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Gas Detection and Separation using IoT Technology

Proposed & Submitted by :

- **HASNAOUI D. Nourine**

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- *Dr. BAMBRIK Ilyes*   *(President)*

- *Dr. BEKKOUCHE Amina*   *(Examiner)*

- *Dr. ZIANI-CHERIF Salim*   *(Supervisor)*

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Dedication

First of all,

"Alhamdulillah, I am profoundly grateful to Almighty Allah for guiding me through the journey of my master's thesis and academic studies. Every moment of this educational endeavor has been a blessing, and I am thankful for the knowledge and wisdom I have gained. Your divine guidance has illuminated my path, and I am humbled by the opportunities and challenges that have shaped me into a better scholar.

As I move forward, I pray for Your continued blessings and guidance. May I always strive for knowledge, wisdom, and understanding. May my work contribute positively to my university.

Almighty Allah, I am grateful for the opportunity to learn and grow, and I entrust my future to Your divine plan. With a heart full of gratitude, I say, 'Alhamdulillah' for every moment, every lesson, and every blessing."

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Hasnaoui D. Nourine

Table of Contents

Table of Figures

Introduction

The oil industry, an indispensable pillar of global economies, is enmeshed in intricate environmental challenges. Among these, the emission of CO_2 gases during the flaring phase stands as a formidable concern, with far-reaching implications for climate dynamics, human health, and ecological equilibrium. Addressing this conundrum mandates an exigent quest for effective mitigation strategies.

In the course of conducting this research, it became evident that certain reservations and challenges exist in accessing precise and comprehensive information pertaining to the oil industry. This observation underscores the complex and often guarded nature of this sector, where proprietary data and industrial practices can be closely held. Moreover, the critical issue of flaring, which is a central focus of this thesis, presents a unique challenge due to its environmental and regulatory implications. Access to specific and detailed data related to flaring practices, emissions, and mitigation strategies can be limited, making it a noteworthy challenge in our quest for accurate information. Nonetheless, despite these reservations and information gaps, this research persevered, leveraging available resources and methodologies to shed light on the critical issues at hand and contribute to the collective effort to eliminate flaring in the oil industry.

The contemporary epoch is witness to an intricate interplay between technology and environmental stewardship. At the forefront of this convergence is the emergence of the Internet of Things (IoT), which beckons industries towards a transformative path. This symbiosis between IoT and gas dynamics unveils a compelling avenue for redefining the operational architecture of the oil sector, with discernible ramifications for gas detection and separation paradigms.

Imbued within this interdisciplinary juncture is a nuanced exploration of IoT's integration within the domain of gas management. The focal point on CO_2 emissions during the flaring phase steers the compass, delineating an ambitious trajectory of real-time emissions monitoring fortified by IoT's strategic embrace. Encompassing IoT's foundational principles, this inquiry extends to unravel the intricate landscape of gas detection and separation, accompanied by a contemplative immersion into the potential offered by IoT-enabled sensors in sculpting the contours of emissions data acquisition.

This endeavor transcends the theoretical precincts, embarking upon a pragmatic odyssey. The assimilation of IoT and gas dynamics engenders a metamorphic recalibration of the oil industry's operational ethos, echoing in resource optimization, procedural efficacy, and a harmonious interplay with environmental resilience. This symphony of interface, resonating with economic underpinnings, delineates a landscape where the pursuit of gas management choreographs a symmetrical dance with fiscal stewardship.

In the symposium of pragmatic discourse, the thesis traverses a terrain where sustainability meets pragmatism, where CO_2 emissions find a counterpoint in IoT-driven recalibration. This scholarly sojourn is a testament to the potential for synergy between IoT and gases, enveloping the oil industry in an ecumenical tapestry of scientific ingenuity and economic prudence. As the contours of industry dynamics merge with ecological equilibrium, this inquiry echoes as a clarion call for the harmonious confluence of scientific innovation and environmental resilience within the annals of the oil sector.

1. Chapter I : Problematic & countermeasures

1.1. Introduction :

As mentioned earlier, the CO_2 emissions is one of the major problems in the oil industry which are the consequences of the flaring phase. Gas flaring occurs as a result of the burning process that involves the release and combustion of the natural gas that is commonly found in association with oil extraction activities. This practice involves the intentional disposal of this gas through combustion, which not only leads to the release of greenhouse gases into the atmosphere but also represents a significant waste of a valuable energy resource.

1.2. Greenhouse Effect In The Oil Industry :

The greenhouse effect within the context of the oil industry embodies a pivotal environmental challenge of our time, stemming from the intricate interplay between fossil fuel combustion, atmospheric greenhouse gas accumulation, and the far-reaching consequences for Earth's delicate climate system. This phenomenon is intricately tied to the extensive utilization of fossil fuels, predominantly oil, which yields the emission of a myriad of greenhouse gases, notably carbon dioxide (CO2), into the Earth's atmosphere. The subsequent repercussions of these emissions are multifaceted and possess profound ramifications that reverberate globally.

The fundamental mechanism underlying the greenhouse effect is the creation of a metaphorical thermal blanket within the atmosphere. As fossil fuels burn, they unleash a surge of CO2 and other greenhouse gases into the air, forming an invisible barrier that traps and re-radiates heat from the sun. This heat-trapping effect triggers a gradual rise in average global temperatures, a phenomenon commonly identified as global warming. The amalgamation of these factors drives the broader process of climate change, amplifying the frequency and intensity of extreme weather events, impacting sea levels, and jeopardizing delicate ecosystems.

Addressing the intricate nexus between the greenhouse effect and the oil industry necessitates an unwavering commitment to proactive, sustainable practices that catalyze a transformation

towards an environmentally conscientious future. The urgency of this imperative is underscored by a multitude of scientific studies and reports, such as those conducted by the Intergovernmental Panel on Climate Change (IPCC), which consistently demonstrate the irrefutable link between greenhouse gas emissions and climatic shifts. These findings have been widely acknowledged and referenced in prominent international agreements and platforms, including the Paris Agreement—a monumental accord aimed at uniting nations in the global effort to combat climate change [1].

As the world collectively grapples with the monumental challenge of environmental degradation, the oil industry stands at a critical crossroads. Embracing a paradigm shift towards sustainable operations, clean energy technologies, and reduced carbon emissions is not only a moral obligation but also an imperative for the long-term viability of our planet. By curbing greenhouse gas emissions through the deployment of innovative techniques, renewable energy sources, and the enhancement of operational efficiency, the oil industry can contribute substantively to the global quest for mitigating the adverse impacts of the greenhouse effect.

In essence, the intricate relationship between the greenhouse effect and the oil industry encapsulates a defining epoch of our time, marked by the imperative for collective action and the adoption of sustainable solutions. The journey towards a harmonious coexistence between industry and environment hinges upon a resolute commitment to sustainable practices and the preservation of Earth's ecological equilibrium.

1.3. Energy resource wastes:

In the oil industry, the efficient utilization of energy resources stands as a paramount challenge. As a sector responsible for a significant portion of global energy consumption, it is essential to address the issue of energy resource waste to promote sustainability and minimize environmental impact. The extraction, processing, and transportation of crude oil and its derivatives involve intricate operations that often result in substantial energy losses.

Statistics underscore the magnitude of this challenge. According to a report by the International Energy Agency (IEA) [2], the energy intensity of oil production, including extraction, refining, and distribution, remains a considerable concern. It is estimated that a substantial portion of the energy consumed within the oil industry is lost during various stages of production. These losses not only impact the industry's operational efficiency but also contribute to elevated greenhouse gas emissions and environmental degradation.

Efforts to combat energy waste in the oil industry are multifaceted. Advancements in technology have introduced innovative approaches to streamline operations and minimize inefficiencies. One example is the adoption of advanced drilling techniques, such as rotary steerable systems [3], which enhance drilling precision and reduce energy-intensive practices. Additionally, the implementation of data-driven analytics and machine learning algorithms has enabled predictive maintenance and optimized energy utilization in refining processes [4].

Another critical aspect is the adoption of sustainable practices. Integrated energy management systems [5] have been introduced to monitor and optimize energy consumption across various stages of oil production. By closely monitoring energy use and identifying areas of waste, companies can implement targeted measures to enhance energy efficiency and minimize losses.

Collaborative initiatives and industry-wide partnerships have also played a pivotal role in addressing energy waste. Organizations like the Oil and Gas Climate Initiative (OGCI) [6] are committed to driving innovation and promoting sustainable practices within the sector. These initiatives facilitate knowledge sharing, research, and the development of best practices to tackle energy waste and reduce the environmental footprint of the oil industry.

As the world seeks to transition to more sustainable energy sources, addressing energy waste in the oil industry becomes imperative. By embracing technological advancements, sustainable practices, and collaborative efforts, the industry can significantly mitigate its impact on energy

resource waste, contribute to environmental conservation, and pave the way for a more sustainable energy future.

1.4. Diverse Ideas Presented to Counteract This Phenomenon:

Navigating the intricate challenge of the greenhouse effect within the realm of the Oil Industry demands a comprehensive and dynamic array of approaches and solutions, each carefully tailored to mitigate its environmental ramifications. As this phenomenon continues to underscore the urgency of sustainable practices, the industry finds itself at a pivotal juncture, compelled to innovate and adapt to secure a harmonious balance between energy demand and environmental preservation.

A cornerstone of combating the greenhouse effect lies in enhancing energy efficiency throughout the extraction, refining, and distribution processes. Advanced technologies, such as integrated gasification combined cycle (IGCC) and cogeneration systems, optimize energy utilization, minimize waste, and reduce emissions. By adopting these solutions, the industry can effectively curtail the release of greenhouse gases into the atmosphere [7].

The implementation of carbon capture, utilization, and storage (CCUS) technologies holds transformative potential. CCUS mechanisms capture CO_2 emissions directly from industrial operations, subsequently repurposing them for enhanced oil recovery or secure geological storage. This approach not only diminishes atmospheric carbon levels but also enhances oil recovery rates, offering a dual benefit to the industry [8].

In tandem with these technological advancements, the oil sector can strategically diversify its energy portfolio by incorporating renewable energy sources. Solar power, wind energy, and biofuels provide viable alternatives to fossil fuels, enabling the industry to substantially reduce its carbon footprint [9].

The concept of circular economy gains traction within the oil domain, advocating for closed-loop systems that minimize waste generation. Recycling and repurposing waste products, such as plastics and petrochemical byproducts, not only reduce emissions but also contribute to the sustainable utilization of resources [10].

Policy and regulatory frameworks play a pivotal role in steering the industry towards a low-carbon trajectory. Stringent emissions standards, carbon pricing mechanisms, and incentivized renewable energy integration foster a conducive environment for sustainable practices [11].

As the oil industry's drive towards sustainable progress gains momentum, the amalgamation of IoT-driven data-driven strategies emerges as a catalyst for transformation. The infusion of real-time data insights, harnessed through the Internet of Things (IoT), wields a paradigm shift that ushers in predictive analytics and enhanced monitoring. This orchestrated synergy propels operational efficiencies, refines resource distribution, and orchestrates emissions reduction, solidifying the industry's march towards a more environmentally conscious and proficient future.

In this transformative journey, the oil industry can draw inspiration from groundbreaking research and initiatives. Studies from the International Energy Agency (IEA) and influential reports, such as "Energy Technology Perspectives," offer critical insights into the technological pathways and policy imperatives to counteract the greenhouse effect [12].

