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Optimization of Dry Beneficiation Process for Lignite Using Advanced RAMDARS System with VFD, IoT, and Vibrating Crusher: A Case Study

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Abstract

The study investigates the effectiveness of an improved RAMDARS system in reducing the environmental impact and carbon footprint associated with coal and lignite utilization. The RAMDARS system, which uses radiometric detection and automatic removal of stones from coal/lignite stream, has been optimized using Variable Frequency Drives (VFD), the Internet of Things (IoT), and a vibrating crusher. The study evaluates the performance of the optimized RAMDARS system in terms of quality improvement and reduction of environmental impacts, as well as its economic feasibility. Results indicate that adopting VFD, IoT, and vibrating crusher has significantly improved the efficiency of the RAMDARS system in removing pyrite from lignite. The system can now effectively remove pyrite of all sizes and types, a significant improvement over the previous system limited to removing only larger pyrite particles. The improved RAMDARS system has several economic and environmental benefits, such as reducing carbon dioxide emissions and other pollutants and lowering transportation costs and energy consumption. This study contributes to developing more sustainable and efficient coal and lignite utilization technologies, with significant implications for the mining industry.

Keywords: *Coal Beneficiation, IoT, Pyrite Removal, RAMDARS Technology, Variable Frequency Drives*

1.0 Introduction

The extraction and utilization of coal and lignite have been identified as significant contributors to environmental pollution and climate change. Burning coal and lignite releases harmful greenhouse gases such as carbon dioxide and methane into the atmosphere, contributing to global warming and climate change[1-5]. Reducing the carbon footprint and pollution associated with coal and lignite utilization has become a pressing concern[6-10]. The development of dry beneficiation technologies such as the RAMDARS system has shown promise in improving the quality of coal and lignite, reducing their environmental impact, and enhancing their economic value. It is a technique used to detect and remove stones and other unwanted material from coal and is typically used in coal processing plants to remove stones and other impurities from coal before it is sent to a power plant or other end-users.

RAMDARS stands for RAdiometric Mass Determination cum Automatic Removal of Stone/Shale; it is an innovative online measurement system that ARDEE and ANATEC have jointly patented in India and Germany[11-13]. However, there is still a need for further research and development to optimize these technologies and to address challenges such as low efficiency and high operational costs. Therefore, this research study aims to investigate the effectiveness of an improved RAMDARS

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system in reducing carbon footprint and pollution associated with coal and lignite utilization. The study seeks to answer research questions such as the feasibility and efficiency of the improved RAMDARS system, its impact on the quality and value of coal and lignite, and its potential for reducing greenhouse gas emissions. The study's objectives are to optimize the RAMDARS system using Variable Frequency Drives (VFD), Internet of Things (IoT), and vibrating crusher to evaluate its performance in quality improvement and reducing environmental

Figure 1. RAMDARS system installed in GHCL Bhavnagar Lignite deposits.

impacts to determine the economic feasibility of its implementation. The significance of this study lies in its potential to contribute to developing more sustainable and efficient coal and lignite utilization technologies with significant economic and environmental benefits.

The conventional wet technology for coal beneficiation faces significant water-related challenges, with approximately 160 liters of water per ton of coal input required even in a zero effluent discharge system. However, for lignite beneficiation, water-based methods are not suitable due to the softness of the material, and the presence of large quantities of pyrites in lignite seams, such as those in the Bhavnagar Lignite Deposit, make wet beneficiation impossible. Moreover, contact between pyrites and water produces acid, further complicating the process. In this regard, dry lignite beneficiation, explicitly using the RAMDARS, is a viable and immediate solution. The efficient removal of pyrites from lignite using RAMDARS is a game changer for the industry.

1.1 Related Work

Bhargava *et al.*, identified the lignite mining waste at the Giral mining site in the Barmer district of Rajasthan, commonly called clay lignite inter burden, as a promising energy source. The inter burden contains finely dispersed lignite in clay, which can be upgraded by developing a sustainable, cost-effective technology. In their study, Bhargava and colleagues successfully upgraded this waste material, resulting in carbonaceous clay with a calorific value of approximately 2500 kcal/kg. This work represents a significant advancement in sustainable energy, demonstrating the potential for effectively utilizing previously discarded lignite mining waste as a valuable energy source[14].

