ENERGY EFFICIENCY ASSESMENT OF CENTRIFUGAL GAS COMPRESSOR

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ABSTRACT: Centrifugal gas compressors are critical for energy consumption in petrochemical industry. However, **c**ontinuous operations under varying load due to supply and demand mismatch cause energy performance inefficiency. Existing approaches lacks integration of operational data to assess actual energy efficiency of the centrifugal gas compressor. Therefore, this study monitors a real time performance parameter to assess energy efficiency of the centrifugal gas compressor (CC). Furthermore, energy consumption & load in terms of shaft speed as function of capacity were used as a key indicator to verify the actual operation and energy consumption of CC. To determine the condition and operation of centrifugal compressors, a detailed performance analysis was conducted. However, it was observed that drop in performance was due to the internal component degradation, mechanical wear, and fouling, resulted higher energy consumption, reduce reliability, costly unplanned shutdowns. The results showed that the lower and upper limits for compressing production gas for stage 1 are 71.52 and 88.20MMSCFD, which consuming power 4772.89 and 5239.54 kW respectively. Moreover, for stage 2 the lower and upper limits for compressing production gas are 181.3 and 196.9 MMSCFD, consuming power with 9813.10 and 10995.70 kW respectively. Moreover, results showed that on most working days, the energy consumption is less 1995.60 kWh/MMSCFD in the First stage due to the production of low-pressure gas and it will increase in the second stage up to 5175.89 kWh/MMSCFD due to the production of high-pressure gas and performance drop.

Keywords: OEM (Orignal equipment manufacturer), MMSCFD (Million standard cubic gas per day), Energy Efficiency (EE), Energy Performance (EnP), Centrifugal Compressor (CC)

(Received 14.04.2026 Accepted 01.06.2026)

INTRODUCTION

Energy saving is very important and priority across all the industries, specifically in the petrochemical industry, where energy related operations of centrifugal gas compressors significantly influence the operation, maintenance, and energy costs.Energy efficiency measures, improve overall energy consumption, operational cost, and minimize carbon footprints [1]. In CC energy, operational, and maintenance costs impact the total running and life cycle cost. Therefore, improving CC energy efficiency is the key objective of the gas industries to reduce energy consumption and promote sustainable measures to cut the extra running cost of the industrial assets. [2]. The CC used for various industrial applications to supply high pressurized gas and air to upstream and downstream applications. Variations in performance parameters due to supply and demand mismatch causing surging in CC which badly impact on the performance and energy efficiency. Furthermore, performance degradation in CC affects reliability, causing costly unplanned shutdown, and energy inefficiency. Compared with axial compressor, CC offers operational advantages such as wider operating range, maximum reliability, and relatively low maintenance and running cost. Due to these advantages CC is extensively used in various industries such as power generation, and other energy industrial sectors. Major energy savings can be accomplished in CC through the implementation of suitable maintenance strategies, energy efficient technologies, and optimization of performance parameters. Energy performance assessment and suitable maintenance approaches can effectively increase energy efficiency, operational performance and reduce the risk of failure [3,4]. Centrifugal compressors are important mechanical equipment used in various industrial applications to reduce the volume of gas and increase the pressure. Centrifugal compressors employ a revolving disc to derive gas or impeller to impart kinetic energy to the gas as shown in Figure 1. The centrifugal force of the gas increases as it travels radially outward along the impeller blades. The gas is then guided into a diffuser, where it slows down using a diffuser to transform the kinetic energy into pressure energy. As a result, pressure rises, and compressed gas is discharged at a higher pressure through an outlet at the periphery of impeller [5].

