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Artificial Intelligence Applications in Natural Gas Industry: A Literature Review

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***Abstract:** One of the more controversial uses of artificial intelligence (AI) in the petroleum industry has been in technological advancement. The gas business generates data on a constant basis from several operational procedures. The gas sector is now very concerned about recording these data and using them appropriately. Making decisions based on inferential and predictive data analytics facilitates timely and accurate decision-making. The gas business is seeing a significant increase in the use of data analytics for decision making despite numerous obstacles. Considerable progress has been made in the aforementioned field of study. With the use of artificial intelligence (AI) and machine learning (ML) techniques, many complicated issues may now be resolved with ease. This study, which looks at artificial intelligence applications in the natural gas sector, collected its data from numerous sources between 2005 and 2023. The current work might offer a technical framework for selecting pertinent technologies that will enable efficient information extraction from the massive amount of data produced by the gas industry.*

***Keywords:** Artificial Intelligence, Applications, Gas Industry, Machine Learning Models, Natural Gas*

I. INTRODUCTION

With the introduction of artificial intelligence (AI) technology, the natural gas sector—a vital part of the world's energy landscape—has seen tremendous changes in recent years [1, 2]. The optimization of several facets of the natural gas value chain, from distribution and consumption to exploration and extraction, has been greatly aided by AI technologies [3, 4]. It involves generating new ideas on how to approach research, development, production, transportation, refining, and sales, starting with the early stages of the process and ending with the end user [5, 6].

Artificial intelligence (AI), in all of its integrated forms—from fuzzy logic to neural networks to genetic optimization—has come a long way in the past few years and is starting to gain traction in the gas sector [7].

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It's becoming evident from recent advances in the gas upstream sector that the petroleum industry has grasped the enormous potential that intelligent systems present [8, 9]. Furthermore, a vast quantity of data including critical and essential information is now accessible due to the introduction of new sensors that are permanently installed in the wellbore [10]. In order to fully utilize these inventive hardware instruments, an operator must handle the software to process data in real time [11]. The only practical methods for enabling real-time analysis and decision-making capabilities on the new hardware are intelligent systems [12]. Models used in traditional petroleum extraction techniques fall into three categories: mathematical, physical, and empiricalm according to Thanh et al. [3]. The empirical model is founded on experimentation and observation, while the mathematical model depends on the conservation of momentum, energy, or mass [13, 14, 22]. Due to the limitations of mathematical models under different operating conditions and the imprecision of models derived from empirical modeling, these models necessitate certain assumptions and are unable to manage complicated relationships, noise, and incomplete data [15, 16, 17]. This study examines how artificial intelligence (AI) has been applied in the natural gas business in studies conducted to support data-driven decision making. The applications of machine learning modeling and the analytical modeling tools utilized in the gas industry [21][30]. The latest study on the use of AI approaches in the gas upstream industry is described in this publication. This paper's main goal is to demonstrate the benefits of AI approaches across several gas industry. Based on a methodical comprehension of this sector, the article outlines procedures that employ AI to facilitate efficient computing and decision-making. This study examines the ways in which an intelligent system and the gas sector might work together to shake hands in order to facilitate work and increase production.

II. METHODOLOGY

Using the databases Springer Link, Elsevier, PubMed, and Google Scholar, a review of relevant research publications published between 2005 and 2023 was carried out. The substantial increase in articles in the database and the close relationship between these articles and the gas industry sector served as the driving forces behind the choice of this bibliographic system as the main source of data. The search terms "machine learning," "AI," "natural gas," and "gas industry" were among them. Boolean operators (AND, OR) were used to carefully combine these phrases to generate a very focused and thorough search strategy.

After then, an objective dataset of articles was created by combining each of these datasets. Every reference mentioned in the datasets was thoroughly examined. Lastly, a thorough search of the examined articles' bibliographies was conducted to locate titles that were pertinent to the study's primary topic.