Ramana argues that coal is an abundant and affordable energy source but suffers from an image problem as a dirty fuel. Coal washing to reduce ash levels is widespread but often conflicts with water-challenged communities, particularly the farming sector. The coal industry is viewed as insensitive to its societal and environmental impact and in need of change. Dry beneficiation of coal offers an environmentally friendly alternative. Recent advances in dry beneficiation technologies, such as ArdeeSort, are game changers in improving the techno-economic efficiency of coal beneficiation without using water. Such technologies have made clean coal processing more affordable and are immediate steps toward improving coal quality. Failure to address the industry's image and environmental challenges risks punitive measures and could threaten its survival[13].

Zhu *et al.*, designed and investigated an Air-Dense Medium Fluidized Bed (ADMFB) integrated drying and beneficiation system for lignite under mild conditions. For refractory lignite with diameters between 13-25 mm, the system achieved a surface water removal efficiency of up to 91%, reducing the adhesion efficiency of the dense medium to 0.16% at 85°C for 2 minutes. The probable separation error was 0.048 g/cm^3, lower than common ADMFB[15].

Bhatti *et al.*, developed a process for the beneficiation of low-rank coal with high ash (25.97%) and sulfur (5.78%) content found in the Makerwal Area, Surghar Range, Punjab Province, Pakistan. Froth flotation technology was used to obtain high-quality clean coal for commercial use, with optimization of various parameters, including coal grind size, pH of the pulp, pulp solids, agitation, collector dosage, frother, and depressant[16].

Shanmugan *et al.*, introduced a new vibrating screen designed for dry screening of moist coal in the size range of -3 + 1 mm. This screen employs circular vibration, which allows for flexible operational parameter adjustments, including changes to the screen angle and frequency of vibration. The circular vibration mode also reduces screen clogging by incorporating inertial forces on particles[17].

Dong *et al.*, proposed a novel approach utilizing a combined ADMFB and FGX separator. This low-cost, water-free, pollution-free approach achieved effective coal separation (100-0 mm) for the first time. The study included an analysis of ADMFB's fluidization characteristics and separation effectiveness and an investigation of the coal transport process and ash segregation under different vibration parameters for the FGX separator[18].

2.0 Materials and Methods

Mining is vital in supporting the national economy and has a rich growth history. Among the thermal energy sources, lignite stands out as the most affordable. However, the presence of pyrite in coal and lignite is a significant concern. Pyrite is dangerous for human health, ecology, and the environment. Pyrite, when burned, releases arsenic and other hazardous compounds that can cause occupational lung diseases in miners.

Moreover, pyrite is a significant source of acid gases in the atmosphere and pollutes water, leading to harmful acid mine drainage. Therefore, it is crucial to address the issue of pyrite in lignite and coal to ensure a safe and sustainable mining industry. This research paper aims to investigate and propose solutions to mitigate the impact of pyrite in lignite and coal, ultimately contributing to the betterment of the mining industry and the environment.

2.1 Collecting Information

In three different lignite mines- Khadsaliya Lignite Mine (GHCL LTD), Ghogha Surka Lignite Mine (GPCL), and Surkha North Lignite Mine (GMDC)- the percentage composition of various components is shown in Table 1. Organic material, pyrite, sulfates, and the sum of the components' percentages are among the elements.

The Khadsaliya Lignite Mine contains 4.44% of all the elements, 1.24% organic matter, 2.60% pyrite, and 0.61% sulfates. The Ghogha Surka Lignite Mine has 4.77% of all the elements, 1.55% organic matter, 2.78% pyrite, and 0.44% sulfates. The Surkha North Lignite Mine contains 4.48% of all the elements, 1.99% of organic materials, 2.73% pyrite, and 0.82% sulfates.

2.2 Detection Principle

Clearing coal and other unwanted material in RAMDARS uses Density differential to identify contamination, and separation is achieved using pneumatic ejectors. Coal has a density of 1.2 to 1.8, and other unwanted materials will have a density of more than 1.8. The density of any material can be calculated using the formula:

Density = MPA/Height

Where,

MPA = Mass per Surface Area

In RAMDARS, the height of the particle is measured using a Laser Displacement Sensor. To

Calculate the MPA Gamma Ray Attenuation principle is applied.

The Beer-Lambert law, which states that a beam of radiation loses strength exponentially as it travels through a medium, may be used to compute the attenuation of gamma rays. The amount of attenuation is proportional to the material's thickness and absorption coefficient at the radiation's energy[19-22].

