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Investigating the Effect of Natural Gas Composition on Centrifugal Gas Compressors Used in Gas Turbine Power Plants

Daido Fujita*, Takahiko Miyazaki

Department of Advanced Environmental Science and Engineering, Kyushu University, Kasuga-City 816-8580, Japan

Corresponding Author Email: fujita.daido.856@s.kyushu-u.ac.jp

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ABSTRACT

The investigation of the substantial impact of natural gas composition on the parameters for operation as well as the performance of centrifugal gas compressors in gas turbine power plants is presented in this paper. The efficiency and dependability of these compressors are greatly impacted by the composition of natural gas, which is defined by the different proportions of methane, ethane, propane, butane, nitrogen, carbon dioxide, and other trace elements. This paper attempts to outline the complex effects of different gas compositions on compressor efficiency, maintenance needs, and overall plant operations through a thorough examination. Important factors to consider include how compressor longevity and performance are affected by gas density, energy content, corrosive components, moisture content, inert gases, and combustion characteristics. In addition, the study examines mitigating tactics to deal with issues brought on by variations in gas composition, including material compatibility, adaptive technologies, monitoring systems, and maintenance plans. This study offers insightful information that is crucial for maximizing the dependability and efficiency of centrifugal gas compressors in gas turbine power plants under various natural gas compositions.

1. INTRODUCTION

Gas turbine power plants have become an important source of energy generation and have made a substantial contribution to the global energy landscape. By compressing the incoming natural gas before combustion, centrifugal gas compressors are used in these plants to increase the efficiency of gas turbines. But the constituents that make up natural gas, such as methane, ethane, propane, and trace contaminants like carbon dioxide and hydrogen sulfide, vary greatly between the sources from which it is produced. The erratic composition of natural gas presents a serious obstacle to the dependable and efficient operation of centrifugal gas compressors in gas turbine power plants. The energy industry continues to be very interested in and concerned about the complex interactions between the many components of natural gas and how these interactions affect the compressors' longevity, dependability, and operational efficiency [1]. The performance and efficiency of gas turbine power plants are significantly influenced by the composition of the natural gas used as fuel. Natural gas, primarily composed of methane, also contains varying amounts of other hydrocarbons such as ethane, propane, butane, and pentane, as well as non-hydrocarbon gases like nitrogen, carbon dioxide, and hydrogen sulfide. These compositional variations can impact the operational parameters and performance of centrifugal gas compressors, which are critical components in gas turbine power plants. The efficiency, stability, and reliability of these compressors are directly linked to the physical and chemical properties of the natural gas they process. Changes in gas composition can affect the density, viscosity, and compressibility of the gas, which in turn influence the compressor's performance characteristics such as pressure ratio, flow rate, and energy consumption [2].

It is essential to comprehend how the composition of natural gas affects centrifugal gas compressors to maximize their efficiency, guarantee operational stability, and extend their lifespan. In addition, as the world's energy scene changes, the use of unconventional gas sources like biogas and shale gas makes the complexity of the gas compositions these compressors deal with even more problematic. Understanding the relationship between natural gas composition and centrifugal gas compressor performance is essential for optimizing the design and operation of gas turbine power plants. This research paper aims to investigate how variations in natural gas composition affect the performance parameters of centrifugal gas compressors. By analyzing these effects, the study seeks to provide insights that could lead to improved efficiency and reliability of gas turbine power plants, ultimately contributing to more sustainable and cost-effective energy production. While there has been substantial research on the performance of gas turbines and centrifugal compressors individually, the specific interplay between natural gas composition and centrifugal gas compressor performance in gas turbine power plants remains underexplored. Most existing studies focus on the effects of natural gas composition on combustion efficiency and emissions in gas turbines, or the mechanical and aerodynamic aspects of centrifugal compressors without considering the variability in gas composition. There is a lack of comprehensive studies that integrate the effects of natural gas composition on both the thermodynamic and mechanical performance of centrifugal gas compressors. This integration is crucial for a holistic understanding of the operational impacts in real-world scenarios. Secondly, the composition of natural gas can vary significantly depending on the source and processing methods. Despite this variability, many studies assume a standardized natural gas composition, neglecting the practical implications of these variations on compressor performance. The purpose of this study is to investigate the complex relationship that exists between the performance of centrifugal gas compressors in gas turbine power plants and the different compositions of natural gas. Through an examination of the impacts of various gas compositions on compressor efficiency, dependability, maintenance needs, and overall performance metrics, this research aims to offer significant perspectives and recommendations for minimizing possible operational difficulties and optimizing the effectiveness of these vital elements in the energy infrastructure [2].