The global community's collective pursuit of environmental stewardship and sustainable development necessitates an unwavering commitment to harmonizing energy demands with ecological preservation. By embracing a holistic blend of technological innovation, regulatory guidance, and industry collaboration, the oil sector can manifest its role as a catalyst for meaningful change, ultimately shaping a more sustainable and resilient future.

1.5.   Existing/available solutions & attempts:

Amid the intricate tapestry of the oil industry, the looming shadow of the greenhouse effect has ignited a fervent pursuit of innovative solutions and technical interventions aimed at mitigating its far-reaching impact. As the combustion of fossil fuels, including oil, continues to

unleash a torrent of greenhouse gases into the atmosphere, scientists, engineers, and industry leaders have embarked on a multifaceted journey to curtail emissions, foster sustainable practices, and reshape the industry's trajectory.

One cornerstone of this effort lies in the realm of carbon capture and storage (CCS), a transformative approach designed to intercept and sequester carbon dioxide emissions before they escape into the atmosphere. By leveraging advanced technologies, such as solvent-based absorption and membrane separation, CCS offers a mechanism to capture CO2 emissions from various sources, including industrial processes and power plants. These captured emissions are then transported and securely stored in geological formations deep beneath the Earth's surface, effectively preventing their release into the environment.

Additionally, the development and integration of renewable energy sources have emerged as a pivotal strategy to diminish the carbon footprint of the oil industry. Leveraging solar, wind, and hydropower, these alternatives offer a cleaner energy matrix while reducing reliance on fossil fuels. The synergy between conventional oil production and renewable energy adoption not only curtails greenhouse gas emissions but also contributes to the diversification of energy sources.

Technological innovations also extend to the domain of enhanced oil recovery (EOR), wherein carbon dioxide is harnessed not as a pollutant but as a strategic tool. Carbon dioxide injection during EOR not only enhances oil production but also results in the permanent geological sequestration of CO2. This twofold advantage underscores the potential of merging oil extraction practices with carbon capture, thereby presenting an avenue for sustainable resource utilization.

Simultaneously, advancements in methane detection and reduction technologies aim to curb emissions of this potent greenhouse gas often associated with oil production. Innovations such as drone-based methane detection systems enable rapid identification and mitigation of leaks, minimizing the environmental impact and enhancing overall operational efficiency.

Furthermore, the concept of circular carbon economy seeks to close the carbon loop by reusing CO2 emissions as feedstock for various products, ranging from plastics to construction materials. Such a holistic approach transforms emissions from a liability into a valuable resource, offering a potential avenue to significantly reduce the industry's carbon footprint.

In sum, the oil industry is witnessing a remarkable shift towards embracing technical solutions that counteract the greenhouse effect. From pioneering carbon capture and storage technologies to the integration of renewable energy sources, innovative approaches are reshaping the industry's landscape. These efforts underscore a collective commitment to sustainability, environmental stewardship, and the transformation of challenges into opportunities.

2.Chapter II : Gas Detection and Separation

2.1. Introduction :

Recognizing the list of consequences including grave environmental aspects and inertial economic ones consequences associated with the process of flaring in the oil industry, it becomes paramount to delve into alternative measures that can effectively mitigate this pressing issue.

By adopting an efficient and sustainable gas management approach, centered around the crucial phases of Gas Detection and Separation, we can squarely address the challenge of flaring. A comprehensive and meticulous analysis of the residual gases following the extraction of oil allows for a thorough understanding of their composition.

Through the implementation of cutting-edge diagnostic procedures, we can precisely identify the individual components present within the gas mixture. This intricate analysis provides valuable insights into the chemical makeup of the gases, enabling us to make informed decisions about their potential uses and environmental implications.

Subsequent employment of advanced separation techniques, tailored to the unique characteristics of each component, facilitates the isolation and categorization of the gases. These techniques leverage the principles of chromatography, a powerful tool that exploits the differential interactions between gas molecules and a stationary phase.

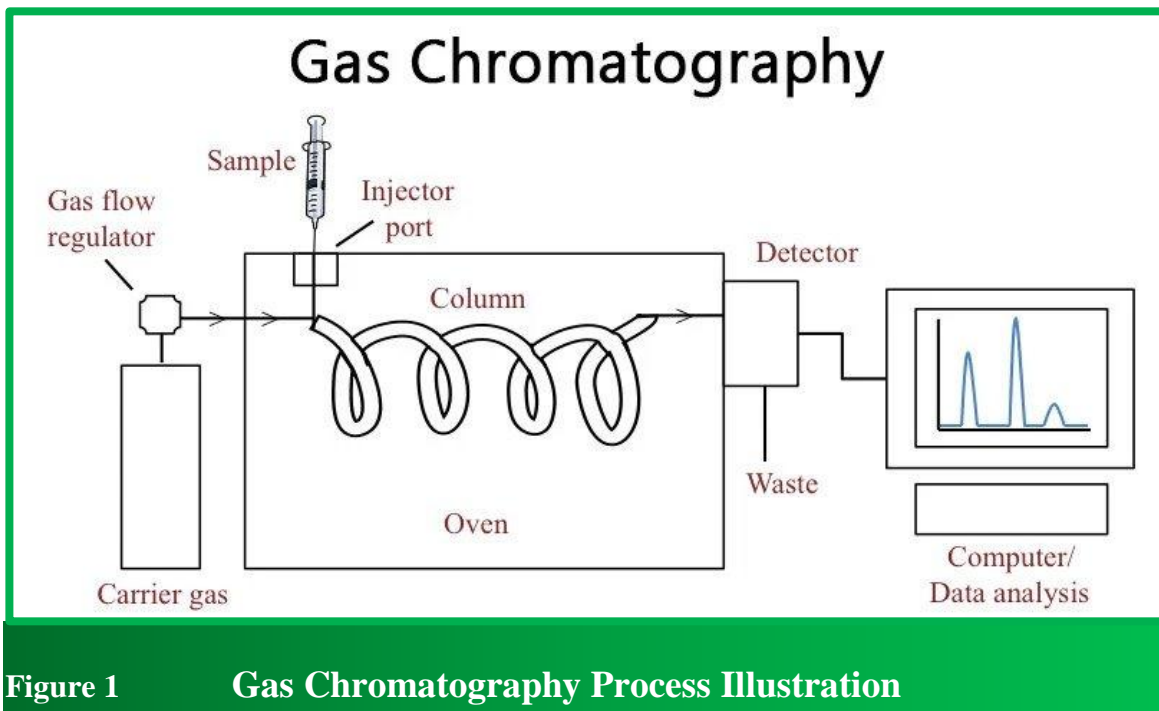**Figure 1**   **Gas Chromatography Process Illustration**

This affords us the opportunity to chart optimal utilization pathways for each discerned gas component, ensuring their redirection towards designated purposes that are harmoniously aligned

with energy generation, environmental sustainability, and the prudent optimization of valuable resources. By repurposing these gases for beneficial applications, we not only reduce wastage but also contribute to the overall efficiency and sustainability of the oil industry.

In doing so, we pave the way for a paradigm shift in the management of gas resources, fostering a more sustainable future for the oil industry and mitigating the adverse ecological impact associated with flaring practices. This approach aligns with broader global efforts to reduce greenhouse gas emissions, enhance resource efficiency, and promote responsible industrial practices.

Through a comprehensive and synergistic integration of Gas Detection and Separation techniques, the oil industry can usher in a new era of environmentally conscious practices that prioritize both economic viability and ecological integrity. This transformative approach underscores the industry's commitment to minimizing its environmental footprint and embracing innovative solutions for a more sustainable energy landscape.

2.2. Gas Chromatography:

2.2.1. What is gas chromatography:

Gas Chromatography (GC) is a powerful analytical technique used to separate and analyze complex mixtures of gases or volatile compounds in various samples. It operates on the principle of partitioning compounds between a stationary phase and a mobile phase, allowing for the separation of different components based on their affinities for these phases [13].

This versatile technique finds applications across a wide range of industries, including environmental analysis, pharmaceuticals, petrochemicals, food and beverage, and more. GC provides invaluable insights into the composition, purity, and concentration of substances, making it an essential tool for quality control, research, and regulatory compliance.

Key components of a GC include the injection port, column, detector, and data analysis software. As the sample vaporizes and is introduced into the system, the compounds traverse the column at varying rates, leading to their separation based on factors like boiling points and

chemical interactions. The detector identifies and quantifies the separated compounds, generating data that can be further analyzed to draw meaningful graphics about the sample's composition [14].
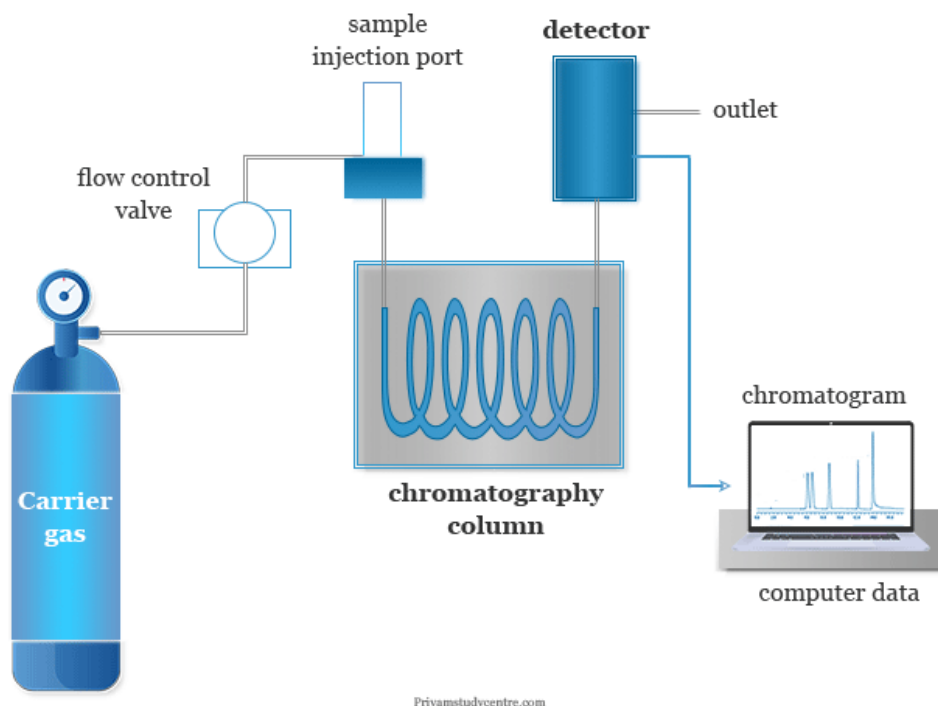
Figure 2   **Gas Chromatography Components**

Recent advancements in GC technology have led to enhanced sensitivity, efficiency, and automation, allowing for more precise and rapid analyses. Researchers continually explore innovative applications and methodologies, further expanding the utility of gas chromatography in diverse scientific and industrial domains [15].

2.2.2.   GC Technical Constraints:

GC is a sophisticated analytical technique that enables the separation and identification of volatile compounds within complex mixtures. Successful implementation of GC requires careful attention to various conditions and parameters to achieve accurate and reliable results.