The formula for the Beer-Lambert law[19] is:

$$I = I_0 \times e^{-\mu x}$$

Where,

'I' is the intensity of the radiation after passing through a material

'I_0' is the initial intensity of the radiation before passing through the material

'μ' is the linear attenuation coefficient of the material at the energy of the radiation

'x' is the thickness of the material through which the radiation passes

The linear attenuation coefficient, μ, is a material property that depends on the radiation's energy and the material's composition. It is typically measured in units of cm^{-1}.

We can write again, x = MPA/Density.

Table 1. The percentage composition of various components in three different lignite mines

S. No.	Khadsaliya Lignite Mine(GHCL LTD)	Ghogha Surka Lignite Mine (GPCL)	Surkha North Lignite Mine (GMDC)
Organic(%)	1.24	1.55	1.99
Pyritic(%)	2.60	2.78	2.73
Sulfates(%)	0.61	0.44	0.82
Total (%)	4.44	4.77	4.48

If we substitute the value of x in the above formula:

$$I = I \times e^{-\mu\left(\frac{MPA}{Density}\right)}$$

It is evident from the above formula that attenuated gamma rays are proportional to the mass per surface area of the particle to be measured. If the value of the initial strength and attenuated strengths of the gamma-ray is known using the above formula, the MPA of the material can be calculated. The density of the particle can be determined by using the calculated value of MPA and the measured value of height.

2.3 Operation

RAMDARS units are placed in two modules at the GHCL Plant. Module 1 separates stone/shale from 100 to 200 mm particles, while Module 2 separates particles of 50 to 100 mm.

In each module, the following equipment is included:

- **Scintillation Detectors:** These detectors are used to detect and measure gamma radiation emitted from the Cs-137 source. The detectors are made of scintillating materials, such as sodium iodide or caesium iodide, emitting light when gamma radiation interacts.
- **Cs-137:** This is a radioactive isotope of caesium that emits gamma rays. It is used as the source of gamma radiation in the system.
- **Shielding Container:** This container is used to shield the scintillation detectors and other equipment from the gamma radiation emitted by the Cs-137 source. The container is made of lead or other radiation-shielding materials.
- **NI Controller:** This is used to control and monitor the system. It provides interfaces for the solenoid valve, relay board, and signal conditioning cards.
- **Solenoid Valve:** This valve controls water flow to the vibrating screen and crusher.
- **Relay Board:** This board controls the power supply to the vibrating screen and crusher.
- **+/- 15V DC Power Pack:** This power supply provides power to the signal conditioning cards and other equipment.
- **Signal Conditioning Cards:** These cards are used to condition the signals from the scintillation detectors and other sensors. They amplify, filter, and convert the signals to a digital form that the NI controller can process.
- **Vibrating Screen:** This screen separates the crushed material into different size fractions. It vibrates at a high frequency to ensure efficient separation.
- **Vibrating crusher for sizing:** This crusher is used for crushing the material into smaller pieces before it is screened. It vibrates at a high frequency to ensure efficient crushing.
- **IOT-based Monitoring system** monitors the equipment's performance and the output material's quality. It uses sensors and data analysis algorithms to detect and diagnose any issues with the system. The system is accessible remotely through a web-based interface.

Coal/Lignite is fed to the RAMDARS module after screening it. The material is fed to the RAMDARS conveyor from the screen through a vibratory feeder and vibrating crusher. The feeder will spread the material in a monolayer so that the detection of every piece is analyzed. Before passing through the detector, the RAMDARS conveyor material covers a distance of 7000 mm for particle detection and stabilization. The Shielding container is beneath the conveyor belt, while the Detector box is 250mm above the conveyor.

The detector collects radiation from the source when no material is on the conveyor belt. Every time the material passes across the detection region, the particle attenuates a portion of the radiation, and the detector picks up some of the radiation. The difference in the radiation signal is proportional to the MPA of the particle.

The signal from the scintillation detector is fed to the signal processing unit. In the signal processing unit, the signal is amplified to the required level and fed to the controller. The Laser sensor will give the information in DC volts proportional to the height of the particle. This DC signal is directly fed to the controller.