This research aims to contribute to the development of strategies and technologies that allow gas turbine power plants to adapt to a wide range of natural gas compositions, fostering enhanced operational flexibility, reliability, and sustainability in the constantly changing energy production landscape. It will do this by means of thorough analysis, experimentation, and simulation techniques [1]. This research study provides several key insights into the effects of natural gas composition on the performance of centrifugal gas compressors used in gas turbine power plants. Changes in natural gas composition influence critical performance parameters such as pressure ratio, flow rate, and isentropic efficiency. Specifically, gases with higher molar masses require adjustments in compressor operation to maintain desired performance levels [2].

With the goal to fully understand and tackle the complicated connection between the composition of natural gas and the operation of centrifugal gas compressors, this investigation thus lays the groundwork for future research that will improve the efficiency and dependability of gas turbine power plants and contribute to the global effort to generate energy that is both sustainable and efficient [3].

2. MATERIALS AND METHOD

2.1 Literature review

There has been a great deal of research in the fields of gas processing and energy engineering regarding the impact of natural gas composition on centrifugal gas compressors used in gas turbine power plants. Natural gas is a complicated mixture of hydrocarbons and other components, and depending on its source, location, and extraction techniques, it can vary greatly in composition. The performance, efficiency, and dependability of gas turbine systems using centrifugal compressors are significantly impacted by this unpredictability [4].

Numerous investigations have explored the complex connection between compressor behavior and gas composition. Variations in the quantities of heavier hydrocarbons such as butane, propane, ethane, and methane have a substantial effect on the thermodynamic properties of natural gas. These differences affect specific heat, energy content, and gas density, which modifies the compression process in centrifugal compressors. Increased hydrocarbon content has an impact on the total volumetric flow rate and may need adjusting compressor settings for best performance [1].

Compressor component deterioration and corrosion can be caused by hydrogen sulfide, carbon dioxide, and other corrosive substances found in natural gas, which can be problematic for equipment longevity and maintenance. It has also been determined that the amount of moisture present in the gas stream has a significant impact on compressor performance and may cause erosion or corrosion of the compressor casings and blades [1].

Moreover, research conducted by Goldmeer [4] has emphasized the impact of inert gases, like nitrogen, on compression processes. Despite not adding to the energy content, inert gases have an impact on compression efficiency and must be taken into account when designing and operating compressors. The necessity to comprehend how changes in gas composition might affect overall power production efficiency is further highlighted by Khan et al. [5] emphasis on the impact of gas composition on combustion characteristics in gas turbines.

The use of corrosion-resistant specialty materials, the creation of adaptable compressor technologies that can handle different gas compositions, and the deployment of sophisticated monitoring systems to identify changes in gas properties are some of the mitigation strategies that have been suggested in the literature. It's also advised to follow regular maintenance plans to take care of wear and tear brought on by changes in gas composition. The literature concludes by emphasizing how important it is to thoroughly examine how the composition of natural gas affects centrifugal gas compressors in gas turbine power plants. To effectively develop strategies to optimize gas turbine performance under varying gas composition conditions, it highlights the necessity of having a nuanced understanding of the effects of diverse gas compositions on compressor performance, corrosion resistance, and overall plant operations [6, 7].

2.2 Methodology and modelling

The modeling is performed based on three cases of gas compositions using DWSIM process simulation software [6]. Kwanchanok et al. [7] investigated the accuracy of simulation results from DWSIM open-source gas compression model simulation is comparable to Aspen Plus which is a popular commercial software in the process engineering industry and no noticeable difference was observed [7-9]. The ideal process in the compressor is isentropic which is also known as (constant entropy) and it is considered based on the thermodynamic path (adiabatic or polytropic), and the efficiency of the compressor [6, 10].

Isentropic (Adiabatic) or Polytropic power is calculated from the following Eqs. (1) and (2) [11].

$$P = \frac{H_{2s} - H_1}{\eta} W \quad (1)$$

$$P = (H_{2s} - H_1) \times W \times \eta \quad (2)$$

where,

H_{2s}: Outlet Enthalpy for Isentropic Process

H_1: Inlet Enthalpy

W: Mass Flow

η: Adiabatic or Polytropic Efficiency

Adiabatic and Polytropic Heads are calculated from Eq. (3):

$$H = P/(W \times g) \tag{3}$$

where,

H: Adiabatic or Polytropic Head

P: Adiabatic or Polytropic Power

W: Mass Flow

η: Adiabatic or Polytropic Efficiency

g: Gravitational Constant (9.8 m/s²)

The isentropic process is an idealized thermodynamic process in which the entropy of the gas remains constant. In fuel gas compressors, isentropic power calculation assumes no heat transfer with the surroundings, meaning all the work done on the gas increases its internal energy while the polytropic process is a more realistic representation of actual gas compression, where heat transfer with the surroundings is considered. It provides a better approximation for the performance of real compressors [12, 13].