The process begins with the preparation of the sample, which is injected into the chromatograph. The choice of injection technique, whether split, splitless, or others, depends on the nature of the sample and the desired sensitivity. The sample is vaporized and transported by a carrier gas through the chromatographic column, where separation occurs based on the differential interactions between the sample components and the stationary phase.

One critical factor is the selection of the appropriate column and stationary phase, tailored to the specific compounds being analyzed. Temperature control is essential during gas chromatography. The column's temperature is programmed to increase or decrease at specific rates, influencing the separation process. For instance, increasing the temperature can elute compounds faster, while lowering it can separate closely eluting compounds more effectively.

The flow rate of the carrier gas also plays a significant role. A balance must be struck between efficient separation and avoiding excessive pressure, which can damage the column or compromise the detector's performance. The choice of carrier gas, such as helium, hydrogen, or nitrogen, affects efficiency and sensitivity.

Detection is another critical aspect. Different detectors, such as flame ionization detectors (FID), electron capture detectors (ECD), and mass spectrometers (MS), offer varying levels of sensitivity and selectivity. These detectors provide signals that are processed and displayed as chromatograms, allowing for the identification and quantification of sample components.

Here's a brief overview of some common GC detectors:

1. Flame Ionization Detector (FID):

   - Particularities: Highly sensitive and versatile. Suitable for a wide range of organic compounds.

   - Technical Aspects: In FID, carbon-containing compounds are burned in a hydrogen flame, producing ions that generate an electrical current, which is measured.

   - Compatibility: Ideal for hydrocarbons, pesticides, and many organic compounds.

2. Thermal Conductivity Detector (TCD):

   - Particularities: Non-destructive and universal. Detects changes in a sample's thermal conductivity.

- Technical Aspects: Measures the difference in thermal conductivity between the sample and a reference gas.

- Compatibility: Suitable for analyzing permanent gases (e.g., hydrogen, helium, nitrogen) and inorganic gases.

3. Electron Capture Detector (ECD):

- Particularities: Exceptional sensitivity to compounds containing electronegative elements (e.g., halogens).

- Technical Aspects: Utilizes a radioactive source to ionize carrier gas, and when electronegative compounds are present, they capture electrons, reducing the current in the detector.

- Compatibility: Effective for detecting halogenated compounds, pesticides, and some pharmaceuticals.

4. Mass Spectrometry Detector (MSD):

- Particularities: Provides compound identification through mass spectra. Exceptional selectivity and sensitivity.

- Technical Aspects: Ions generated from sample molecules are separated based on their mass-to-charge ratio.

- Compatibility: Versatile and suitable for a wide range of compounds, making it a preferred choice for qualitative and quantitative analysis.

5. Flame Photometric Detector (FPD):

- Particularities: Sensitive to sulfur and phosphorus compounds, particularly organosulfur and organophosphorus compounds.

- Technical Aspects: Employs a hydrogen flame and measures the intensity of light emitted when sulfur or phosphorus compounds are burned.

- Compatibility: Used for environmental analysis, petrochemicals, and organosulfur/organophosphorus compound detection.

6. Thermal Conductivity Detector (TCD):

- Particularities: Highly stable and durable. Measures changes in thermal conductivity between the sample and a reference gas.

- Technical Aspects: Often used for permanent gases and inorganic compounds.

- Compatibility: Suitable for hydrogen, helium, nitrogen, and other gases, making it versatile for industrial applications.

7. Photoionization Detector (PID):

- Particularities: Sensitive to volatile organic compounds (VOCs) and other compounds with ionization potentials below the energy of the UV lamp.

- Technical Aspects: Utilizes a UV lamp to ionize compounds, and the resulting ions are detected.

- Compatibility: Widely used in environmental monitoring, occupational safety, and detection of VOCs in air and water samples.

The choice of detector depends on the specific analytes of interest, sensitivity requirements, and the intended application. GC systems often allow for detector switching to accommodate different analytes within a single analysis, providing flexibility and comprehensive insights into complex samples.

2.2.3.   Latest technologies:

In the ever-evolving landscape of analytical chemistry, Gas Chromatography (GC) stands as a cornerstone, continually propelled forward by a surge of innovative technologies. These advancements have not only redefined the boundaries of separation science but have also catalyzed breakthroughs in fields ranging from environmental analysis to pharmaceutical research. The convergence of cutting-edge tools, techniques, and methodologies has ushered in a new era of precision, sensitivity, and efficiency in GC analysis [16].

One of the most striking revolutions in modern GC lies in the integration of high-resolution mass spectrometry (HRMS). The fusion of GC with HRMS has unraveled an unprecedented realm of molecular insight, enabling precise identification and quantification of compounds with unparalleled accuracy [17]. By unveiling detailed molecular structures, isotopic compositions, and

fragment patterns, this synergy has significantly expanded the scope of GC applications across diverse sectors, from forensic analysis to metabolomics research.

Additionally, the advent of comprehensive two-dimensional Gas Chromatography (GCxGC) has initiated a paradigm shift in sample separation. GCxGC capitalizes on the power of dual dimensions to deconstruct complex mixtures, enabling the characterization of compounds that would otherwise remain obscured in conventional GC analysis [18]. This breakthrough technique has fostered a deeper understanding of intricate sample matrices and paved the way for enhanced fingerprinting and trace-level detection.

The digital age has ushered in a renaissance of automation, where GC systems are endowed with smart functionalities and intuitive interfaces. Automated sample handling, injection, and data analysis have streamlined workflows, saving time and minimizing human intervention [19]. Furthermore, the integration of advanced software solutions and data processing algorithms has elevated GC analysis to the realm of real-time insights, allowing for swift decision-making and optimization [20].

2.3. Mixed gas properties:

The mixed gas resulting from oil extraction in the oil industry encompasses a dynamic composition of various compounds, each playing a distinct role in the overall characteristics of the gas mixture. This intricate blend typically consists of components such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentanes (C_5H_{12}), carbon dioxide (CO_2), hydrogen sulfide (H2S), and nitrogen (N_2) [21].

Typical natural gas composition

Compound	Molar fraction
Hydrocarbons	
Methane	0.75 – 0.99
Ethane	0.01 – 0.15
Propane	0.01 – 0.10
n-Butane	0.00 – 0.02
Isobutene	0.00 – 0.01
n-Pentane	0.00 – 0.01
Isopentane	0.00 – 0.01
Hexane	0.00 – 0.01
Heptane plus higher hydrocarbons	0.00 – 0.001
Nonhydrocarbons	
Nitrogen	0.00 – 0.15
Carbon dioxide	0.00 – 0.30
Hydrogen sulfide	0.00 – 0.30
Helium	0.00 – 0.05

Table 1   Mixed Gas Properties and Proportions

Methane, the primary constituent of natural gas, often accounts for a significant portion of the mixture, constituting around 60-90% [22]. Ethane, propane, and butane contribute varying percentages, influencing the calorific value and energy potential of the gas. Pentanes, although present in relatively lower concentrations, play a role in the overall energy content of the mixture.

On the other hand, carbon dioxide, hydrogen sulfide, and nitrogen, while present in smaller proportions, can significantly impact the quality and usability of the gas. Carbon dioxide, a greenhouse gas, may comprise up to 10-20% of the mixture [23]. Hydrogen sulfide, with concentrations as low as a few parts per million (ppm), poses safety concerns due to its toxic nature. Nitrogen, while relatively inert, can dilute the gas and affect its combustibility.

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These various gas components find diverse applications in the oil and gas industry and beyond:

1. Methane (CH4): Methane is a valuable energy resource and is primarily used for power generation, heating, and as a fuel for various industrial processes. It is also the main component of natural gas used for residential and commercial heating.

2. Ethane (C2H6): Ethane is used as a feedstock in the petrochemical industry for the production of ethylene, a crucial component in the manufacture of plastics.

3. Propane (C3H8) and Butane (C4H10): These gases are commonly used as fuels for heating, cooking, and as engine fuels in vehicles and forklifts.

4. Pentanes (C5H12): Pentanes are used as a gasoline additive to enhance octane ratings and improve engine performance.

5. **Carbon Dioxide (CO2):** While a greenhouse gas, carbon dioxide is also used in enhanced oil recovery (EOR) processes to increase oil production from reservoirs.

6. Hydrogen Sulfide (H2S): Hydrogen sulfide is often removed from natural gas due to its toxicity and corrosion effects. It is also used in the chemical industry to produce sulfur compounds.

7. Nitrogen (N2): Nitrogen is used for inerting purposes to prevent the combustion of flammable materials in storage tanks and pipelines.

The intricate nature of these gas components necessitates careful analysis and separation to optimize their utilization. Advanced techniques, including Gas Chromatography (GC), enable the precise determination of each component's concentration, aiding in strategic decision-making regarding the gas's potential applications [24].

2.4.   Gas Detection:

2.4.1.   Gas sensors:

In the intricate landscape of the oil industry, where safety, environmental responsibility, and operational efficiency reign supreme, the deployment of gas sensors emerges as a technological cornerstone that safeguards both human lives and the delicate equilibrium of the environment. Amidst this expansive terrain, the integration of advanced gas sensors signifies a remarkable leap, epitomizing the fusion of scientific innovation with industrial practice. These sensors serve as vigilant sentinels, ceaselessly surveying the atmosphere to identify the presence and concentration of various gases, thereby preempting potential risks and propelling the industry's sustainable progression.

Gas sensors, with their diverse and innovative manifestations, have ushered in a new era of gas detection and identification. Leveraging an array of cutting-edge technologies, each meticulously tailored to target specific gases, measurement ranges, accuracy thresholds, and environmental conditions, these sensors embody the epitome of scientific ingenuity. Among these technological marvels, catalytic bead sensors, exemplified by the Honeywell EC-FX-NH3 [25] and MSA Ultima X Series [26], harness catalytic reactions to identify gases like ammonia and combustible gases. Their persistent monitoring ensures the safety of sprawling industrial environments, including the intricate infrastructure of oil refineries.

Electrochemical sensors, represented by the Rae Systems ToxiRAE Pro [27] and Industrial Scientific Tango TX1 [28], assume an equally crucial role in upholding safety standards. Proficient in detecting toxic gases such as hydrogen sulfide, carbon monoxide, and oxygen, they provide real-time insights into atmospheric conditions, facilitating rapid responses to potential hazards. Meanwhile, semiconductor sensors, exemplified by the Figaro TGS Series [29] and Alphasense MiCS Series [30], harness the electrical properties of semiconductor materials to identify gases like methane, nitrogen dioxide, and carbon monoxide. This amalgamation of science and technology underpins gas detection systems that are indispensable to the oil industry's intricate operations.

The realm of optical gas sensors, where light's interaction with gases yields measurable responses, introduces advanced technologies like the Aeroqual Series 200/300 [31] and GSS Ozone Sensor [32]. Employing optical absorption principles, these sensors offer precise measurements of gases such as ozone and nitrogen dioxide. This fusion of physics and technology introduces a novel dimension to gas detection, where light beams unravel the unseen composition of the air, aiding in the mitigation of latent hazards.

Comparing these sensor types reveals their unique strengths and suitability for various applications within the oil industry. Catalytic bead sensors excel in detecting combustible gases and ammonia but may not be as sensitive to certain toxic gases. Electrochemical sensors are proficient in toxic gas detection and are suitable for a wide range of applications. Semiconductor sensors offer versatility and cost-effectiveness, making them suitable for general gas detection needs. Optical gas sensors, while precise, may have higher upfront costs but provide valuable insights into specific gas types. The choice of sensor depends on the specific requirements and safety considerations of each industrial setting, highlighting the importance of selecting the right tool for the job.