The inclusion criterion—which required that papers be published in English—emphasized the review's dedication to accessibility and comprehensiveness. By taking into account articles released between 2005 and 2023, the systematic review was able to incorporate the most current and relevant research in the field. In order to aid in the classification of research based on their common and unique qualities, the final collection of papers was separated into multiple categories. The subcategories were combined and adjusted during the systematic review process to allow for the integration of data. After the relevant articles have been retrieved from the databases. The titles, abstracts, and full text reads were used to evaluate the papers. In the end, 15 papers were selected for additional screening and quality assessment.

III. RESULT

Fifteen papers in total were included in the review (Table-I). Numerous crucial management concerns have been examined in relation to the deployment of AI approaches in gas sector solutions. To summarize the most recent contributions and the outcomes detailed in the examined publications, apply the following suggested AI strategies in the gas business in this section.

Table-I: Summary of the Studies

No.	Author and Years	Aim	Model	Key Findings
1	(Ghahfarokhi et al., 2018)	Gas production using DTS data	Machine learning, fiber-optic system	▪ Neural network accuracy is less affected by stages with more fluctuation in DAS energy, which indicate less efficient stimulation.
2	(Ali, 2021)	Novel deliverability prediction models for underground natural gas storage	Machine learning algorithms	▪ The study's machine learning models can be useful instruments for forecasting UNGS deliverability in salt caves with varying capacities.
3	(Aramesh et al., 2014)	Predict the transmission of natural gas (NG)	Neural and fuzzy-neural algorithm	▪ Technique reduces the expense of building a new prediction model for every station
4	(Bai & Li, 2016)	Forecast of natural gas (NG) consumption	Support vector regression approach	▪ SC-SVR approach can increase the forecast accuracy for the daily NG consumption due to the nonlinear mapping capabilities of the SVR and the dynamic nature of the online calibration for the model structure.
5	(Curin et al., 2021)	Operation plans of underground natural gas storage facilities	Deep learning	▪ Intrinsic complexity resulting from the high-dimensional forward market and the several limitations
6	(Demirel et al., 2012)	Natural gas consumption forecasting	Neural networks	▪ Since most purchasing agreements are based on predictions, accurate natural gas consumption forecasting is vital.
7	(Khosravi et al., 2018)	to predict the natural gas density at natural gas pressure	Artificial intelligence	▪ ANFIS-GA and GMDH model performed better than the FIS, MLFFNN and ANFIS models.
8	(Manan et al., 2021)	Failure classification in natural gas	Artificial Neural Networks, Support Vector Machine	▪ The training models predict the testing dataset, the models' performance is evaluated.
9	(Mann & Ayala, 2009)	Underground natural gas storage facilities	ANN technology	▪ ANN technology intelligent system is capable of understanding the intricate relationships between input parameters and output responses.
10	(Sanjari & lay, 2012)	Prediction of compressibility factor of natural gas	Artificial neural network (ANN)	▪ Artificial neural network's correctness has been compared with the most widely used empirical models, Peng-Robinson equations of state, and statistical association fluid theory.
11	(Soldo, 2012)	The area of forecasting natural gas consumption	Artificial intelligence (AI)	▪ Yearly data on the production of fossil fuels, and following the plotting of production over time curves.
12	(Soldo et al., 2014)	Natural gas supplied in distribution systems	Solar radiation	▪ Solar radiation affects natural gas consumption, and the forecasting model performs better when it takes solar radiation into account as an input variable.
13	(Szoplik, 2015)	Forecasting of the gas demand	Artificial neural networks	▪ predictions made using MLP models that varied in the quantity of the training data set.
14	(Taşpınar et al., 2013)	Forecast short-term natural gas consumption	ANN	▪ The algorithm generates positive and significant results when used to forecast short-term natural gas usage.
15	(Thanh et al., 2022)	To predict underground natural gas storage deliverability	Hybrid artificial intelligent models	▪ Use nature-inspired tactics to forecast the deliverability of storage sites.

A. Artificial Intelligence (AI) in Gas Industry

Algorithms used in machine learning and deep learning are black boxes because it is difficult to determine why or how they operate in systems that depend on them [1, 7]. There are extremely intricate multi-dimensional algebraic expressions in these methods [6, 9, and 10]. The definition of the coefficients in these expressions fits the input and output data that describe the object, system, or process [3].