In thermodynamic properties, the Peng-Robinson Equation is used which is stated below:

$$P = \frac{RT}{(V-b)} - \frac{a(T)}{V(V+b)+b(V-b)} \tag{4}$$

where,

P: Pressure

R: Ideal gas universal constant

V: Molar Volume

b: parameter related to hard sphere volume

a: parameter related to intermolecular forces

Gas composition cases used in this study are summarized in Table 1.

Table 1. Gas composition summary [10, 14]

	Case-1	Case-2	Case-3
Methane	95%	90%	91%
Ethane	1%	2%	2%
Oxygen	1%	2%	2%
Nitrogen	1%	3%	3%
Hydrogen sulfide	2%	3%	2%

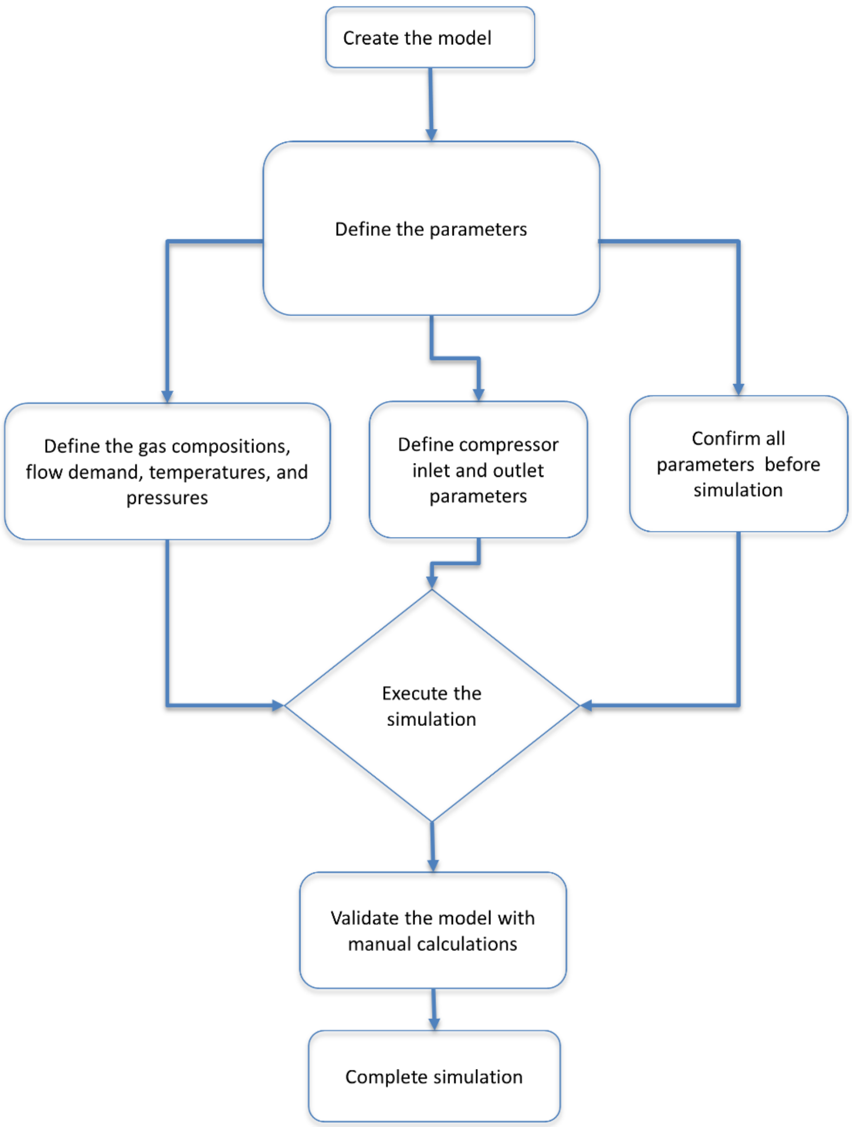

Figure 1. Flowchart of DWSIM simulation model [2, 6]

Figure 1 is the simulation flow chart for the simulation with the DWSIM process simulator. The fuel flow rate (25,000 kg/hour Mass Flow) is considered for full load operation of 400 MW Gas Turbine. A compressor inlet pressure of 25 Bar at 15℃ is considered. The discharge pressure of 40 bar at the discharge header is considered in this simulation. The compositions of natural gas based on the three cases are considered in Table 1. The simulations in DWSIM software were carried out using different gas compositions where case-1 shown in Figure 2, case-2 shown in Figure 3, and case-3 shown in Figure 4 [2, 15].