In summation, the evolution of gas sensor technologies mirrors the convergence of scientific prowess and industrial requisites, standing as a pivotal component in the oil industry's pursuit of safer and more sustainable practices. Their significance transcends beyond mere detection; they empower operators with real-time data, expedite responses, and optimize industrial processes, all while playing a pivotal role in safeguarding human lives and the environment.

2.4.2.   Detection process:

In the intricate landscape of the oil industry, the precise detection of gases holds paramount significance, ensuring not only operational integrity but also safeguarding human lives and environmental preservation. The gas detection process involves the orchestrated interplay of advanced sensors and sophisticated analytical techniques to discern the intricate chemical composition of the surrounding air within industrial settings.

Commencing this process involves the strategic placement of specialized gas sensors at strategic points across oil-related installations. These sensors are painstakingly calibrated to discern specific gases of interest, encompassing an array of compounds such as hydrocarbons,

volatile organic compounds (VOCs), hydrogen sulfide (H2S), methane (CH4), and carbon dioxide (CO2). Employing sophisticated sensor technologies, these instruments continuously sample the surrounding air, meticulously scrutinizing it for the presence and concentrations of target gases.

Upon detecting a gas, the sensors promptly initiate a series of intricate electrochemical or optical reactions. These reactions generate discernible electrical signals that are transduced into digital data.

2.4.3.   How gas sensors work:

Gas sensors, also known as gas detectors or analyzers, operate based on intricate chemical and physical principles to detect the presence of specific gases in the environment. These sensors are essential tools in various industries, including the oil sector, for monitoring and ensuring safety.

At the heart of gas sensor technology is a sensing element that interacts with target gases. This element typically consists of a material that undergoes chemical changes when exposed to the gas being detected. This interaction may cause alterations in electrical properties, such as conductivity, resistance, or potential difference, which can be measured and interpreted as gas concentration.

For instance, in the context of the oil industry, semiconductor gas sensors are often employed. These sensors utilize metal oxide materials as the sensing element. When the target gas interacts with the metal oxide surface, it modifies the electrical conductivity of the material. This change is proportional to the concentration of the gas.

Gas sensors are designed with specific selectivity to particular gases, allowing them to distinguish between different gas types. This selectivity is achieved by optimizing the sensing material and the operating conditions. Some sensors may require elevated temperatures to enhance sensitivity, while others work at room temperature.

To facilitate accurate detection, gas sensors are integrated into measurement circuits. These circuits control the sensor's operating conditions and process the resulting electrical signals. The output signals can be calibrated to reflect gas concentrations. Moreover, advancements in microfabrication techniques have led to the development of miniaturized gas sensors, enabling their integration into various devices and systems.

In the oil industry, gas sensors play a pivotal role in monitoring potentially hazardous gases such as methane (CH_4), hydrogen sulfide (H_2S), and carbon dioxide (CO_2) during extraction, refining, and transportation processes. Real-time data from gas sensors inform safety protocols and preemptive actions, reducing the risk of accidents and ensuring the well-being of personnel.

The technical intricacies of gas sensors underscore their significance in maintaining operational safety and environmental stewardship within the oil industry. Their ability to provide continuous, precise, and rapid gas detection serves as a crucial safeguard against potential hazards and contributes to the efficient and sustainable management of oil-related processes.

2.5.   Separation Process:

The gas separation process utilizing gas chromatography is a sophisticated analytical technique employed to separate, identify, and quantify components within a mixed gas sample. This process, crucial in various industries including the oil sector, relies on the differential interaction of gas molecules with a stationary phase within a chromatographic column. By exploiting these interactions, gas chromatography offers an intricate means to analyze complex gas mixtures.

When dealing with a mixed gas containing compounds like Methane (CH_4) and Hydrogen Sulfide (H_2S), the gas separation process involves several distinct stages. Upon injection into the chromatograph, the mixed gas sample is carried by a carrier gas, such as helium or nitrogen, through the chromatographic column. This column is packed with a stationary phase that interacts differently with each gas component based on their chemical properties.

As the mixed gas travels through the column, interactions between the gas components and the stationary phase lead to differential retention times. Compounds with stronger interactions spend more time interacting with the stationary phase, causing them to elute later from the column. Conversely, compounds with weaker interactions elute earlier.

In the context of the mixed gas with Methane and Hydrogen Sulfide, Methane, being a non-polar molecule, exhibits weaker interactions with the stationary phase compared to the polar Hydrogen Sulfide. Consequently, Methane tends to elute earlier, while Hydrogen Sulfide has a longer retention time.

Upon elution from the column, the separated gas components are detected by a detector, such as a Flame Ionization Detector (FID) or Thermal Conductivity Detector (TCD). The detector generates electrical signals proportional to the quantity of each component, and this data is then processed and analyzed.

By employing gas chromatography in the separation of gas mixtures, including those containing Methane and Hydrogen Sulfide, the oil industry can enhance operational efficiency, reduce environmental impact, and promote safe working conditions. This technique exemplifies the marriage of scientific precision and industrial utility, underscoring its vital role in advancing oil-related processes.

3.Chapter III : The Use of IoT Technology

3.1. Introduction:

In this chapter, our focus shifts toward a comprehensive examination of the oil industry, delving into its state prior to the integration of Internet of Things (IoT) technologies. By doing so, we aim to provide an empirical foundation for contrasting the industry's past with its present IoT-enabled landscape.

We begin by presenting a contextual backdrop that encapsulates the pre-IoT era, detailing the operational paradigms, limitations, and challenges that defined the industry's modus operandi. This retrospective analysis offers a springboard for understanding the catalysts driving the industry's transition toward IoT integration.

Transitioning to the contemporary landscape, we embark on an exploration of the transformative impact brought forth by IoT integration within the oil sector. We illuminate the paradigm shifts resulting from IoT-enabled data acquisition, real-time monitoring, and predictive analytics, highlighting how these advancements have redefined operational efficiency, sustainability, and decision-making processes.

An integral facet of this chapter is the introduction of a comprehensive simulation, which serves as a tangible bridge between theory and practice. By meticulously replicating the entire project's process within this simulation, we offer readers a dynamic window into the intricate interplay between IoT technologies and the oil industry's multifaceted operations.

In summary, this chapter assumes the role of an illuminating chronicle, unraveling the metamorphosis of the oil industry before and after the advent of IoT integration. By threading historical context, present-day realities, and the simulation's immersive insights, we aspire to provide a holistic understanding of the industry's trajectory, enriched by the technological evolution that IoT has ushered in.

3.2. The Internet of Things Explained:

The Internet of Things (IoT) is a transformative technological paradigm that has revolutionized the way devices, objects, and systems interact and communicate with each other

through the internet. It encompasses a vast network of interconnected physical devices embedded with sensors, software, and other technologies, enabling them to collect and exchange data autonomously. This data can then be processed and utilized to inform decision-making, enhance efficiency, and enable automation across various industries.

The origins of the IoT can be traced back to the late 20th century, when the concept of embedding sensors and actuators into everyday objects was first explored. The term "Internet of Things" itself was coined by Kevin Ashton in 1999, who envisioned a future where physical objects could communicate seamlessly through the internet. However, it was not until the early 21st century that advancements in technology, such as miniaturization of sensors, increased connectivity, and improved data processing capabilities, paved the way for the widespread adoption of IoT solutions.

The development of the IoT has been characterized by a continuous evolution of technology and its integration into various aspects of our lives. Early applications focused on simple data collection and remote monitoring, such as tracking inventory in supply chains or monitoring environmental conditions. As technology progressed, IoT applications became more sophisticated, enabling real-time analytics, predictive maintenance, and enhanced user experiences.

One of the key drivers of IoT's development has been the rapid growth of internet connectivity and the proliferation of smart devices. The advent of high-speed wireless networks, coupled with the increasing affordability of sensors and processors, has enabled the seamless connection of a multitude of devices, from smartphones and wearables to industrial machinery and infrastructure.

Today, the IoT has permeated diverse industries, from healthcare and agriculture to manufacturing and energy. It has catalyzed the emergence of smart cities, where interconnected systems enhance urban living through efficient resource management and improved services. As the technology continues to evolve, concepts like edge computing and 5G connectivity promise to further accelerate the capabilities of the IoT, enabling faster data processing and more responsive applications.

In conclusion, the Internet of Things represents a transformative force that has reshaped the technological landscape by creating an interconnected web of devices and systems. Its origins

date back to visionary ideas of connected objects, and its development has been driven by advancements in connectivity, sensors, and data processing capabilities. Today, the IoT is an integral part of modern life, offering innovative solutions to challenges across industries and shaping the way we interact with the world around us.

3.3. IoT in The Oil Industry:

In the annals of industrial evolution, the integration of the Internet of Things (IoT) into the oil industry marks a pivotal juncture that has revolutionized its operational landscape. This transformation, precipitated by the convergence of advanced sensor technology, data analytics, and digital connectivity, has reshaped the traditional paradigms of oil exploration, extraction, and refinement.

The genesis of IoT in the oil industry can be traced back to the early 21st century, with its formal introduction gaining momentum around the mid-2010s. Scholarly discourse often points to seminal works such as the article "IoT-Enabled Smart Oilfield for Efficient and Sustainable Oil Production" by Zhang et al [33], which underscored the potential of IoT to optimize oilfield operations by amalgamating real-time data insights and predictive analytics.

This nascent integration was not devoid of challenges. The oil industry, characterized by its sprawling and often remote operations, confronted obstacles in seamlessly integrating IoT devices within the rigors of its environments. However, innovation spurred solutions, and the development of ruggedized sensors and communication protocols tailored for oilfield exigencies began to bridge this gap.

The impetus driving IoT's adoption in the oil industry was manifold. With mounting pressures for operational efficiency, cost-effectiveness, and sustainable practices, the potential of IoT to provide real-time insights into equipment performance, resource utilization, and environmental impact became increasingly appealing. Articles like "IoT and Big Data in the Oil Industry: A Review" by Gubbi et al[34]. emphasized IoT's role in streamlining maintenance, minimizing downtime, and optimizing energy consumption.

Fast-forward to the present day, and the integration of IoT in the oil industry has yielded transformative outcomes. IoT-enabled sensors embedded within drilling equipment, pipelines, and storage facilities gather real-time data on parameters such as pressure, temperature, and flow

rates. This data is transmitted to centralized platforms, facilitating predictive maintenance strategies that preemptively identify potential equipment failures and mitigate risks, thereby enhancing safety and minimizing operational disruptions.

The interplay between IoT and data analytics has fostered a realm of possibilities in predictive modeling. The integration of machine learning algorithms enables the extrapolation of trends and patterns from historical data, thereby informing strategic decisions regarding production optimization, energy efficiency, and risk assessment. The result is an oil industry empowered with insights to enhance yield, minimize environmental impact, and bolster its contribution to energy security.