The controller calculates the density based on the information received from the Laser and Scintillation sensor and calculates the density of the piece. After calculating the density, it will be compared with the pre-defined set limit in the software. If the calculated

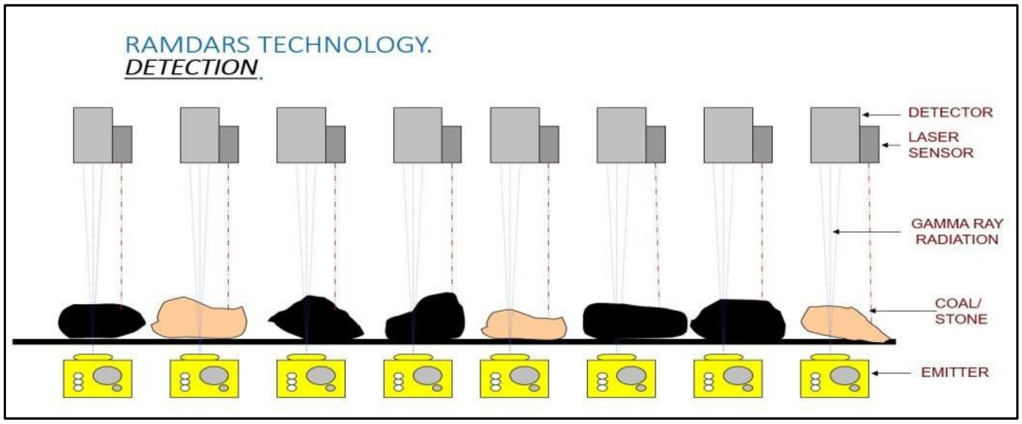

Figure 2. Detection of foreign material in coal/lignite using RAMDARS Technology.

density exceeds the set limit, the controller considers it an unwanted material and generates a control signal for the solenoid to activate. After a pre-defined time, delay, the signal is extended to the solenoid through the relay board. The time delay is set by calculating the time required for the material to reach the transfer point on the conveyor from the detection point; the solenoid is installed at the conveyor's transfer point and will turn on when the material reaches there. Whenever the solenoid is activated, it releases a jet of compressed air onto the particle, diverting the material travel path and guiding it to the reject belt. An inverted chute is provided below the transfer point, and it will act as a barrier for cleaning and rejects.

Figure 2 depicts detecting foreign material in coal/lignite using the RAMDARS technology. A conveyor belt transporting coal or lignite can be observed in the figure. The coal or lignite passes through the RAMDARS system, where radiometric detection technology is employed to detect and locate any extraneous material, such as pyrites, present in the coal or lignite. The automatic removal system eliminates the identified extraneous material, producing clean coal or lignite.

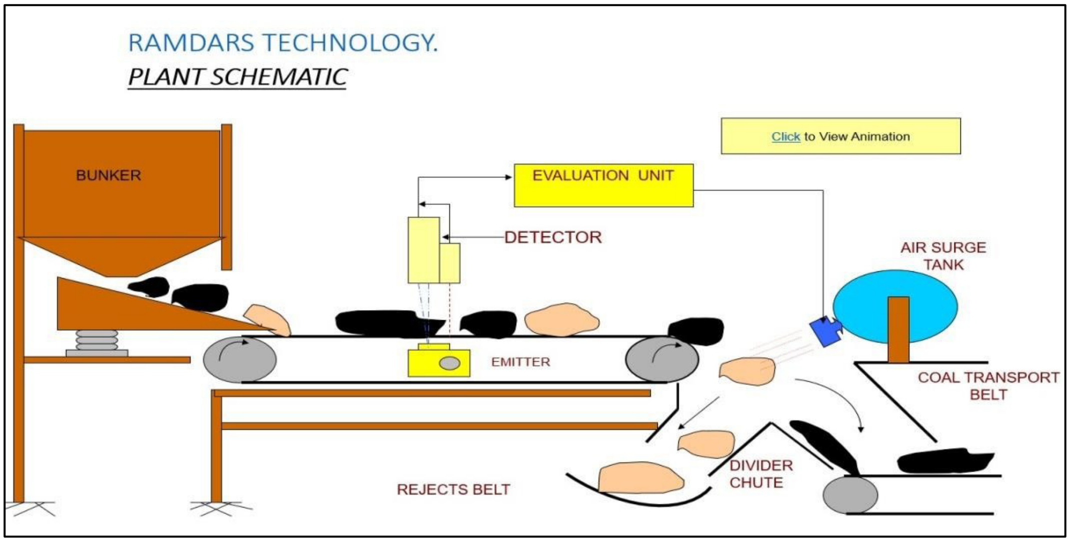

Figure 3. Plant schematic diagram of RAMDARS technology in GHCL lignite mines.