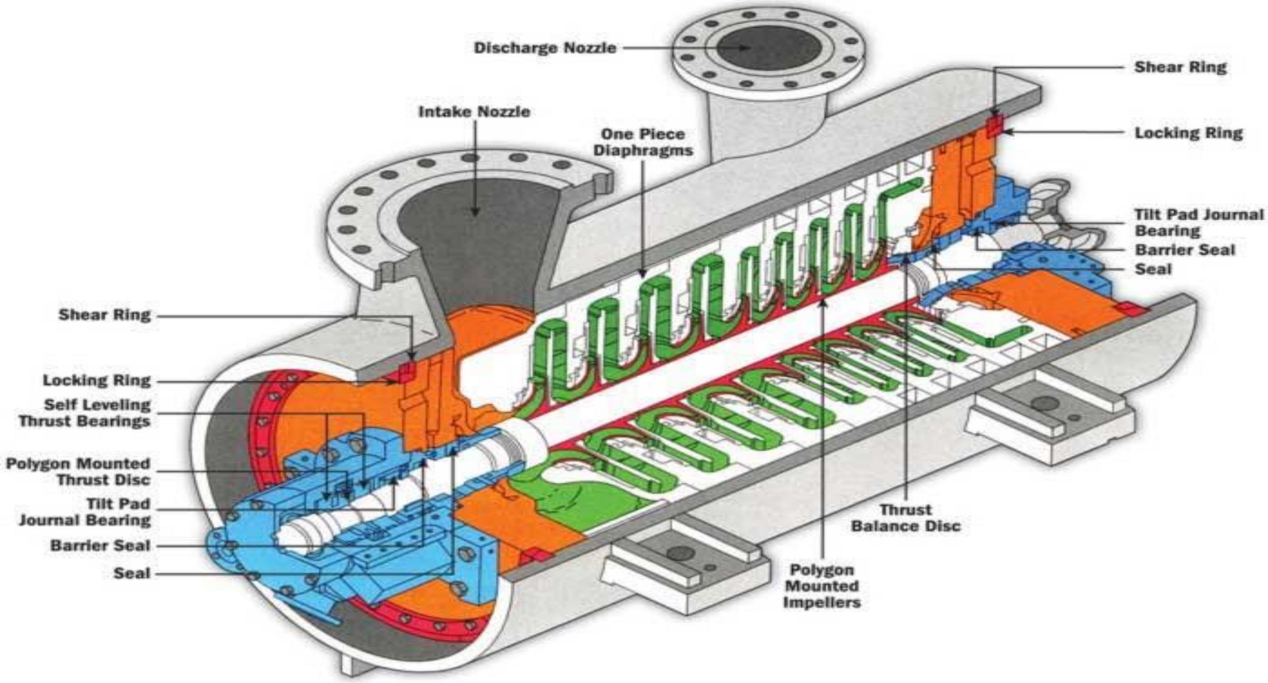

Figure 1. Working of centrifugal compressors [5].

There have been so many contributions in industrial energy management that this study cannot reasonably cover them all. However, let us discuss a few studies that primarily address technical issues of industrial energy efficiency, which is the subject of this study [6]. Various research covers different techniques for energy management to increase efficiency. A few of them examine the potential applications of energy audit in various industries. The authors investigate the use of production planning and scheduling to improve energy performance in industry. They also investigate modelling methods for meeting energy performance objectives. Modelling contributes to the development of prediction and optimization approaches. An important development in energy management has been the 2011 induction of the ISO 500001standard in 2011, which is a significant advance in energy management (ISO). It creates a foundation for the industrial use of energy management systems (EMS). As previously stated in the two paragraphs, this has inspired more research and development that takes various aspects of its implementation into account [7,8]. While existing literature addresses a wide range of difficulties, none are specifically focused on energy efficiency assessment of centrifugal gas compressors. In this paper, the authors proposed methodology and energy efficiency assessment tools be implemented to support in the decision-making to improve and increase the energy efficiency of CC by considering energy consumption as an indicator. This approach can also allow plant operators to track centrifugal gas compressor condition monitoring, energy efficiency assessment.