In summation, the journey of IoT in the oil industry has witnessed a trajectory from conceptual inception to transformative implementation. As evidenced by articles such as "The Internet of Things (IoT) in the Oil and Gas Industry" by Hanachi et al. [35], IoT has emerged as a cornerstone of operational modernization, redefining the industry's modus operandi and ushering in an era of data-driven excellence. This evolution underscores the adaptive nature of the oil sector, harnessing technological innovation to navigate challenges and engineer sustainable growth.

3.4. IoT Integration in Gas Detection and Separation (In The Real World):

Within this section, we delve into the theoretical framework of our gas detection and separation process, envisioning its potential real-world implementation with cutting-edge IoT-based gas sensors. While our exploration primarily resides within the theoretical realm, it offers a glimpse of how this innovative gas management paradigm could materialize if fully realized. We will elucidate the critical requisites, components, and methodologies essential for this theoretical construct.

In this theoretical exercise, we recognize the pivotal role of IoT-enabled gas sensors as the linchpin of our system. These smart sensors, equipped with real-time monitoring capabilities and data-driven insights, form the cornerstone of our gas detection strategy. However, it's important to note that the realization of this concept is contingent upon various factors, including technological advancements, resource allocation, and industry readiness. As we navigate this

theoretical landscape, we shall uncover the intricacies of this vision, paving the way for a sustainable and efficient gas management paradigm, even if it remains primarily theoretical at this juncture.

3.4.1. Detection:

In the real-world oil industry, the detection of gases using smart IoT gas sensors represents a paradigm shift in safety, efficiency, and environmental compliance. These sensors, meticulously designed to navigate the intricacies of oil well operations, offer a seamless and comprehensive gas monitoring solution.

Imagine an oil extraction site where smart IoT gas sensors are strategically deployed throughout the facility. These sensors continuously and autonomously sample the ambient air, detecting the presence of various gases commonly encountered during the oil extraction process, such as methane, hydrogen sulfide, and carbon dioxide. In real-time, these sensors transmit data to a centralized monitoring system via the Internet of Things (IoT) connectivity.

Within this monitoring system, advanced algorithms and machine learning models process the incoming data streams. These algorithms not only identify the type and concentration of gases but also assess the data against predefined safety thresholds and compliance standards. In the event of any deviations or anomalies, the system triggers immediate alerts to on-site personnel and central control centers.

This real-time gas detection and alert system drastically enhance operational safety. Personnel receive timely warnings of potentially hazardous gas levels, enabling swift evacuation or the implementation of safety protocols. Moreover, the system logs all data, creating a comprehensive record for compliance reporting and incident analysis.

Beyond safety, the utilization of smart IoT gas sensors offers profound benefits for operational efficiency. By continuously monitoring gas emissions, operators gain insights into the efficiency of extraction processes. For instance, fluctuations in methane levels may indicate areas with untapped resources, prompting adjustments in drilling or extraction methods to optimize resource recovery.

Furthermore, the data collected by these sensors contribute to environmental stewardship. By monitoring and minimizing gas emissions, oil companies can demonstrate their commitment to reducing their carbon footprint and complying with environmental regulations.

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In conclusion, the integration of smart IoT gas sensors into the real-world oil industry revolutionizes gas detection by providing continuous, accurate, and actionable insights. This technological advancement enhances safety, operational efficiency, and environmental responsibility, marking a transformative step forward in the oil and gas sector.

3.4.3. Types of IoT Gas Sensors:

These sensors are compatible with IoT (Internet of Things) technology, making them "smart" gas sensors for real-time monitoring and data collection:

- **Honeywell EC-FX-NH3:** This smart gas sensor is designed for ammonia detection, which can be relevant in oil industry processes. It offers IoT connectivity for remote monitoring and data analysis.

- **MSA Ultima X Series:** MSA's Ultima X Series includes gas sensors for various gases, including methane (CH_4) and hydrogen sulfide (H_2S), which are common in the oil industry. These sensors can be integrated into IoT systems for continuous monitoring.

- **Rae Systems ToxiRAE Pro:** ToxiRAE Pro sensors are suitable for detecting toxic gases like hydrogen sulfide and carbon monoxide. They offer wireless communication options for IoT integration.

- **Industrial Scientific Tango TX1**: Tango TX1 is designed for toxic gas detection, including hydrogen sulfide. It provides wireless connectivity for real-time data transmission to IoT platforms.

- **Figaro TGS Series:** Figaro's TGS Series includes sensors for various gases, including methane and carbon monoxide. While they are not inherently IoT devices, they can be integrated into IoT systems with the appropriate interfaces.

- **Alphasense MiCS Series:** Alphasense MiCS sensors can detect gases like methane and nitrogen dioxide. While they are not IoT devices by default, they can be connected to IoT platforms through data loggers or controllers.

- **Aeroqual Series 200/300:** Aeroqual's optical gas sensors can detect gases such as ozone and nitrogen dioxide. These sensors offer IoT compatibility for remote monitoring and data analysis.

3.4.4. Theoretical Data Processing in the Control Center:

In the modern oil industry, the synergy between smart IoT gas sensors and advanced control centers has revolutionized the way gas-related data is collected, processed, and acted upon. This dynamic interaction ensures that gas detection and safety measures are not isolated events but rather integrated components of a comprehensive operational framework.

Smart IoT gas sensors, strategically placed throughout oil extraction facilities, continuously sample the surrounding air for the presence of gases. These sensors are equipped with sophisticated gas-sensitive materials and technologies that enable them to interact selectively with specific gases, generating real-time data about gas concentrations and potential anomalies.

The collected data from these sensors is then transmitted in real-time to a centralized control center through secure IoT connectivity. This seamless data flow provides the control center with a constant stream of information, allowing for immediate monitoring and analysis. The control center's infrastructure is designed to accommodate this influx of data, with powerful processors, storage systems, and specialized software tailored for gas monitoring and analysis.

Upon receiving the data, the control center employs advanced algorithms and analytical tools to process and interpret the information. This includes real-time data fusion, where incoming

data from multiple sensors is integrated and correlated to create a comprehensive situational awareness picture. The control center also employs machine learning and artificial intelligence (AI) algorithms to identify patterns, trends, and anomalies in the gas data.

One of the central functions of the control center is to set predefined thresholds and safety protocols. If the data indicates that gas concentrations are approaching or exceeding these thresholds, automated alerts are generated. These alerts trigger immediate responses, such as activating safety systems, shutting down specific operations, or notifying personnel in the field.

Furthermore, the control center provides a user-friendly interface for human operators who can visualize the gas data in real-time. This interface displays gas concentrations, trends, and potential safety risks, allowing operators to make informed decisions promptly. It also enables remote control of safety systems and the initiation of emergency procedures when necessary.

In essence, the control center serves as the nerve center of gas monitoring and safety in the oil industry, seamlessly integrating data from smart IoT gas sensors and transforming it into actionable insights. This real-time, data-driven approach not only enhances safety but also optimizes operational efficiency and environmental compliance. It exemplifies the convergence of cutting-edge technology and human expertise in ensuring the well-being of personnel, the integrity of operations, and the sustainability of oil extraction processes.

3.4.5. IoT Based Separation Approaches and Techniques:

In the oil industry, gas separation processes can be enhanced and made more efficient through the integration of Internet of Things (IoT) technology. IoT-based equipment and systems play a crucial role in monitoring and controlling various aspects of gas separation. Here are some IoT-based equipment and technologies utilized for gas separation in the oil industry:

- **Smart Gas Chromatography (GC) Systems:** IoT-enabled GC systems are equipped with sensors that continuously monitor and analyze the composition of gas mixtures. These systems can automatically adjust separation parameters based on real-time data, improving accuracy and efficiency.

- **IoT-Enabled Membrane Separation Units:** Membrane separation units equipped with IoT sensors can monitor membrane conditions, fouling, and performance. This data is used for predictive maintenance and optimization of separation processes.

- **Automated Fractionation Towers:** Fractionation towers equipped with IoT controls can automatically adjust tray or packing configurations based on incoming gas composition. This ensures precise separation of components.

- **IoT-Enabled Valves and Actuators:** Smart valves and actuators can be controlled remotely based on real-time data, allowing for precise control of gas flow and separation processes.

- **Smart Pressure and Temperature Sensors:** These sensors provide accurate and real-time data to ensure that gas separation conditions remain within optimal ranges.

By integrating these IoT-based equipment and technologies into gas separation processes, the oil industry can achieve higher levels of efficiency, safety, and sustainability. Real-time data analytics and remote control capabilities contribute to improved operational performance and reduced operational costs.

4.Chapter IV: Implementation

4.1. Gas Detection:

First the working principle of the MQ sensor utilizes a tin dioxide semiconductor gas sensing material. Operating within a temperature range of 200 to 400 °C which means it needs to be preheated beforehand.

As it shown in the figure 3, this material interacts with the surrounding air by adsorbing oxygen. This interaction reduces the electron density on the semiconductor, consequently leading to an increase in resistance.
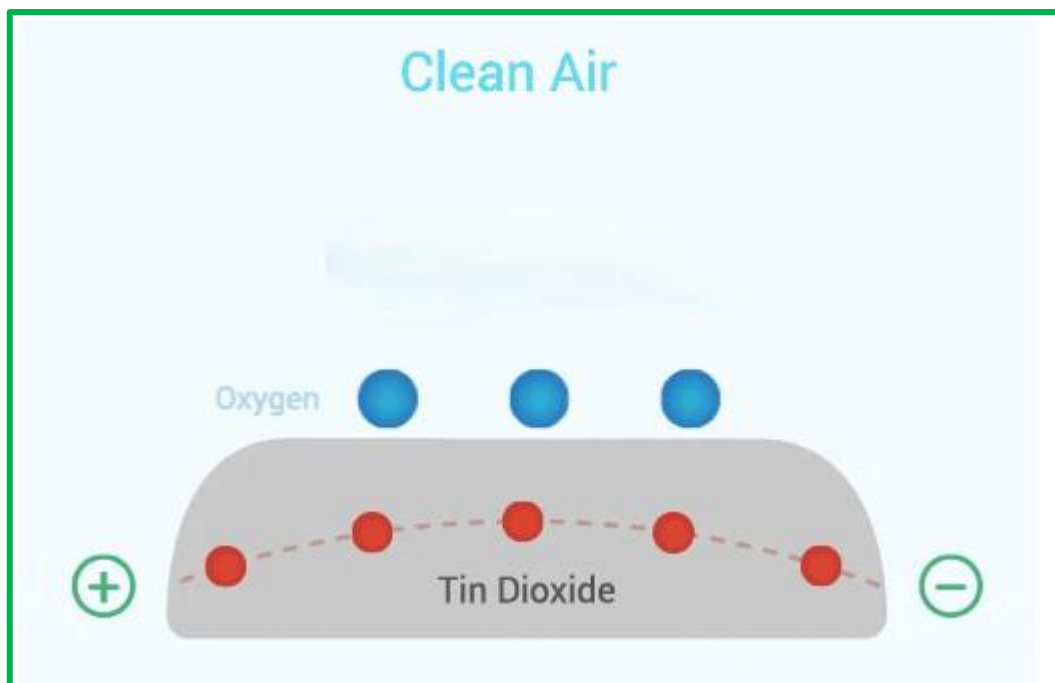