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The algorithms can produce original insights based on fresh inputs once they have been trained on known data [4]. Furthermore, there are industrial uses for hybrid modeling, which combines the use of machine learning techniques with physics-driven models.

There are two types of hybrid models: physics-dominated and data-dominated [13]. In hybrid models dominated by physics, machine learning is used to adapt the equation's coefficients to the actual data generated by an item of interest. On the other hand, with data-dominated hybrid models, the physics-driven model produces a large amount of training data that the machine learning model use to comprehend the physics of the issue and help resolve it [15]. Ultimately, AI planning is being used for the first time in the gas industry [2][26][27]. AI planning is the process of organizing particular actions to achieve a goal using a combination of machine learning and optimization techniques. These actions are usually carried out by intelligent agents, autonomous robots, and crewless vehicles [10].

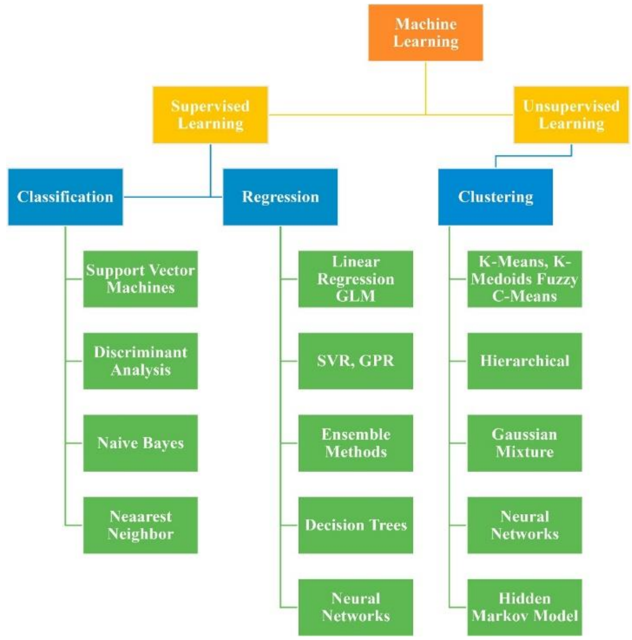

Fig. 1. AI in Gas Industry [7]

B. Forecasting Gas Consumption

In order to simulate the gas network and control the flow of gas through it, it is essential to know the quantity of natural gas consumed, also known as the load on the gas network [6]. Approximately 28% of Poland's gas consumption structure is shaped by municipal users. It appears that regression models are a more sophisticated and precise method of estimating gas consumption [7]. Geem put into practice a linear regression model based on GDP, population size, import and export values, and four other economic variables [15]. The system of points is only partially linear, as Figure 2 illustrates [10]. Gas consumption is constant at around 15 °C and decreases with decreasing temperature below approximately. 15 °C, at which point the value of gas consumption increases directly proportionately. Even though the temperature continues to drop, consumption does not grow after reaching a certain maximum [13].

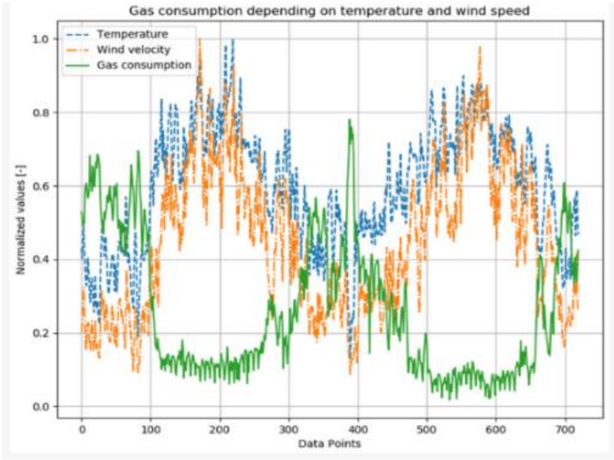

Fig. 2. Natural Gas Consumption [10]

C. Predicting Gas Production

A model was developed to predict the density of natural gas as a function of temperature, pseudo-reduced pressure, and the gas's apparent molecular weight [1]. Their findings showed that the created model can accurately forecast natural gas density across a broad temperature and pressure range [9].