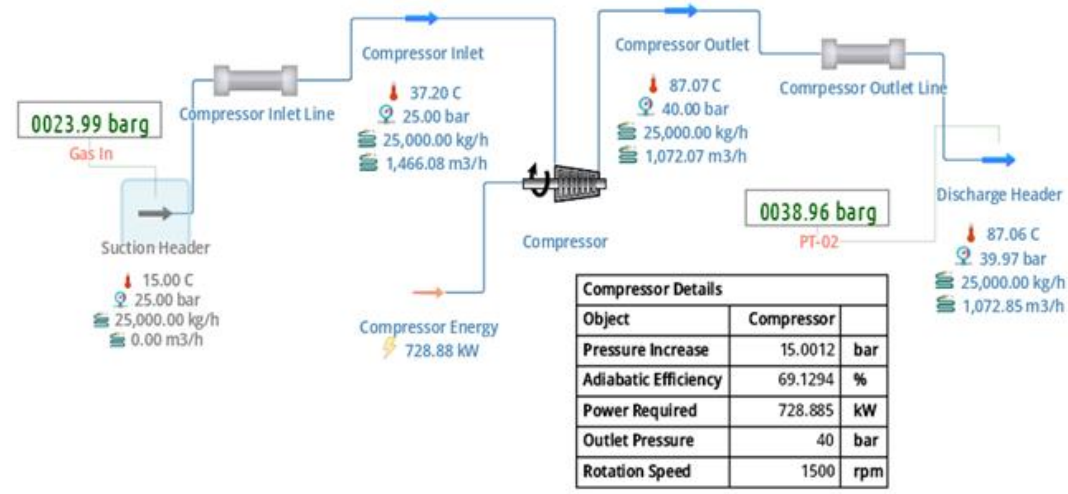

Figure 2. Simulation flow sheet for case-1 gas composition [2, 8]

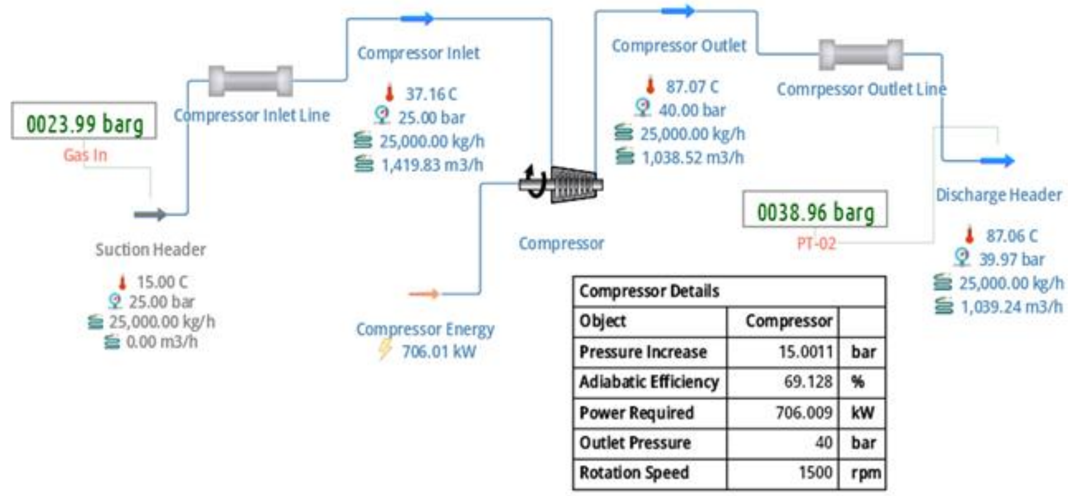

Figure 3. Simulation flow sheet for case-2 gas composition [2, 8]