Figure 3   MQ Sensor Mechanism Step 1

When the sensor encounters the specified gas, changes occur at the grain boundaries within the tin dioxide due to the presence of gas particles. These changes directly affect the surface conductivity of the sensor, allowing for gas detection. Specifically, higher gas density results in increased conductivity and reduced output resistance. (figure 4)
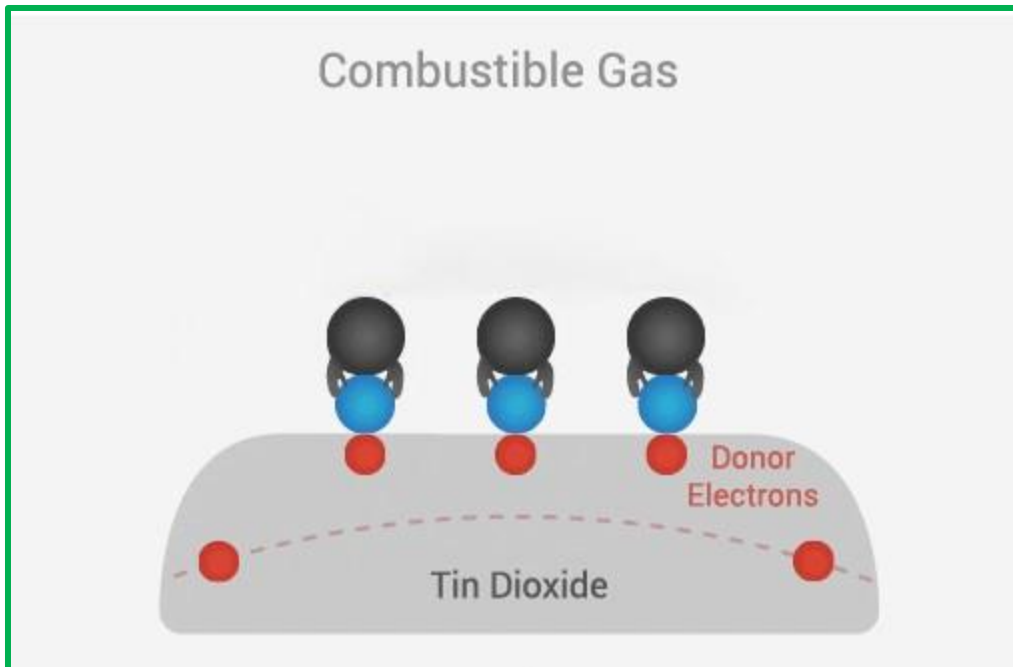
Figure 4   MQ Sensor Mechanism Step 2

- <u>Preheating</u>: As mentioned before the sensors needs to be heated to 400°C in order to function, and that's how we're going to simulate this step in figure 5.
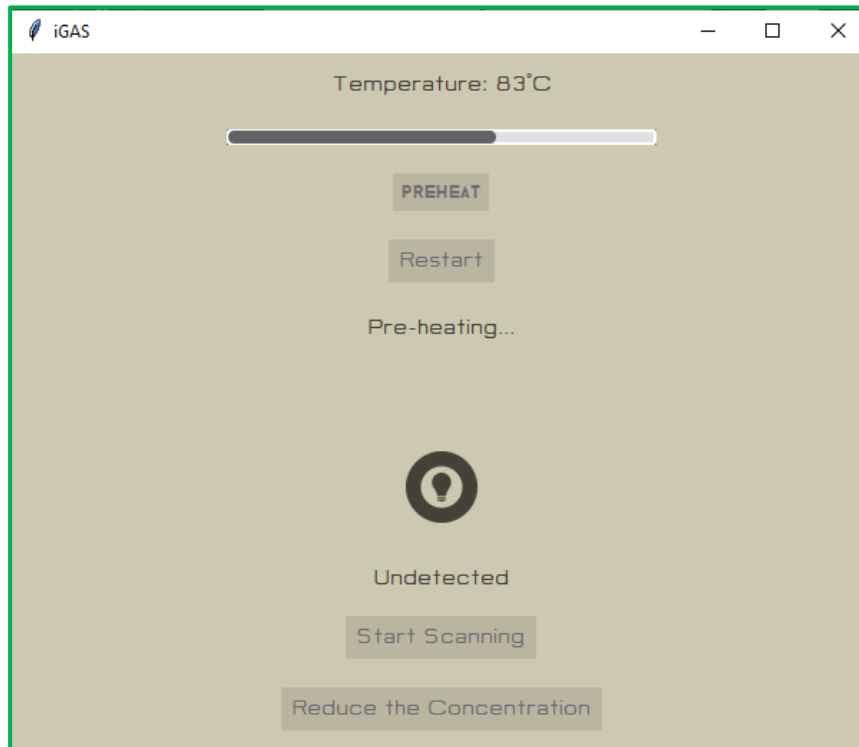
Figure 5   *Preheating MQ Sensors…*

- Preheating Complete: now after the preheating we have to inject our gas mixture so it can be
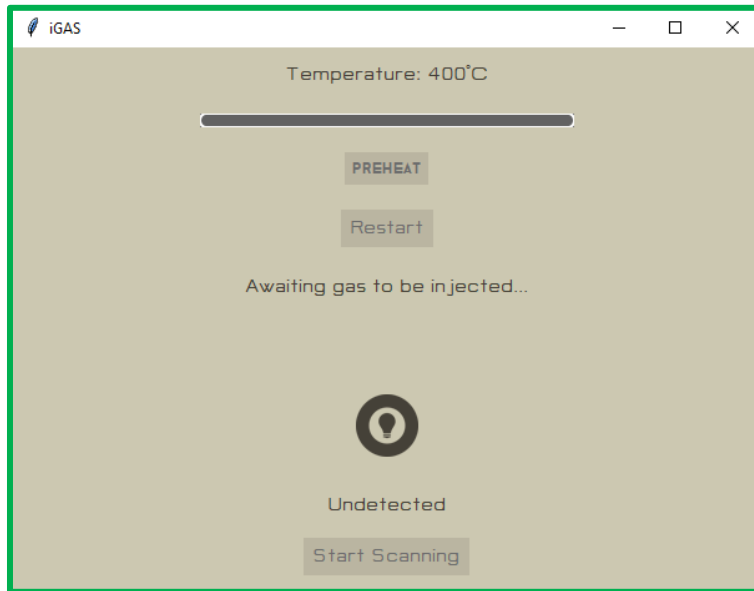

Figure 6 Awaiting the injection of the mixture

detected by the sensors.

- Injection of the Mixture: After a bit of time (figure 6) the mixed gas is finally injected and only
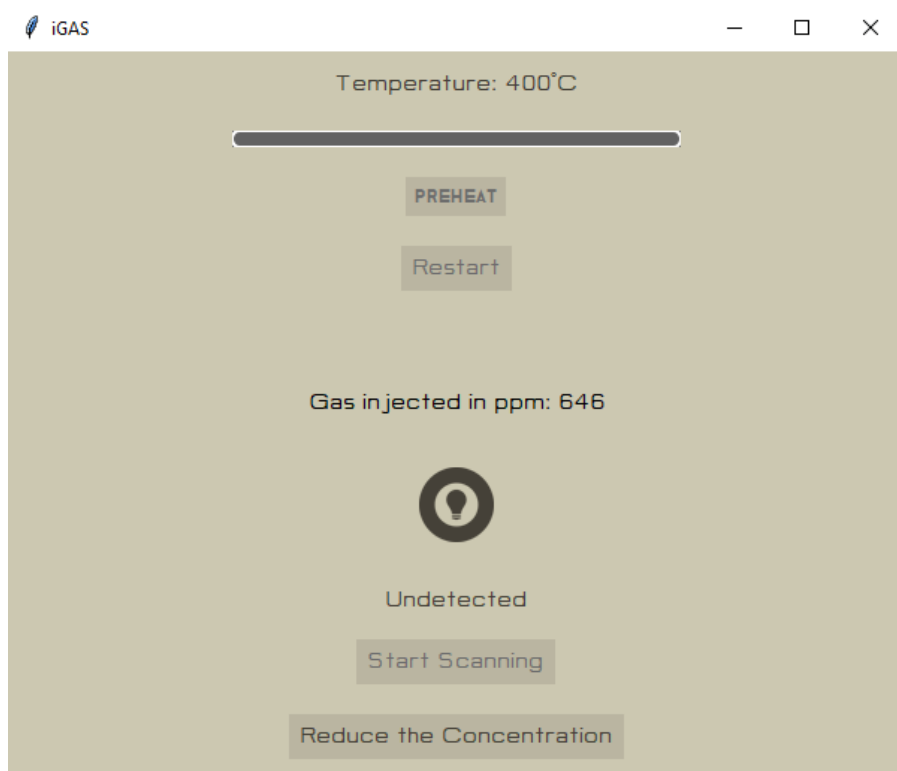

Figure 7 Mixed Gas Injection

then we can began our analysis/scanning.

As we observe in figure 7, our current mixture registers at 646 ppm (parts per million). However, uncertainty persists regarding the presence of Methane (CH_4) and Hydrogen Sulfide (H_2S) in our gas blend. Consequently, we are initiating an analysis. It is essential to note that the designated MQ Sensors for these gases exhibit differing capabilities, even when operating under optimal conditions. For instance, the MQ-4 sensor specified for Methane can reliably detect concentrations as high as 10,000 ppm. Conversely, the MQ-136, designated for Hydrogen Sulfide, operates effectively within a narrower range, specifically between 1 and 200 ppm. Given our objective, which is solely to determine the presence of Methane and Hydrogen Sulfide, we will focus our analysis on a limited portion of the mixture, specifically below 200 ppm.Analysis:
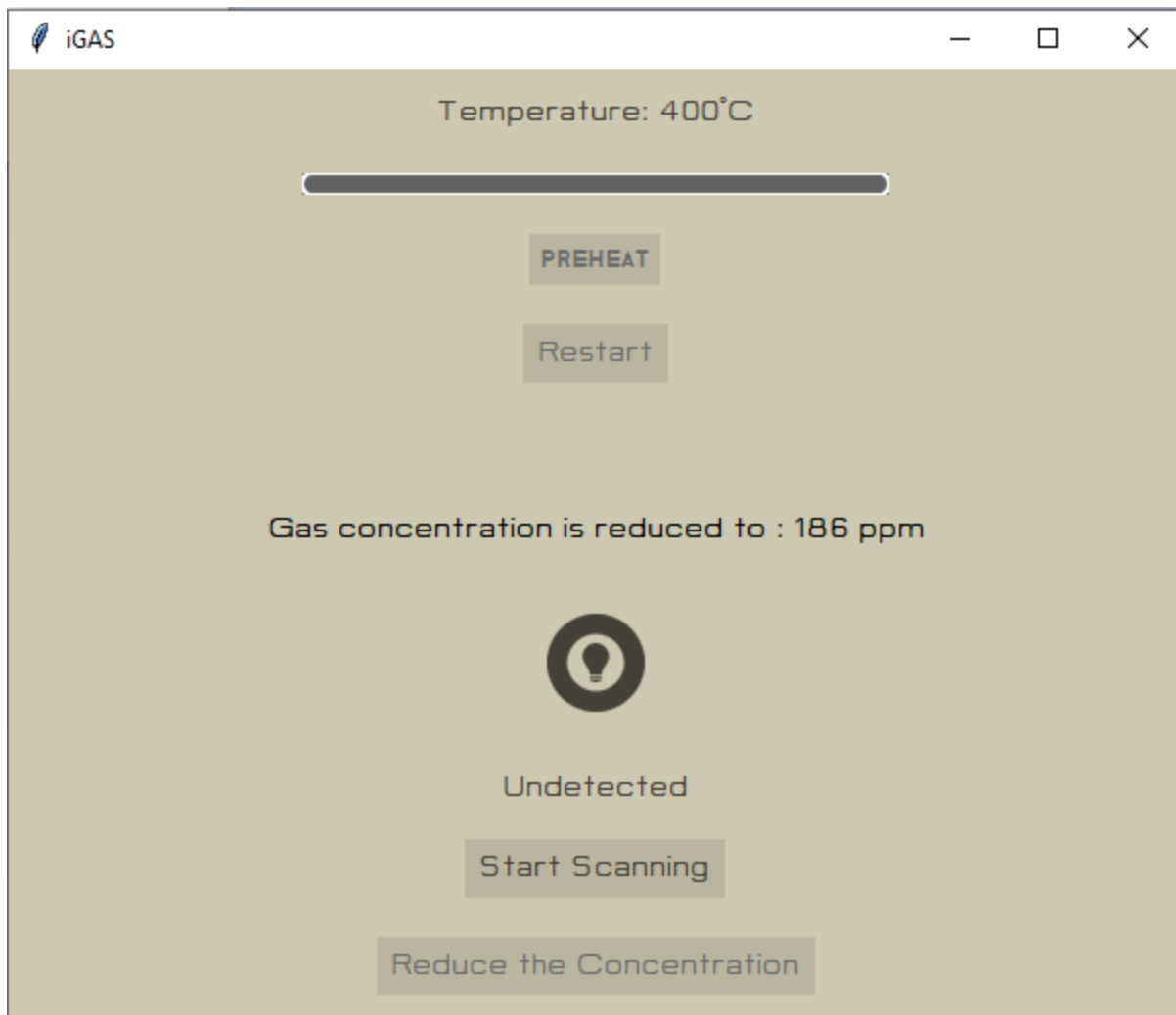
Figure 8   Mixture Reduction