LITERATURE REVIEW

Many research papers go beyond technical specifications to examine the context in which energy efficiency or performance measures are implemented. These address energy policy, EE barriers and promoters' technology adoption rates, maturity profiles, and adoption patterns [9]. These studies also assess EE practices and investigate attitudes towards energy management (EM). Furthermore, focus is made on the requirement for improvements to EE standards as well as the development of tools to facilitate their applications [10]. Investing in energy-efficient technologies (EET) saves energy. However, Backlund et al. [11] pointed out, effective maintenance and monitoring are required to fully realize the benefits of these reductions. In the absence of these measures equipment degradation over time may result in increased energy use and urge the efficient maintenance and monitoring methods be used to detect inefficiencies and defects in compressors. The implementation of energy management techniques in industrial sectors received limited attention in early 1970s. However, the global oil crises in 1970s intensified serious attention regarding energy security, increasing energy price, and the sustainability of industrial energy consumption. This was the result of a significant drive for more energy-efficient practices and technologies. The energy sector has shifted dramatically since the early 1970s. Due to economic and environmental concerns, people are increasingly more concerned with efficiency and minimizing unnecessary losses [12,13]. Researchers have been actively working on these problems, a large body of literature addressing various aspects of industrial energy efficiency has been produced. Due to their multidisciplinary nature, these subjects invite both technical and social/economic contributions. To analyze track performance and development in energy efficiency, it is necessary to build efficient key performance indicators (KPIs). The literature has addressed several types of KPIs. At the core of the concept of energy efficiency is the ratio that these EEI indicators essentially describe as: the amount of energy input required to produce a given useful output [14,15]. Ikuobase et al [16] three key elements of a maintenance system were outlined, such as risk evaluation, maintenance plan selection and maintenance task interval determination tools used in the reliability-centered maintenance framework (RCM) for energy efficiency. Xu et al [17] worked on brief overview about the PdM system in the age of big data, with specific focus on data-driven fault diagnostic and prognostic models, methods, and algorithms for energy efficiency of CC. From the literature review it is identified that there is limited work that has been undertaken on the energy efficiency assessment techniques that provide suitable opportunities to increase energy efficiency, optimize operational performance, reduce energy cost that support sustainable operations of industrial assets, specifically centrifugal gas compressor.

METHODOLOGY

Methodology for the Energy efficiency assessment of CC explained in the flow chart as shown in Figure 2. This study was conducted on two stage centrifugal gas compressors, and the data for various performance parameters was obtained from various sensors which impact the energy efficiency of CC. Furthermore, a detailed literature review was conducted to assess the latest approaches, and their limitations. Thermodynamic analysis was performed to determine power requirements, and energy consumption. The operating parameters were compared with the design and manufacturer performance curves to identify energy losses and inefficiencies. Potential causes which impact energy consumption such as leakages, pressure drop, overheating, and mechanical losses were investigated. Orange software and MS Excel were used for data analysis and through patterns energy consumption trends were investigated in order to take decisions for energy saving and energy efficiency.

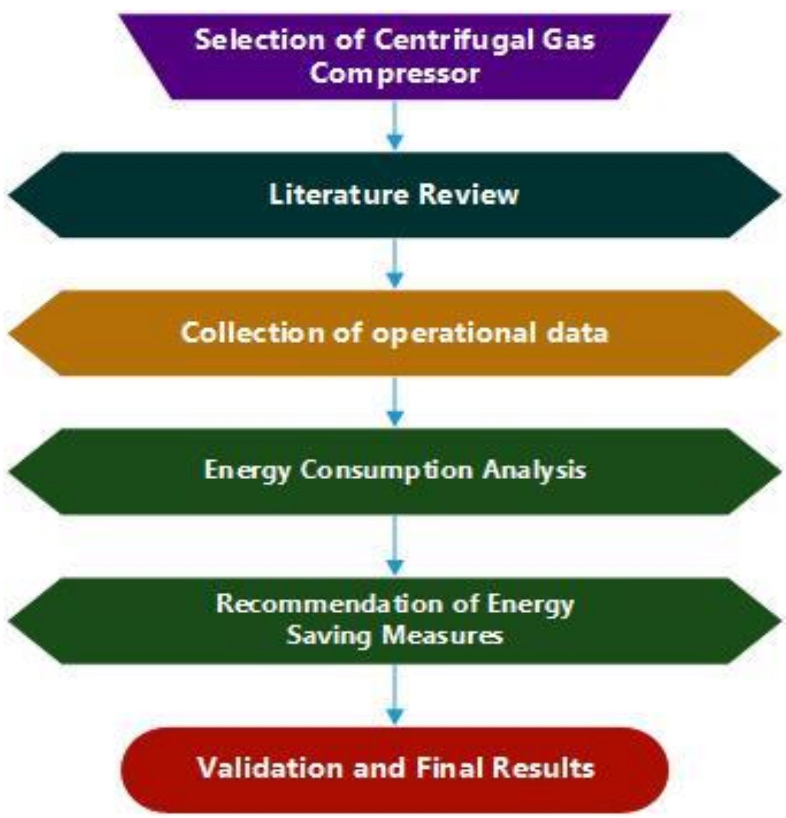

Figure 2. Methodology Flow chart

RESULTS AND DISCUSSION

After detailed analysis and investigation, the energy efficiency assessment model was developed by considering key performance parameters such as compressor shaft speed, compressor power consumption which mainly impact the energy consumption of CC. After evaluation of these parameters finally energy efficiency assessment for both the stages of CC were monitored.