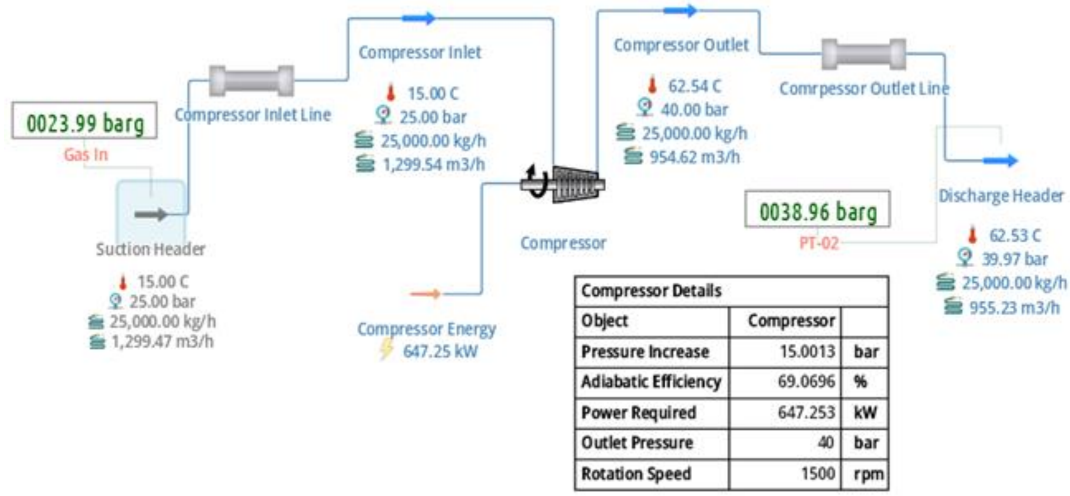

Figure 4. Simulation flow sheet for case-3 gas composition [2, 8]

3. RESULTS AND DISCUSSION

The results show that the adiabatic efficiency decreases from case-1 to case-3 gradually as shown in Figure 5. The lower adiabatic efficiency defines the less effectiveness in the compression process [2].

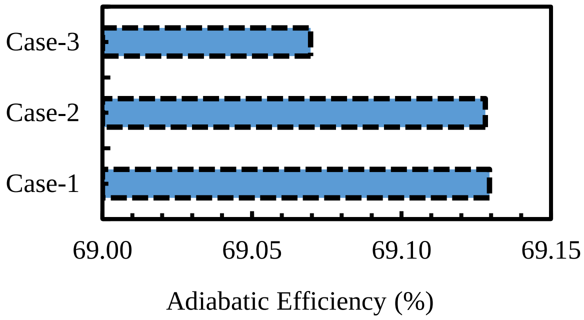

Figure 5. Adiabatic efficiency comparison [2, 8]

The temperature difference (ΔT) increases in case-2 and decreases in case-3 as shown in Figure 6. The increases in discharge temperature require a bigger size of cooler to cool down the discharge side of fuel gas [16].

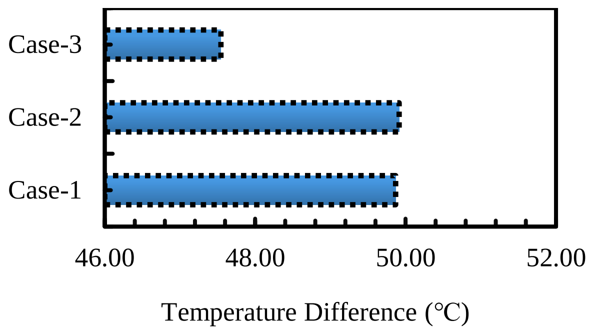

Figure 6. Temperature difference (ΔT) in different cases [2, 8]

The density and molecular weight slightly increased from case-1 to case-3 as shown in Figure 7, which means that, to store the same amount of energy, a larger volume to be compressed.

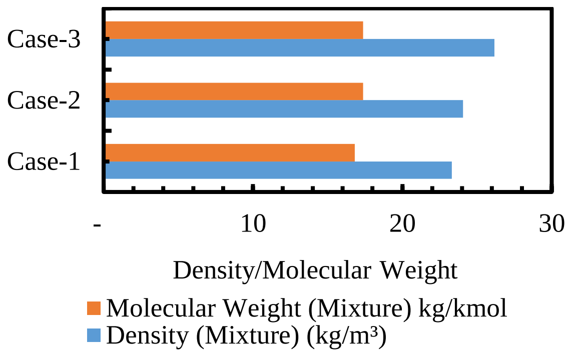

Figure 7. Density/Molecular in different cases [2, 8]

Driving motor power capacity is the major factor to be considered while selecting the compressor as it is usually directly proportional to compressor capital cost [17]. Power consumption tends to decrease from case-1 to case-3 as shown in Figure 8.