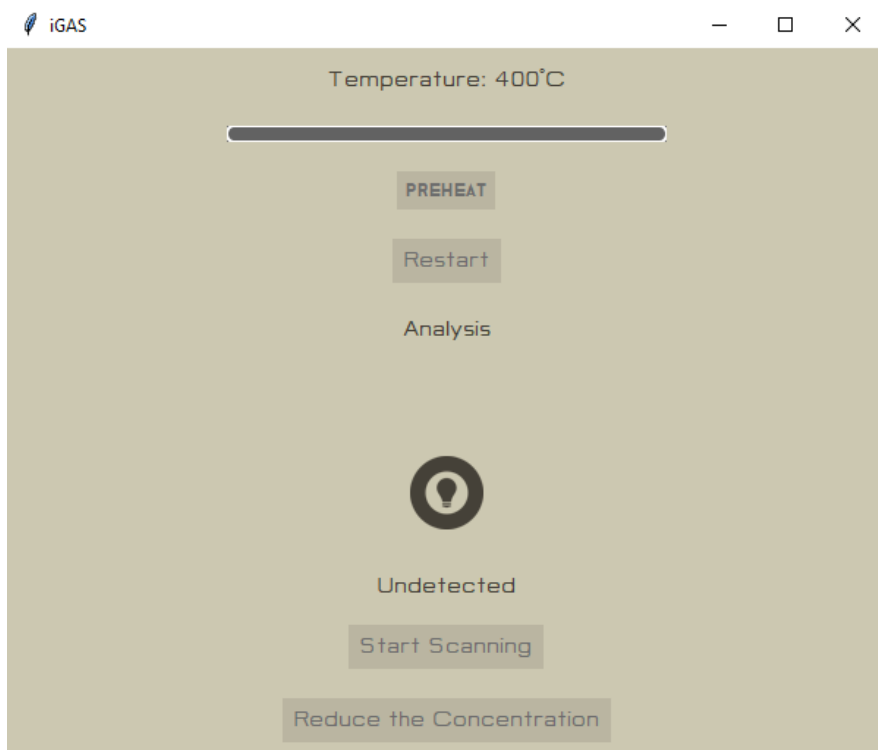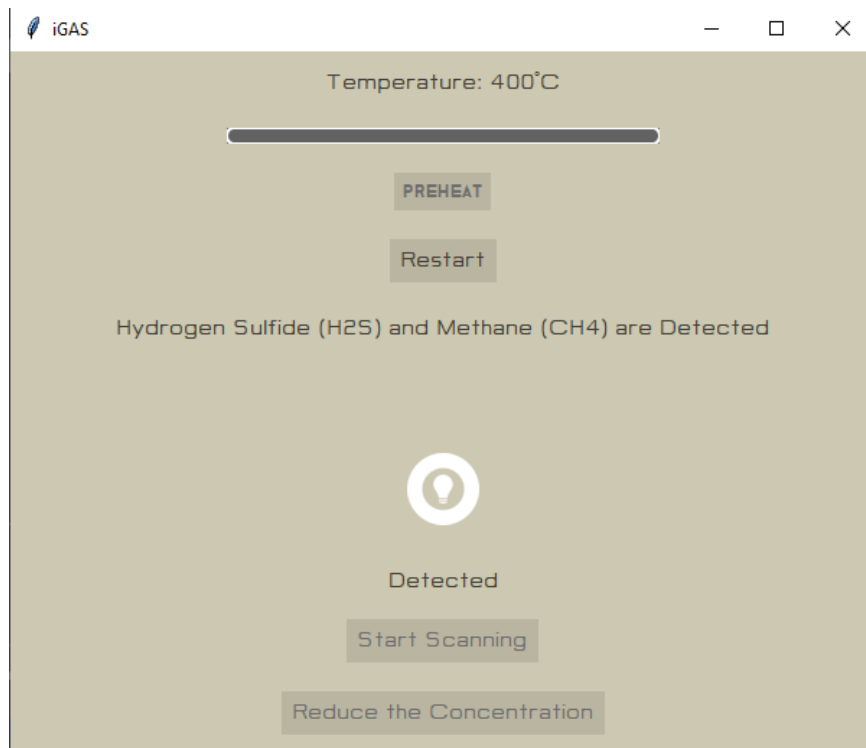Now given the current information in figure 8, we can start scanning this portion 186 ppm.

Figure 9   Analysis in progress

The   analysis   is

Figure 10   Analysis Complete and Detection Occured

complete (figure 9) and both gases are detected (figure 10) successfully and that wraps the simulation of the detection process.

4.2. Gas Separation:

In the separation phase we're going to be using the Gas Chromatography, but some instructions need to be set for this specific gas mixture so the GC can separate our mixture into two substances Methane and Hydrogen Sulfide.

The settings are:

1. Injection Mode: The injection mode determines how the sample is introduced into the GC system. Common injection modes include:

   - Split Injection: In split injection, only a portion of the sample is directed into the column, while the rest is vented out. This is often used for samples with high concentrations to prevent overloading the column.

   - Splitless Injection: In splitless injection, the entire sample is directed into the column initially, with the split vent closed to maximize sensitivity for trace-level analytes.

   - On-Column Injection: On-column injection involves injecting the sample directly onto the head of the column. This is often used for thermally labile or trace-level compounds.

2. Injection Volume: The injection volume is the amount of sample introduced into the GC system. It is typically measured in microliters (µL) and can vary depending on the sample concentration and the sensitivity of the detector.

3. Column Type: The choice of column type is critical for separating compounds of interest. There are capillary columns (narrow-bore) and packed columns (filled with solid support

material). The specific column selected depends on the nature of the analytes and the separation requirements.

4. Column Temperature: The temperature of the GC column is controlled to optimize the separation of compounds. Temperature programming, where the column temperature is changed over time, can be used to achieve better separation.

5. Carrier Gas Flow Rate: The carrier gas (e.g., helium, hydrogen, nitrogen) flows through the column and carries the sample components. The flow rate can affect separation and analysis time. The choice of carrier gas and flow rate depends on the column type and the application.

However though for our case, we have a mixture of 646 ppm Methane and Hydrogen Sulfide, so we should set our settings
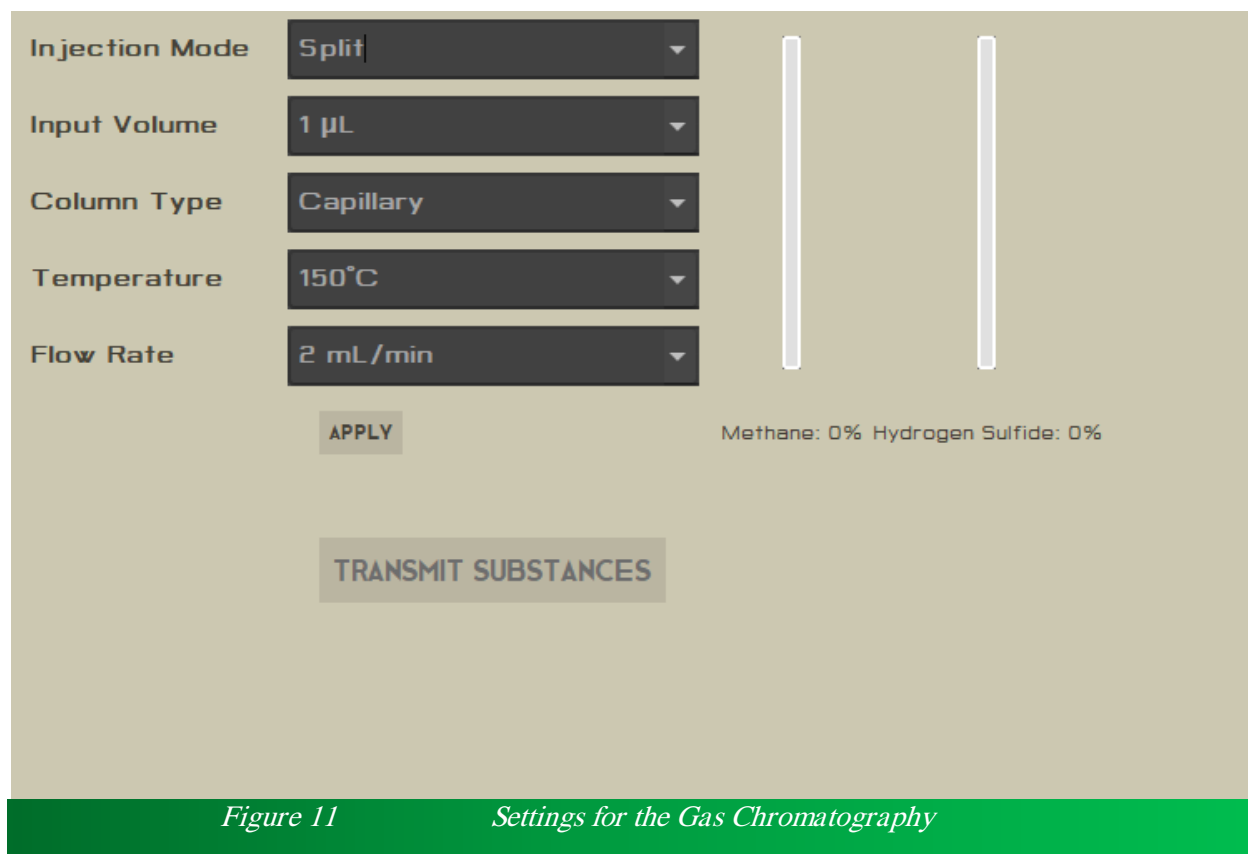
Figure 11   *Settings for the Gas Chromatography*