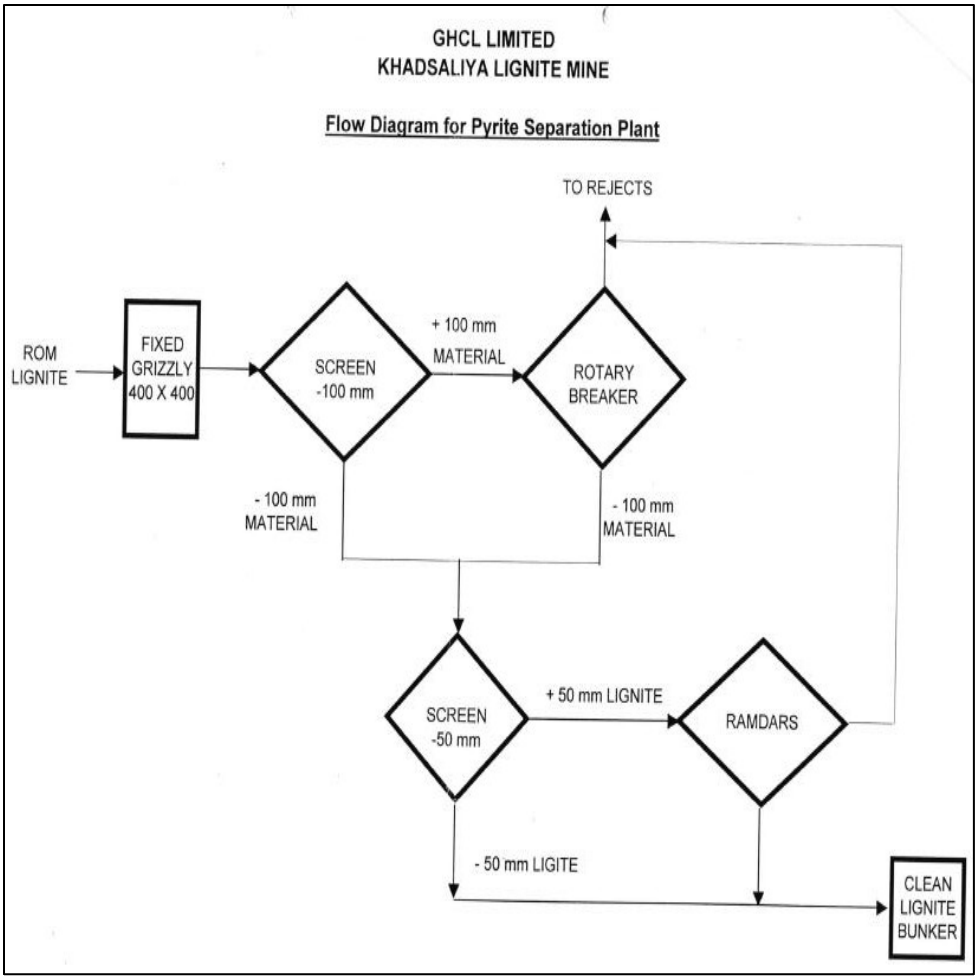

Figure 4. Flow diagram for pyrite separation plant in GHCL, Khadsaliya Lignite Mines.

Figure 3 is a plant schematic diagram of the RAMDARS technology used in GHCL Lignite Mines. The diagram shows the various components of the system, including a bunker for storing coal or lignite, a coal transport belt for carrying the material to the RAMDARS system, and a divider chute for separating the material into different streams.

The RAMDARS system includes a detector and an emitter, which use radiometric detection technology to identify and locate any foreign material, such as pyrites, in coal or lignite. The evaluation unit analyzes the data from the detector and emitter and determines the location of the foreign material.

If any foreign material is detected, the system activates an air surge tank, which sends a blast of air to remove the foreign material from the material stream. The clean coal or lignite is discharged onto a coal transport belt for further processing.

Any foreign material the air surge tank removes is collected on a reject belt for disposal. The schematic diagram represents the RAMDARS technology and its various components in a plant setting.