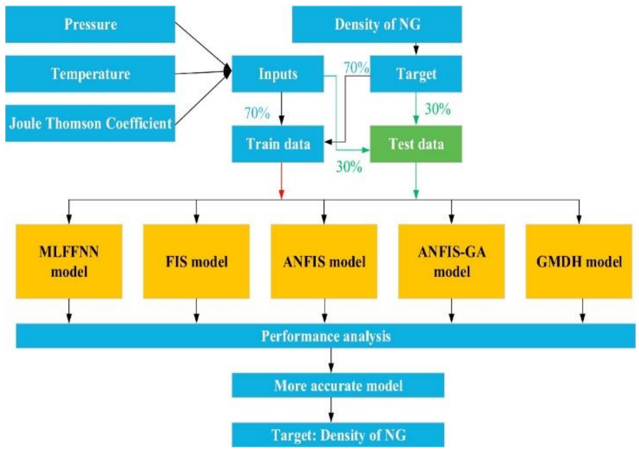

Fig. 3. Prediction of Natural Gas Density [7]

The ability of artificial neural networks (ANN) to effectively identify incredibly complex patterns without assuming anything about the data being investigated has led to an increase in ANN popularity [3]. Without clearly specifying the link between input and output parameters, ANNs offer a flexible solution for regression and classification problems (Table-II). Because neural networks have been applied to many different disciplines of research, they offer a wide range of uses [14, 23][28]. The proposed model for determining the mass flow rate of natural gas is schematically shown in Fig. 4. As seen in the figure, the mass flow rate of natural gas is calculated by the volume corrector using the density of natural gas, which is ascertained by the optimal model of the proposed artificial intelligence techniques, along with the volume flow rate value received from the volume flow meter [7].

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The temperature and pressure recorded before and after the throttle valve are compared to determine the standard deviation of the temperature, strain, and JT coefficient of determination [15].

Table-II: Dynamic Inputs for the Neural Network [8]

Inputs	Outputs
Upscaled DTS (t-1) for stage 1 to 28	Gas production (t)
Flowing time (t-1)	

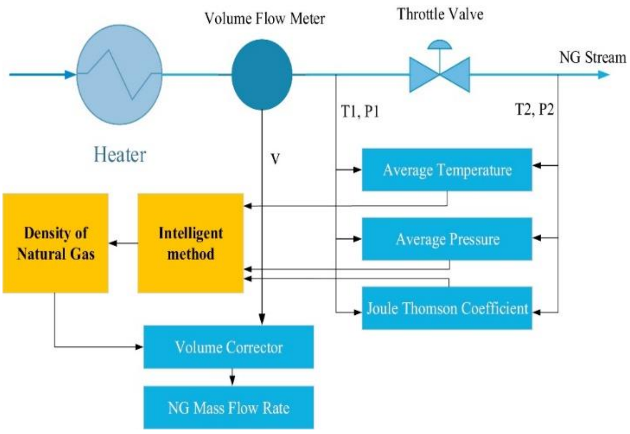

Fig. 4. Predict the Density of Natural Gas [7]

In particular, it has been demonstrated that they can improve sparse data in engineering and geology to boost reservoir modeling performance. Data mining methods for assessing production from shale [9]. A more recent work [5] demonstrated the use of machine learning to the Marcellus Shale to categorize hydraulic cracks. The estimate for reservoir output has also been applied to a number of non-traditional Shales. The study demonstrates that gas production from an unconventional shale resource can be predicted using a continuous stream of fiber optic data (DTS). Downhole temperature is a dynamic metric that varies with production at every stage, as demonstrated by Ghahfarokhi [1]. A production log for a single day does not represent stages of production in the modern sense.

