of the adjustments and foundation improvement, it should be noted that using a gas engine considering the higher maintenance costs as well as the higher probability of failure and interruption presents more operational complications compared to using electrical engines or a gas turbine. In this option, the fixed costs include the costs of comprehensive repairs of the gas compressors, changing the arrangement of the compressors, replacing the rotor, buying and installing the gas engines (each with a capacity of 10 MW along with the related gear boxes) as well as the fixed costs of gas burn out. It should be noted that the recurring costs include the gas burn out costs and the gas fuel consumption after the implementation of adjustment operations. Table 1 presents the discounted costs as well as the present value.

3.4. Option 4 (O4): increasing the efficiency of the compressor and replacing the current gas turbine with a new gas turbine

In this method besides the comprehensive repairs of the gas compressors and replacing the rotor of the compressors, the current gas turbines will be removed from the compression arrays and replaced with new gas turbines. Under such conditions, it is required that the current gear box used in the compression arrays will be removed and replaced with new gear boxes. The time frame for the adjustments in this method is estimated to be around five months. The advantages of this method are similar to the option three; however, the disadvantages are solely limited to the high adjustment costs and foundation improvement costs. In this option, the fixed costs include the costs of carrying out the comprehensive repairs of the gas compressors, changing the arrangement of the compressors, replacing the rotor, buying and installing the gas turbines (each with a 10 MW capacity along with the related gear boxes) and fixed costs of gas burn out. It should be noted that the recurring costs include the costs of gas burn out as well as the cost of gas fuel consumption after the adjustment operations. Table 1 presents the discounted costs as well as the present value.

Table 1. Economical consideration of options (Values in dollar).

No. of option(s)	Fixed costs	Maintenance &repair costs of 20 years	Gas burn costs in adjustment period
1	13,180,000	47,500,000	7,200,000
2	20,300,000	47,500,000	19,200,000
3	16,600,000	60,440,000	18,700,000
4	49,114,000	43,900,000	19,200,000

Continue of Table 1.

Gas burn costs of 20 years	Consumption costs of gas fuel in 20 years	Power costs of 20 years	Present value	Priority
174,800,000	51,480,000	…	294,160,000	1
181,700,000	…	180,500,000	423,100,000	4
177,600,000	49,800,000	…	323,140,000	2
180,800,000	51,486,000	…	344,500,000	3

Therefore, considering the present values calculated for the proposed options, the comparison of the economic implications of the proposed options is presented in Table 1 which indicates that option 1 is the most cost-effective choice.

3.5. Comparison of proposed options based on MCDM

Since besides the economic and financial criteria, other technical and operational indicators (e.g., Kurz et al., [2]) are also important in this regard. Accordingly, the related criteria were analysed with the help of HSE, engineering and the production departments and six criterions include Avoidance of Environmental Pollution (C1), the Ease of Maintenance and Repair (C2), Covering Safety Standards (C3), *Mtbf* indicator (C4), Returns of the Operations (C5) and Economic Evaluation (C6) were considered in the form of an MCDM problem that analysed using the AHP technique. Therefore, the hierarchical model of the study is as presented in Fig. 2.

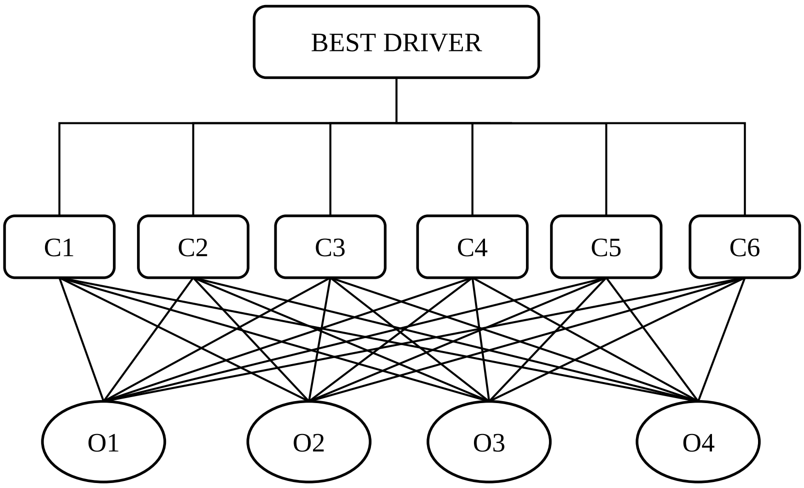


Fig. 2. Hierarchical evaluation model.

Based on the analyses carried out and the opinions extracted from the above-mentioned departments as well as the AHP calculations, the obtained weights using the Expert Choice software application for the selected criteria and options are presented in Tables 2 and 3 by considering an inconsistency rate of less than 0.1.

Table 2. Weights of selected criteria.

Criteria	Economic evaluation	Returns of the operation	*Mtbf* indicator
Final weight	0.320	0.248	0.197
Rank	1	2	3

Continue of Table 2.

Covering safety standards	Ease of maintenance and repair	Avoidance of environmental pollution
0.106	0.045	0.084
4	6	5

Table 3. Weights of selected criteria and options.

Options	1	2	3	4
Final weight	35.4%	18.5%	12.3%	33.8%
Rank	1	3	4	2

The obtained results show a significant difference from the Economic Evaluation (before considering the mentioned criteria). While the comprehensive adjustments of the current system (option 1) is chosen as the best possible option in both cases, option 4, which had a poorer economical stance compared to option 3, indicated a better stance in the AHP technique. Moreover, option 2, which was ranked last regarding economic concerns, indicated a better ranking compared to option 3 using the AHP technique.

4. Conclusions

Considering the importance of stabilizing the pressure of the reservoirs, collecting the associated gases, preventing them from burning out and preserving the right of the next generations for using hydrocarbon resources, injecting high pressure gas into the oil reservoirs is of utmost importance. Regards to the objectives and methodology of the study, the results indicate that by solely considering the results of the economic evaluations of the options, the present value of the costs of option 1 is lower than other options and it is completely cost-effective and compared to other options, option 2 provides poorer economic status and is ranked last among the recommended options. Therefore, by considering the above-mentioned information, option 1 is better than all the other options due to lower present value, shorter time frame and lower initial investment cost and this option is followed by options 3 and 4.

Next, by considering the other important criteria based on technical conditions (due to the necessity of evaluating other criteria beside economic criterion), decision-making techniques were employed. Hence, the results show indicate that option 1 is identified as the best possible option and option 4, despite the fact that it is ranked lower compared to option 3 in the economic evaluations, ranked number two in this analysis. Moreover, option 2, which presented the lowest economic desirability, ranked better in compared to option 3. Furthermore, the economic evaluation criterion with a weight of 32% had the highest weight, while the criterion of ease of maintenance and repair with the weight of 4.5 % had the lowest weight.

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