Figure 4 depicts the flow diagram of the pyrite separation plant at GHCL Khadsaliya Lignite

Mines begins with raw lignite being fed into the plant from the ROM Lignite stockpile.

The lignite first passes through a fixed grizzly with a dimension of 400x400 to remove oversized material. The lignite then moves to a screen where material over 100 mm is directed to a rotary breaker, which breaks down the oversized material to a product size of -100 mm.

Material under 100 mm goes to a separate screen which splits it into two streams: one over 50 mm and the other under 50 mm.

The material with a size of over 50 mm then passes through the RAMDARS technology, which uses radiometric detection to identify and locate any foreign material, such as pyrites, in the lignite. If any foreign material is detected, the RAMDARS system activates an air surge tank, removing the foreign material from the stream.

The clean lignite, free of any foreign material, is then directed to a clean lignite bunker for further processing or transport. Overall, the flow diagram of the pyrite separation plant at GHCL Khadsaliya Lignite Mines outlines the process of removing oversized material and pyrites from raw lignite, resulting in clean lignite for further processing.

2.3.1 Operating procedure for 50-100 mm module

- Switch ON Regulated Power Supply No.3 in the Control Panel. It will generate +/-15V DC for the Signal Conditioning card and Scintillation Probes.
- Observe the Lamp indication on the front panel of the power supply.
- Observe the blinking of LEDs provided on the front panel of the Signal conditioning card.
- These LEDs will indicate that the power is extended to the Scintillation Probe.
- Open the Controller unit (This is installed side of the Signal Conditioning Card).
- Switch ON the Power.
- Observe the Green LED indications on the NI Controller and 24 V DC power supplies provided in the controller unit.
- The program is pre-loaded in the controller as a .exe file and starts running immediately after switching ON.
- Observe the Laser beam on the Conveyor belt.
- Open the source Container by turning the recessed nut in the source container till it reaches the endpoint. Do not apply excessive force.
- Switch ON the AC Drive (the switch is provided below the AC Drive).
- Switch ON the 24V DC power Pack installed bottom rack of the Control Panel.
- Observe the IoT graph.

2.3.2 Problems and Rectification

Table 2 lists several problems encountered during the RAMDARS technology operation at

GHCL lignite mines and their corresponding rectifications.

Table 2. Problems and rectifications

S. No.	Problems	Rectifications
1.	The solenoid is not operating.	• Check the wiring Connection from the RelayBoard to the Solenoid Valve.• Check the 24V DC supply to the relay board from the 24V DC power supply• Activate solenoid manually for its operation
2.	Stones are not falling on reject even after blowing	• Adjust the position of the inverted V chute• Check air pressure.• Check the position of the nozzle bank.
3.	The solenoid is blowing after the stone falls	• Increase the belt speed (in steps of 0.1Hz)
4.	The solenoid is blowing before the stone falls	• Reduce the belt speed (in steps of 0.1 Hz)
5.	Stones are not being detected.	• Check the Wiring to the solenoid.• Check the 24V DC power supply.• Check if the Laser Red beam is falling.
6.	Low pressure in Air Pressure Tank	• Check Solenoid Valve Jam

2.3.3 IoT based Monitoring System for RAMDARS

Figure 5 depicts a flow chart of an IoT-based monitoring system for the RAMDARS technology. The system uses two sensors, a pressure sensor for the air reservoir and an RPM sensor for the RAMDARS belt, to monitor the pressure and RPM values during the operation of the RAMDARS system.

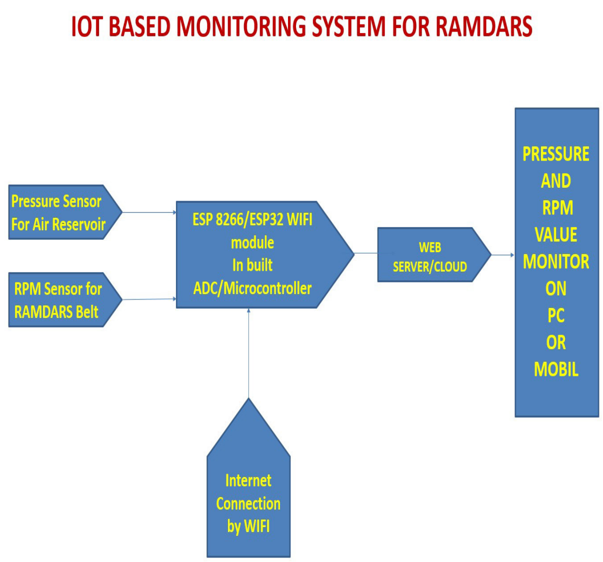

Figure 5. Flowchart of IoT-based monitoring system for RAMDARS technology.