Stage number	Sensitivity analysis error difference	DAS variance	Production log (MCF/d)
28	33.2344	0.084507042	50
27	29.4075	0.481690141	84
26	28.782	0.430985915	67
25	22.5155	0.346478873	158
24	27.5071	0.295774648	192
23	24.355	0.43943662	272
22	26.774	0.346478873	389
21	27.304	0.194366197	198
20	32.8965	0.566197183	99
19	32.5699	0.21971831	119
18	30.7536	0.109859155	231
17	34.4187	0.016901408	250
16	21.8756	0.38028169	378
15	18.7224	0.464788732	59
14	23.611	0.236619718	203
13	23.4141	0.185915493	268
12	17.5225	0.785915493	242
11	23.0408	0.549295775	316
10	13.6376	0.667605634	190
9	16.8706	0.228169014	167
8	24.5391	0.684507042	153
7	23.6815	0.473239437	142
6	26.5018	0.718309859	256
5	17.5871	0.709859155	310
4	16.3985	0.709859155	75
3	25.8073	0.43943662	58
2	21.2219	0.532394366	256
1	-10.5889	0.701408451	251

Fig. 5. DAS Variance and Production

D. Artificial Intelligence in Natural Gas Industry Advantages

By analyzing sensor and equipment data, artificial intelligence (AI) can forecast when maintenance is required, saving downtime and averting expensive equipment breakdowns [7]. Ensuring the integrity of natural gas infrastructure is imperative. From production to distribution, natural gas plants can operate more efficiently thanks to AI algorithms. This entails controlling storage, optimizing supply chain logistics, and raising general operational effectiveness [14]. Through real-time equipment status monitoring, possible hazard identification, and early warning of safety issues, artificial intelligence (AI) can improve safety. This can guarantee worker safety and help prevent accidents [12]. AI systems can optimize energy trading and pricing methods by analyzing geopolitical issues, market trends, and demand-supply dynamics [1]. Businesses in the natural gas industry may benefit from better decision-making and increased profitability as a result [4]. AI can be used to maximize natural gas resource discovery and production through the analysis of seismic data, reservoir modeling, and drilling operations. This can lower exploration expenses and enhance resource recovery [9, 24][29]. AI can help in managing and keeping an eye on the environmental effects of natural gas production. This include monitoring emissions, making sure environmental laws are followed, and putting sustainable policies into action [5].

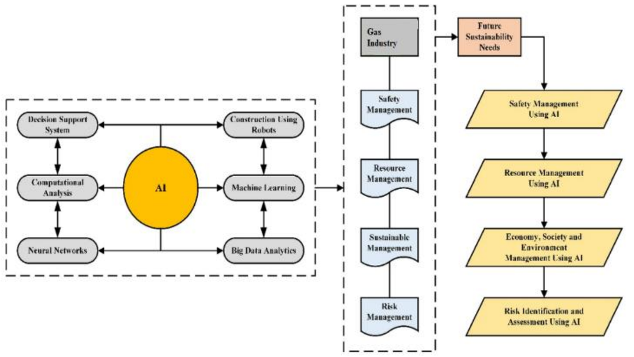

Fig. 6. DAS Variance and Production [2, 5, 9, 11, and 13]

E. Challenges

Reliable and precise data are essential for training and making decisions in AI algorithms. Integrating data from several sources, guaranteeing its accuracy, and managing legacy systems might present difficulties for the natural gas sector [1, 4]. When implementing AI solutions, compliance concerns may need to be carefully considered, and AI applications must be made sure to abide by industry rules and laws. The growing prevalence of AI applications necessitates that the sector tackle the heightened danger of cyber risks [8]. Ensuring the security and integrity of natural gas operations requires safeguarding AI models and sensitive data against cyberattacks [10]. The up-front costs associated with implementing AI technologies may be high for infrastructure, development, and training.

Artificial intelligence (AI) in the natural gas sector may give rise to ethical questions, especially in relation to employment displacement, privacy concerns, and responsible technology use [11, 25]. The processes involved in natural gas operations are complicated, and it takes specialist knowledge to design AI systems that can handle their complexity. Acquiring and maintaining proficient AI experts could be difficult [13].