Expected Compressor performance: For compressor capacities ranging from 100 to 225 million standard cubic feet per day (MMSCFD), and suction pressures ranging from 1724 to 5378 kPa were used, with discharge pressures at 13989 kPa. As a function of energy, plotted power consumption & volume flow rate for stage 1 & 2 to predict the results. It should be remembered that the power estimated in the model is gas power. The compressor is designed to run at peak polytropic efficiency over a relatively large operating window, and the resulting compressor power, as well as volume flow rate, should be compared to real operating conditions to ensure that the model can be used to track power consumption of compressor.

For stage 1 & 2, the approximate compressor power consumption as a function of compressor capacity or volume flow rate is depicted in Figure 3 & 4. For the analysis, the suction temperature and discharge pressure are kept constant to reflect practical scenarios over a broader operating range. The results showed that the lower and upper limits for compressing production gas for stage 1 are 71.52 and 88.20MMSCFD, which consuming power 4772.89 and 5239.54 kW respectively. Moreover, for stage 2 the lower and upper limits for compressing production gas are 181.3 and 196.9 MMSCFD, consuming power with 9813.10 and 10995.70 kW respectively. Furthermore, the results show that, in comparison to the designed value, power consumption in stage 2 is higher during the operation, which indicates a performance drop.

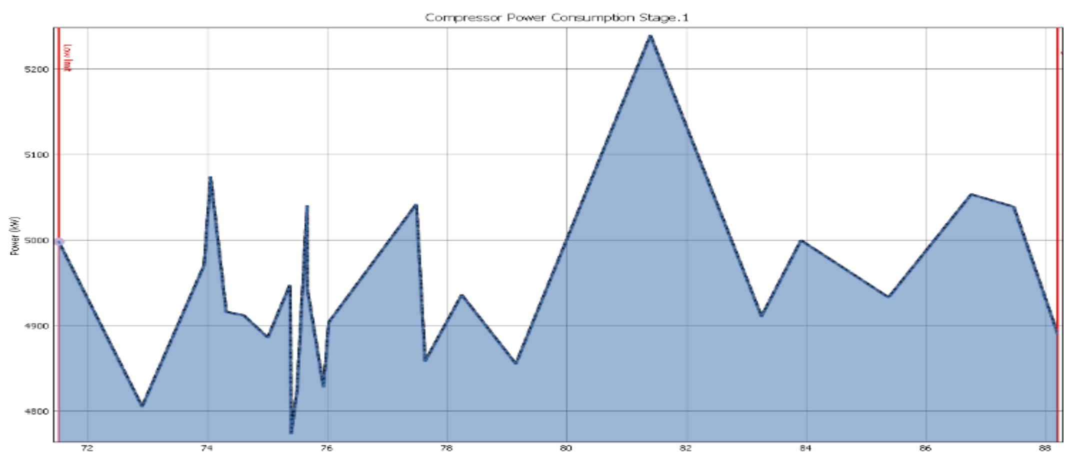

Figure 3. Power Consumption of compressor stage.1

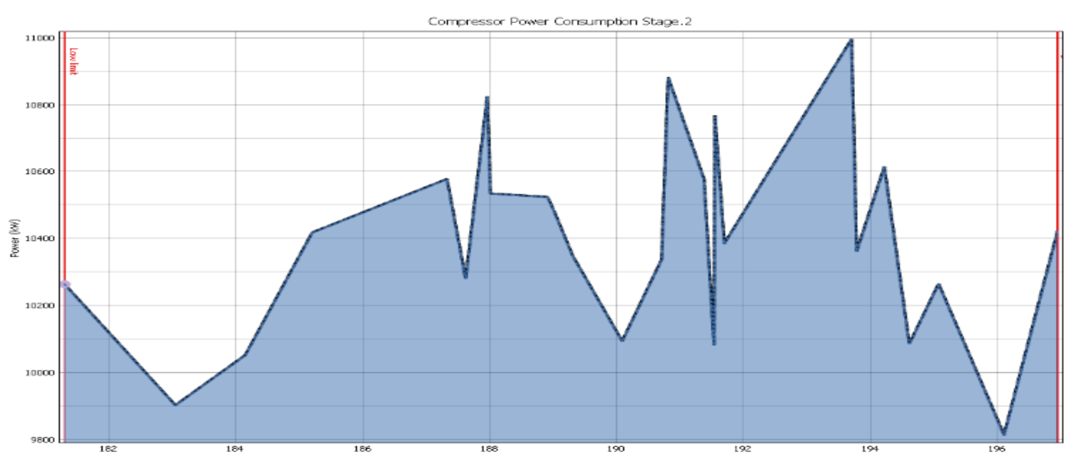

Figure 4. Power Consumption of compressor stage.2

The compressor speed as shown in Figure 5 and Figure 6, is a function of power and compressor capacity is a useful benchmark for confirming real output and comparing model predictions under comparable circumstances. As the suction pressure changes due to a supply/demand mismatch, the compressor speed is a significant predictor for controlling the output. The results reveal that the compressor speed is suitable within the designed limits when compared to the designed value.