The data from the sensors is then transmitted to an ESP 8266/ESP32 WIFI module equipped with an in-built ADC/microcontroller. The WIFI module is connected to the internet via WIFI, allowing the data to be transmitted to a web server/cloud.

The web server/cloud then processes the data and makes it available for PC or mobile device monitoring. The pressure and RPM values can be monitored in real-time using the PC or mobile device, allowing for remote monitoring and analysis of the RAMDARS system's performance.

Overall, the flow chart demonstrates how IoT technology can be integrated with the RAMDARS system to improve monitoring and analysis of the system's performance, ultimately improving efficiency and productivity.

2.3.4 Real-Time Monitoring System

Figure 6 depicts the belt speed graph generated from the real-time monitoring system, typically displaying a line graph with the X-axis representing time and the Y-axis representing the speed of the belt conveyor. The graph would show the variation of the belt speed over time, with the changes in the speed displayed as peaks and valleys on the graph.

Figure 7 depicts the air tank pressure graph generated from the real-time monitoring system would

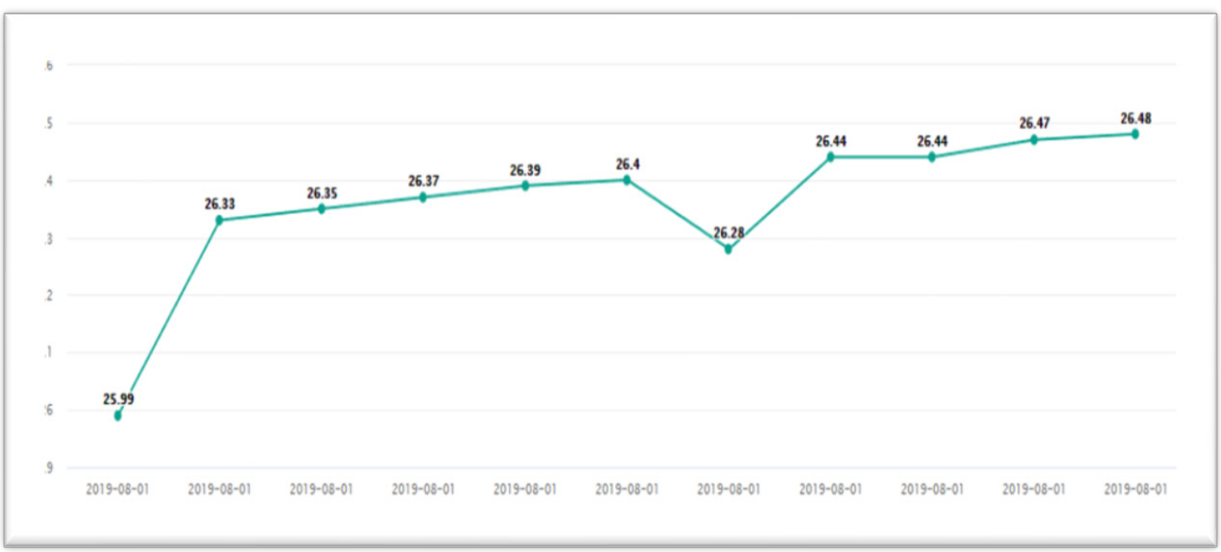

Figure 6. Belt speed.