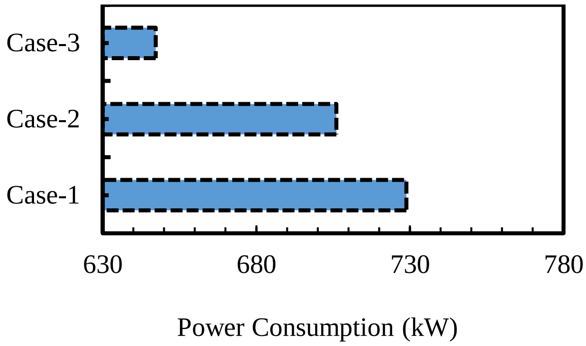

Figure 8. Power consumption in different cases [2, 8]

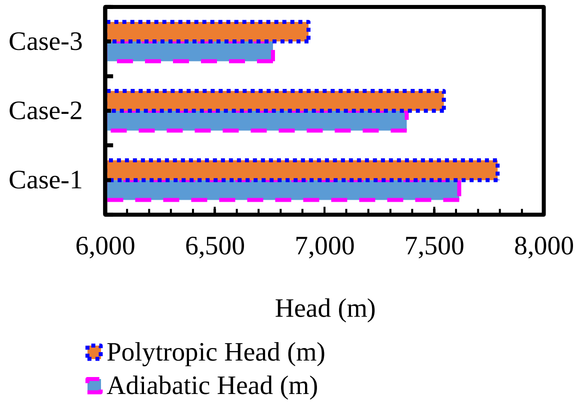

Figure 9. Adiabatic/Polytropic head against fuel ratio [2, 8]

The adiabatic head and polytropic head gradually decrease from case-1 to case-3 as can be seen in Figure 9. The decrease in adiabatic and polytropic heads during gas compression is a consequence of the work done on the gas to raise its pressure [18]. To optimize the operating efficiency of fuel gas compressors due to impurities of feed gases, proper selection of fuel gas filtration systems is highly recommended. These filtration systems often include fuel gas filter separators and knock-out drums if moisture is expected in the fuel gas stream [19, 20].

4. CONCLUSIONS

The complex relationship between the composition of natural gas and the operation of centrifugal gas compressors used in gas turbine power plants was thoroughly investigated in this work. The results demonstrated the significant impact that different gas compositions have on these vital components' operational characteristics, dependability, and efficiency on the infrastructure supporting power generation. The varied composition of natural gas, which is marked by variations in methane, ethane, propane, butane, nitrogen, carbon dioxide, and other trace elements was found to have a substantial effect on the compression process and general operation of centrifugal compressors for the study. Compressor lifetime and efficiency are largely influenced by changes in energy content, gas density, corrosive components, moisture content, inert gases, and combustion properties. The previous studies focus on either the gas turbine or the centrifugal compressor independently, without considering the interconnected effects of natural gas composition where this study adopts an integrated approach, examining the combined impact of natural gas composition on the performance of centrifugal compressors within gas turbine power plants. This study also investigates a wide range of natural gas compositions, reflecting the diversity found in different sources and processing methods, providing a more comprehensive understanding.

Compressor materials were challenged by the presence of heavier hydrocarbons and corrosive components including carbon dioxide and hydrogen sulfide, which led to corrosion and degradation. Another important element that has been identified is the gas stream's moisture content, which may cause erosion or corrosion of the compressor's internal parts. The complexity of the link between gas composition and compressor performance was further highlighted by the effects of inert gases on compression efficiency and the influence of gas composition on combustion characteristics [20].

A comprehensive approach encompassing material selection, creative design techniques, adaptable technology, and reliable monitoring systems is required to meet these problems. Important mitigation methods included the use of corrosion-resistant specialty materials, the development of compressor technologies that are adaptive to different gas compositions, and the installation of sophisticated monitoring systems. Ultimately, this study has demonstrated how critical it is to comprehend and address how the composition of natural gas affects centrifugal gas compressors in gas turbine power plants. The knowledge gained from this study lays the groundwork for improving compressor efficiency, boosting operational dependability, and formulating plans to handle the challenges brought on by varying gas compositions. To adjust and optimize gas turbine operations amid changing gas composition circumstances, future research initiatives should investigate cutting-edge materials, cutting-edge technology, and control systems. This will ultimately lead to more sustainable and efficient power production practices.

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