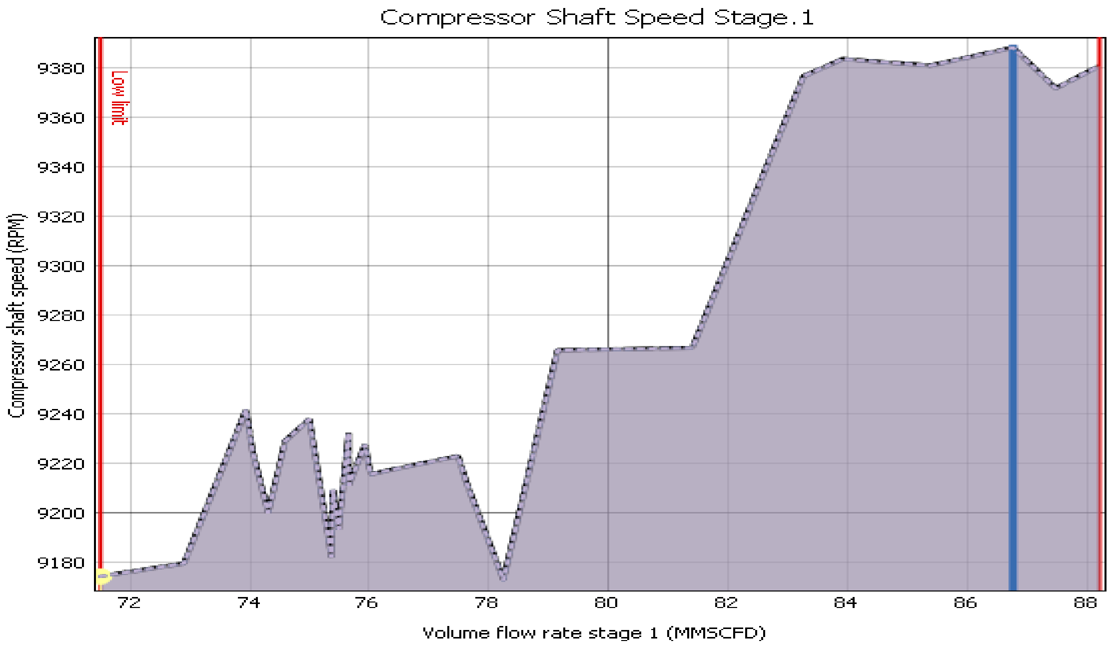

Figure 5. Load for CC stage.1

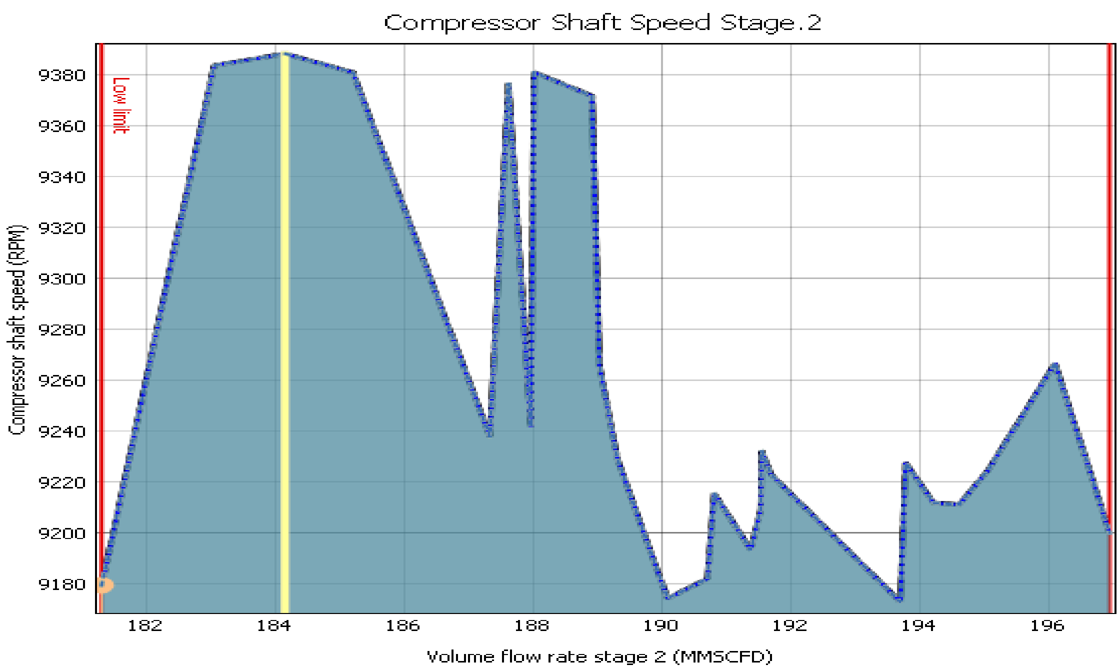

Figure 6. Load for CC stage.2

Energy performance monitoring: Energy performance monitoring is one of the methods to maintain health of a centrifugal compressor in the form of sustainability. The energy consumption for stage 1 and stage 2 was predicted using compressor power consumption and speed. The compressor's energy performance in terms of energy consumption is calculated using KWh/MMSCFD. The compressor's performance in terms of energy consumption is monitored as shown in Figure 7 and Figure 8.