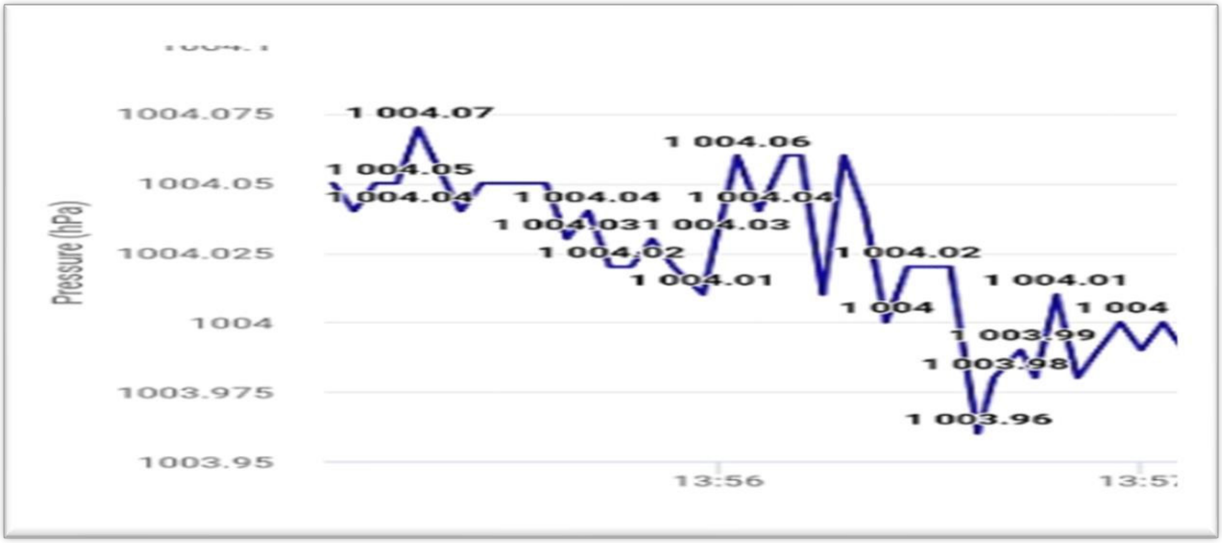

Figure 7. Air tank pressure.

typically display a line graph with the X-axis representing time and the Y-axis representing the pressure of the air tank. The graph would show the variation of the air tank pressure over time, with the changes in the pressure displayed as peaks and valleys on the graph.

3.0 Results and Discussion

The experimental results show that adopting the Variable Frequency Drives (VFD), IOT system, and vibrating crusher in the RAMDARS system has significantly improved its efficiency in removing pyrite from lignite. Before introducing these technologies, the adequate pyrite removal size was limited to 100-200 mm, so smaller pyrite particles could not be removed efficiently. However, after adopting the new technologies, The adequate pyrite removal size has been reduced to 50-100 mm, indicating that the system can now effectively remove even smaller pyrite particles.

In addition, introducing the vibrating crusher for size reduction has eliminated the need for manual size reduction, which can be time-consuming and labor-intensive. The vibrating crusher can crush the coal and lignite to the desired size quickly and efficiently, thus improving the overall efficiency of the beneficiation process.

Moreover, the RAMDARS system with the VFD, IOT system, and vibrating crusher can now effectively remove pyrite of all sizes and types, representing a significant improvement over the previous system that was limited to removing only larger pyrite particles. By removing pyrite of all sizes and types, the system can prevent acid mine drainage and reduce carbon dioxide emissions and other pollutants associated with burning high-sulfur coal and lignite.

The adoption of the improved RAMDARS system has several economic and environmental benefits. By removing pyrite and other impurities, coal and lignite can be burned more efficiently, reducing carbon dioxide emissions and other pollutants. Additionally, the reduced ash content of the coal and lignite means that there is less ash to handle and transport, resulting in lower transportation costs and energy consumption.

4.0 Conclusion

In conclusion, adopting the VFD, IOT system, and vibrating crusher in the RAMDARS system has significantly improved the efficiency of the coal and lignite beneficiation process. The improved system can remove pyrite of all sizes and types, preventing acid mine drainage and reducing environmental pollution. By removing pyrite and other impurities, coal and lignite can be burned more efficiently, reducing carbon dioxide emissions and other pollutants. Additionally, the reduced ash content of the coal and lignite means that there is less ash to handle and transport, resulting in lower transportation costs and energy consumption.

The economic benefits of coal and lignite beneficiation include increased efficiency, reduced transportation costs, and increased market value. However, the costs of the beneficiation process must also be considered, including the cost of the new technologies and the transactional costs associated with integrating the process into the established coal supply and distribution system.

Adopting the improved RAMDARS system can bring significant economic and environmental benefits to the coal and lignite industry. Future research could further optimize the beneficiation process and explore new technologies to improve efficiency and effectiveness.

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