This information displayed in Figure 11 are the best settings for our mixture and as for temperature it's better to start with 40°C and then gradually increase the temperature. After all being set, we only have to apply it to the mixed gas.

| Figure 12 | Apply Settings and Waiting the end of the separation Process |

Now that the settings are applied, we have to wait a bit (figure 12) for the Gas Chromatography to do the separation process and it should eventually tell us how many Methane and Hydrogen Sulfide is presented.
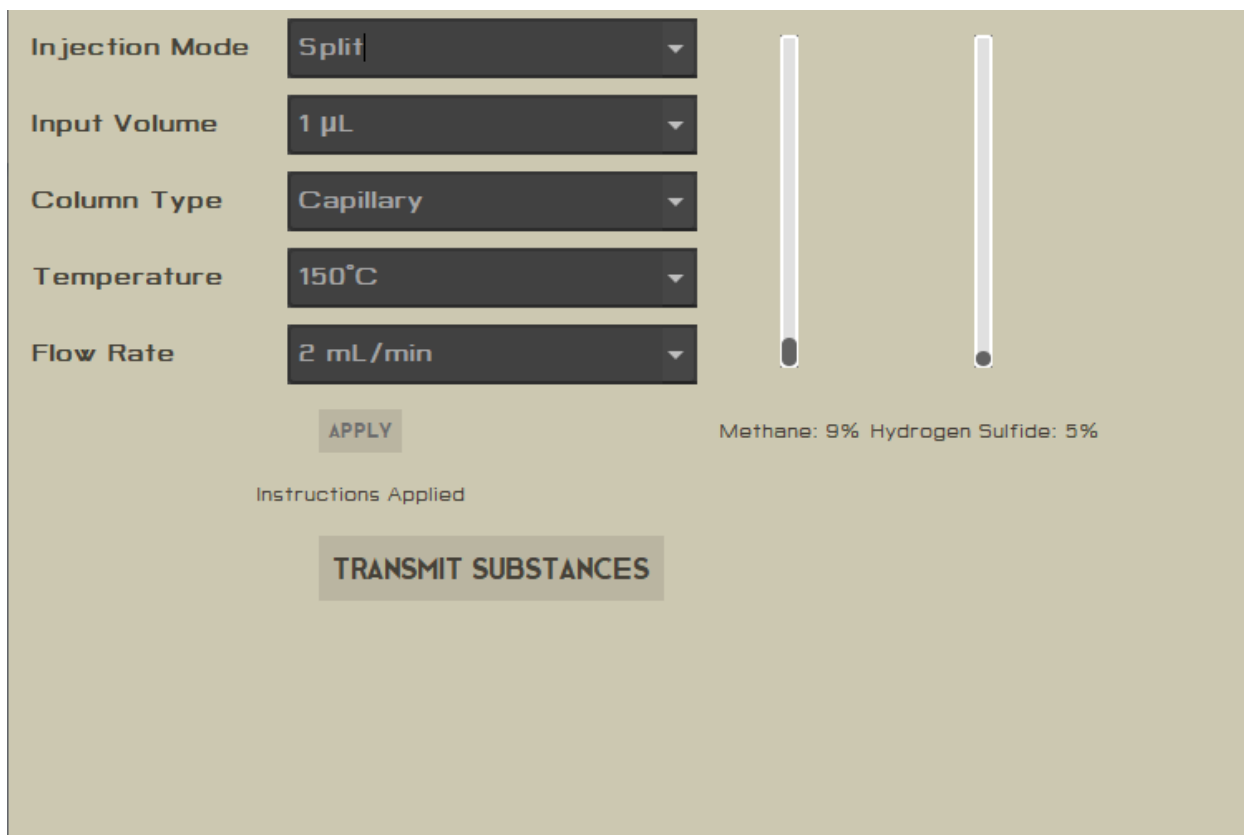
Figure 13 *The Amount of Methane & Hydrogen Sulfide*

Indeed, it told us in the figure 13 that the amount of the Methane (CH_4) and the Hydrogen Sulfide (H_2S) which is 9% and 5% of the mixture respectively.

The reason though why we had these smaller portions of the entire gas is because there might be other gases present in the mixture but we only analyzed the Methane and Hydrogen Sulfide.

For the last step (figure 14) is to transmit these substances.

Injection Mode	Split
Input Volume	1 μL
Column Type	Capillary
Temperature	150°C
Flow Rate	2 mL/min

APPLY

Methane: 9% Hydrogen Sulfide: 5%

Instructions Applied

TRANSMIT SUBSTANCES

Transmission Occurred

| *Figure 14* | *Substances Transmission* |

And that wraps the separation process.

4.3. Substances Uses:

4.3.1. Methane:

Natural Gas: Methane is the primary component of natural gas, a crucial source of energy used for heating, electricity generation, and as a fuel for vehicles.

Cooking and Heating: It's commonly used in households for cooking and heating through natural gas stoves and furnaces.

Industrial Processes: Methane is utilized in various industrial applications, including as a feedstock in chemical manufacturing and as a fuel in industrial boilers.

Transportation: Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) made from methane are used as alternative fuels for some vehicles, particularly buses and trucks.

Methane Hydrates: Research is ongoing on the potential extraction and use of methane hydrates, which are found in deep-sea sediments and permafrost regions.

4.3.2.   Hydrogen Sulfide:

Chemical Industry: Hydrogen Sulfide is used in the chemical industry to synthesize various sulfur-containing compounds, including sulfuric acid and sulfides.

Oil and Gas: In the oil and gas industry, H_2S can be present in natural gas and crude oil. It's removed during refining processes due to its toxicity and corrosive properties.

Mining H_2S can be encountered in mining operations, particularly in sulfide ore deposits. It's a safety concern due to its toxicity and flammability.

Wastewater Treatment: In wastewater treatment plants, H_2S can be generated as a byproduct of anaerobic digestion. It needs to be controlled due to its odor and toxicity.

Laboratory and Analytical Applications: In laboratories, hydrogen sulfide is sometimes used for specific chemical reactions and analytical techniques. However, its use is limited due to its toxicity.

Both methane and hydrogen sulfide have safety considerations. Methane is flammable and poses an explosion hazard in high concentrations. Hydrogen sulfide is highly toxic and can be lethal even in low concentrations. Safety measures and monitoring are essential when working with these gases.

General Conclusion

In retrospect, this master thesis embarks on a comprehensive exploration at the confluence of gas detection, separation methodologies, and the transformative influence of Internet of Things (IoT) technology, all aimed at a singular and critical goal: the elimination of flaring in the oil industry. Our journey traverses the intricate landscape of gas monitoring and management, emphasizing the multifaceted challenges inherent in this domain and presenting innovative pathways to achieve this vital objective. We have unraveled a narrative that underscores the significance and potential of a multidisciplinary approach in realizing a flaring-free future.

Chapter 1, setting the stage, illuminated the formidable challenges associated with CO_2 emissions and their adverse impact on our environment within the context of the oil industry. It emphasized the imperative of addressing these challenges and introduced diverse ideas and countermeasures to mitigate this phenomenon, with the overarching aim of eliminating flaring.

Chapter 2 delved deep into the realm of gas detection and separation, emphasizing the essential role of gas chromatography (GC) and advanced gas sensors in precisely identifying and quantifying gases emitted during oil industry processes. This chapter provided the foundational understanding needed to eliminate flaring by enhancing gas monitoring and detection capabilities.

Chapter 3 broadened our perspective by showcasing IoT's transformative potential in achieving the flaring elimination objective. It introduced IoT-based gas sensors and IoT-driven separation approaches as crucial enablers poised to revolutionize gas monitoring practices, ultimately contributing to the goal of flaring reduction.

Chapter 4 marked the culmination of our journey, with a practical simulation focusing on the detection process using MQ Sensors for gases like Methane and Hydrogen Sulfide, as well as a simulation of gas chromatography displaying the percentage of Methane and Hydrogen Sulfide. While not explicitly showcasing IoT integration, this chapter underscored the tangible benefits of an integrated approach to gas monitoring and detection, moving us closer to the overarching objective of flaring elimination.

In conclusion, this master thesis embodies the synergy of science, technology, and innovation in addressing the pressing challenge of flaring in the oil industry. It beckons us to confront this challenge with resolve and creativity, leveraging advanced technologies and a multidisciplinary approach. The integration of GC, gas sensors, and the practical simulation, along with the transformative potential of IoT, showcases a path forward, one where precision, sustainability, and technological advancement harmonize seamlessly to achieve the ultimate goal of a flaring-free future.

Abstract

Abstract:

This master thesis delves into the intricate realm of gas detection, separation, and the transformative influence of Internet of Things (IoT) technology. It addresses the pressing challenge of flaring in the oil industry, striving to eliminate this environmentally detrimental practice. Through a multidisciplinary approach, the thesis explores advanced gas detection techniques, gas separation methodologies, and the integration of IoT technology. It illuminates the multifaceted challenges associated with greenhouse gas emissions and resource inefficiency in the oil industry and offers innovative countermeasures. The practical simulation presented in the thesis demonstrates the tangible benefits of integrated gas monitoring, moving us closer to the overarching objective of a flaring-free future.

Résumé:

Ce mémoire de master plonge dans le domaine complexe de la détection de gaz, de la séparation et de l'influence transformative de la technologie Internet des objets (IoT). Il aborde le défi pressant du torchage dans l'industrie pétrolière, visant à éliminer cette pratique nuisible pour l'environnement. Grâce à une approche multidisciplinaire, le mémoire explore des techniques avancées de détection de gaz, des méthodes de séparation des gaz et l'intégration de la technologie IoT. Il met en lumière les défis multiformes associés aux émissions de gaz à effet de serre et à l'inefficacité des ressources dans l'industrie pétrolière, tout en proposant des contre-mesures innovantes. La simulation pratique présentée dans le mémoire démontre les avantages tangibles de la surveillance intégrée des gaz, nous rapprochant ainsi de l'objectif global d'un avenir sans torchage.

ملخص:

يتناول هذا الرسالة العليا المجال الدقيق لاكتشاف وفصل الغازات وتأثير التكنولوجيا الشبكية للأشياء (IoT) الناقلة للتحول في هذا المجال. وتتناول التحدي العاجل المتمثل في حرق الغازات في صناعة النفط، مسعيةً إلى القضاء على هذه الممارسة التي تلحق الضرر بالبيئة. من خلال نهج متعدد التخصصات، تستكشف الرسالة تقنيات متقدمة لاكتشاف الغازات ومناهج فصل الغازات، بالإضافة إلى دمج

تكنولوجيا IoT. وتسلط الرسالة الضوء على التحديات المتعددة المرتبطة بانبعاثات غازات الاحتباس الحراري وضياع الموارد في صناعة النفط، مقدمةً حلاً مبتكراً. تُظهر المحاكاة العملية المقدمة في الرسالة فوائد قابلة للملاحظة لرصد الغازات المتكامل، وتقربنا بذلك من الهدف الرئيسي المتمثل في مستقبلٍ خالٍ من حرق الغازات .

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