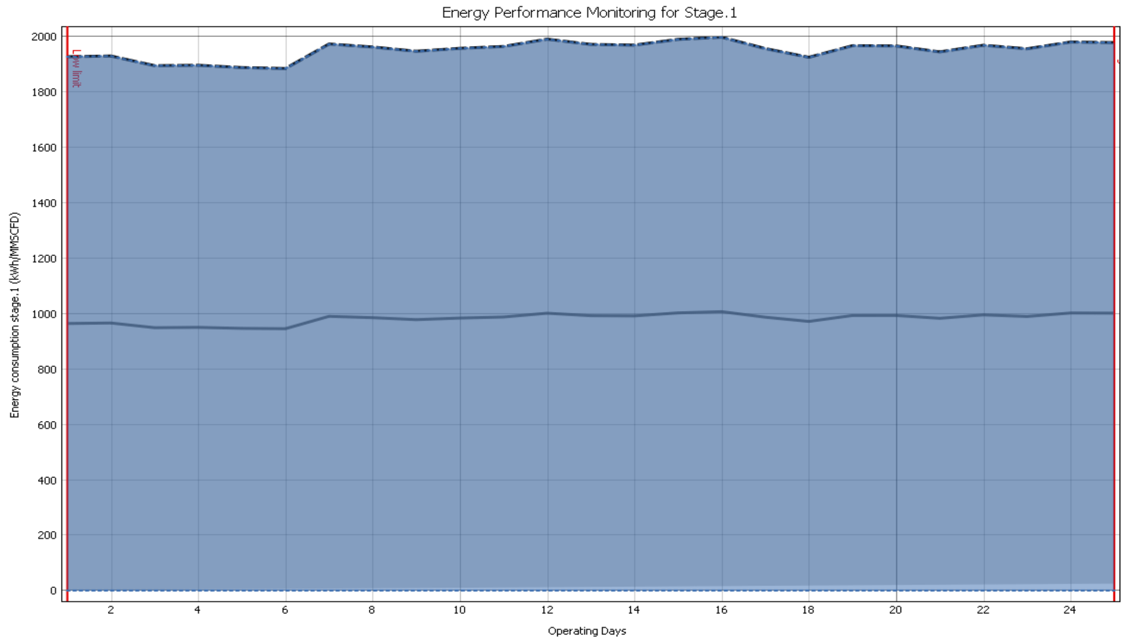

Figure 7. Energy Monitoring for CC stage.1

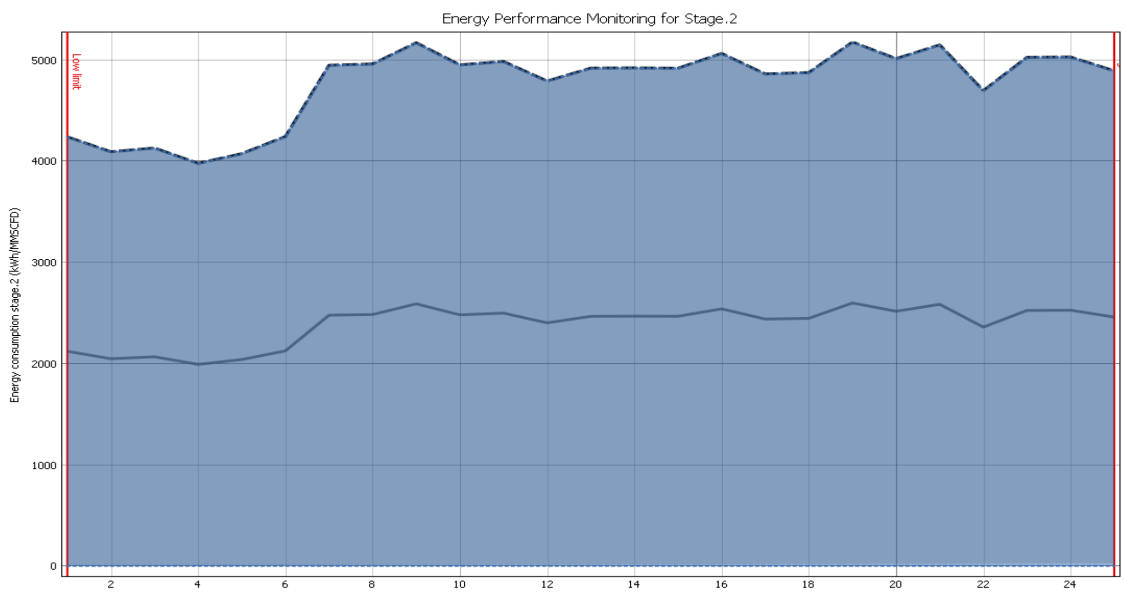

Figure 8. Energy Monitoring for CC stage.2

The current way of calculating energy efficiency is to use a simple regular ratio of energy used to power the compressor. The energy consumption to produce gas for stage 1 is 1882.71 kWh/MMSCFD on the first day of operation and maximum 1995.60 kWh/MMSCFD on day 25, according to the results, while the energy consumption for stage 2 is 3977.64 kWh/MMSCFD on the first day of operation and maximum 5175.89 kWh/MMSCFD on day 25. Furthermore, the results show that, in comparison to the designed data, the power consumption is more in stage 2 due to the production of high pressurized gas and performance drop, due to these factors energy consumption is more in stage 2. The associated Energy performance monitoring is shown in Figure 5 and 6 for both stages , and the following are some key points to note.

- On most working days, the energy consumption is less in the stage 1 due to the production of low pressure gas.
- On most working days, the energy consumption is more in the stage 2 due to the production of high pressure gas and performance drop.
- Energy performance monitoring was considered accurate for monitoring energy key performance indicators (KPIs).

CONCLUSION