IV. RECOMMENDATIONS AND LIMITATION

The suggestions made in this study, which are based on the theoretical framework, are very helpful in directing and resolving potential issues in subsequent research. From the perspective of the research gap, the study makes a contribution by giving upcoming scholars the theoretical know-how required to put into practice a strong technique to advance artificial intelligence technology for the environmentally friendly development of gas projects. Artificial intelligence technologies have a lot of promise to shape a safer, sustainable, and productive future when they are integrated into the natural gas sector. Businesses in the natural gas industry need to adopt these advances as technology develops further in order to remain competitive and meet the demands of a fast shifting energy market [16, 17, and 18]. Through the application of artificial intelligence (AI) in the areas of supply chain optimization, smart grids, safety, improved exploration, and predictive maintenance, the natural gas sector may more adeptly and resiliently manage the challenges posed by future energy requirements [19, 20].

An analysis of the literature shows that the gas industry is well-positioned to benefit from machine learning given its ability to process massive amounts of data quickly and efficiently. This research has identified and examined a wide range of monitored learning strategies. Machine learning has the ability to drastically change the important decisions that engineers and administrators in the gas business make on a daily basis. Information can benefit in the future if appropriate techniques are used to combine different data types or structures and convert it into insightful knowledge that aids in making informed decisions. The study has helped establish the theoretical framework, which is based on a summary of the body of research on artificial intelligence and its relationship to the sustainable development of gas projects. From the standpoint of constraints, it is clear that there are less publications in the databases used for the research evaluation than there are in the total amount of research on gas and AI projects. In the long run, a variety of databases will be needed to enhance both the qualitative and quantitative comprehension of AI's consequences for sustainable development. Though it does not fully represent the body of literature involving research on AI and gas projects, the study is also pertinent to the journal articles. Future researchers will find these constraints to be great opportunities to concentrate their efforts on refining the research findings and increasing the sustainability of oil and gas operations.

V. CONCLUSION

As the idea spreads throughout the gas industry, the use of artificial intelligence (AI) is currently accelerating. This includes intelligent drilling, intelligent improvement, intelligent pipelines, smart processing, and so forth. It will eventually be a fruitful field of study as well. Developers have created a wide range of practical application capabilities in both development and manufacturing by utilizing artificial intelligence algorithms. Developers have created a wide range of practical application innovations in both studies and manufacturing by utilizing artificial intelligence algorithms. Exploration risks have already decreased and well success rates have increased as a result of the ANN technique's implementation. These are positive results.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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Chinmay Shripad Kulkarni is a data science professional with a strong foundation in deploying distributed and scalable machine learning solutions across cloud platforms such as AWS and GCP. His experience spans over five years, including impactful roles at DocuSign and Waymo. He has engineered pivotal models and tools to enhance operational efficiencies—from customer health scoring to collision evaluation and ROI tools for agricultural applications. His academic journey in Data Science and Business Analytics from the University of Cumberlands and Fordham University has equipped me with the theoretical knowledge and practical skills necessary to excel in this dynamic field.

Suraj Kumar is a Lead Data Scientist where my passion for data science powers product innovation and impactful outcomes. his journey has taken me through roles at Walmart, Intuit, and Realtor.com, where he has specialized in experimentation and product analytics. At Walmart, he delved into consumer behaviors to refine shopping experiences, boosting engagement and sales. At Intuit, he used data to tailor financial tools, making complex decisions simpler for users. Realtor.com saw him merging real estate trends with digital preferences to enhance property searches. His mantra is simple: listen to the data, iterate based on insights, and always aim for products that are not just better, but are also more intuitive and aligned with user needs.

Satish Kathiriya is a seasoned software engineer with a robust 9-year tenure in the tech industry, currently enhancing the technological landscape at Amazon. His expertise spans across AI, machine learning, and large-scale distributed systems, reflecting a career adorned with significant contributions to leading corporations such as Walmart and JP Morgan & Chase. Presently, Satish delves into the groundbreaking domain of generative AI, where his innovative work continues to push the boundaries of technology. His diverse experience across various domains showcases his adaptability and commitment to driving advancements in the ever-evolving field of software engineering.

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