From the results it is analyzed that energy efficiency assessment framework is a useful tool to detect energy inefficiency due to sudden load variation during peak and off-peak demand. Furthermore, energy consumption & load in terms of shaft speed as function of capacity are key indicators to verify the actual operation and energy consumption of CC. To determine the condition and operation of centrifugal compressors, a detailed performance analysis was conducted. However, it was observed that drop in performance was due to the internal component degradation, mechanical wear, and fouling, resulted higher energy consumption, reduce reliability, costly unplanned shutdowns. The results showed that the lower and upper limits for compressing production gas for stage 1 are 71.52 and 88.20MMSCFD, which consuming power 4772.89 and 5239.54 kW respectively. Moreover, for stage 2 the lower and upper limits for compressing production gas are 181.3 and 196.9 MMSCFD, consuming power with 9813.10 and 10995.70 kW respectively. Moreover, results showed that on most working days, the energy consumption is less 1995.60 kWh/MMSCFD in the First stage due to the production of low-pressure gas and it will increase in the second stage up to 5175.89 kWh/MMSCFD due to the production of high-pressure gas and performance drop. The findings of analysis provide useful information about performance monitoring of centrifugal gas compressors for a wide variety of operations, which can be used to track and compare real and planned performance. The energy performance monitoring forecast was considered accurate for monitoring energy KPIs.

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