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Evaluation of the Sajau Coal Formation's potential for Underground Coal Gasification in the Berau Basin, North Kalimantan, Indonesia.

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Abstract

To effectively address the environmental challenges stemming from the use of low-calorie coal, underground coal gasification (UCG) technology emerges as a viable and innovative solution. UCG is a process that converts coal into synthetic natural gas, which can significantly reduce harmful pollution emissions compared to traditional coal combustion methods. The Berau Basin, located in North Kalimantan, Indonesia, is recognized as one of the country's most productive coal basins, containing substantial reserves of low-calorie coal. This study aims to meticulously identify potential sites within the Sajau Formation that are optimal for UCG development, focusing specifically on the extraction and utilization of low-calorie coal resources. In our assessment, we conducted a detailed evaluation of the coal seams in three key areas: the Kasai area, the Mangkupadi Block, and the Tanah Kuning Block. This evaluation involved a comprehensive analysis of various geological and coal characteristics to determine their suitability for UCG. The criteria used for screening included: Coal Rank, Seam Thickness. Coal Seam Depth, Depth-to-Thickness Ratio, Coal Seam Dip, roof and Floor Rock Types and Thickness, Coal Density, Geological Structure, and Coal Resources. Our findings indicate that the Kasai area exhibits particularly favorable conditions for UCG development, specifically with coal seam A, which achieved an impressive AHP weight of 92.30%. This highlights its exceptional properties for gasification. By harnessing these resources, the region has the potential to adopt a more sustainable energy approach, contributing to the reduction of carbon emissions and the promotion of cleaner energy alternatives.

Keywords: Berau Basin, Sajau coal formation., UCG, Kasai, AHP.

1. Introduction

The Geological Agency of the Ministry of Mineral and Energy of the Republic of Indonesia reported in 2023, with data from the BP Statistical Review of World Energy, that approximately 25.22 billion tons of low-rank coal (LCR) reserves, specifically lignite and sub-bituminous coal with calorific values of less than 5,100 kcal/kg (adb), represent about 65% of Indonesia's total coal reserves of 38.8 billion tons. The Berau Basin, located on the island of Borneo, is one of Indonesia's largest hydrocarbon-producing basins, rich in coal resources. Within this basin lies the Sajau Formation, a coal-bearing rock formation estimated to hold 500 million metric tons (MT) of lignite and sub-bituminous coal. Currently, the coal in the Sajau Formation has not been optimally utilized due to its poor quality. The quality of Indonesian low-calorie coal is generally subpar, characterized by high total moisture and ash content. As a result, coal with a calorific content of 4,000 GAR (gross as received) or lower faces decreased demand in the export market. In Indonesia, low-calorie coal is primarily used for direct applications in power plants, industry, and household needs. However, one significant issue with the utilization of low-calorie coal is the environmental pollution it causes, including air pollution, dust, spontaneous combustion, and boiler clogging. Consequently, the quality of life for humans may also be negatively impacted [1,2,3].

The Underground Coal Gasification (UCG) process is an innovative approach that entails drilling multiple adjacent boreholes to convert subsurface coal into syngas, a valuable energy resource. This process begins with the strategic placement of boreholes to ensure efficient access to the coal seam. Advanced techniques, such as hydraulic fracturing and directional

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drilling, are employed to connect these boreholes effectively, maximizing the extraction process.

To facilitate gasification, high-pressure oxidants—such as air, steam, or pure oxygen—are injected into the targeted coal layer through specialized injection wells. This injection creates a controlled environment within the coal seam, where the coal undergoes a chemical transformation into syngas, a mixture primarily composed of hydrogen and carbon monoxide.

The syngas produced is then captured via production wells, which are designed to transport the gas safely to the surface [4, 5].. Upon reaching the surface, the syngas undergoes a comprehensive purification process to remove impurities like particulates, sulfur compounds, and other contaminants. This cleaning phase is crucial to ensure the syngas meet quality standards for safe and efficient use. Once purified, the syngas is distributed through an extensive network of pipelines, allowing it to be utilized for various applications. These include generating electricity, serving as a feedstock for the production of methanol or ethanol, and facilitating the creation of chemical products. By harnessing UCG technology, we not only tap into a domestic energy source but also move towards a more sustainable and environmentally friendly energy future. (Fig. 1)

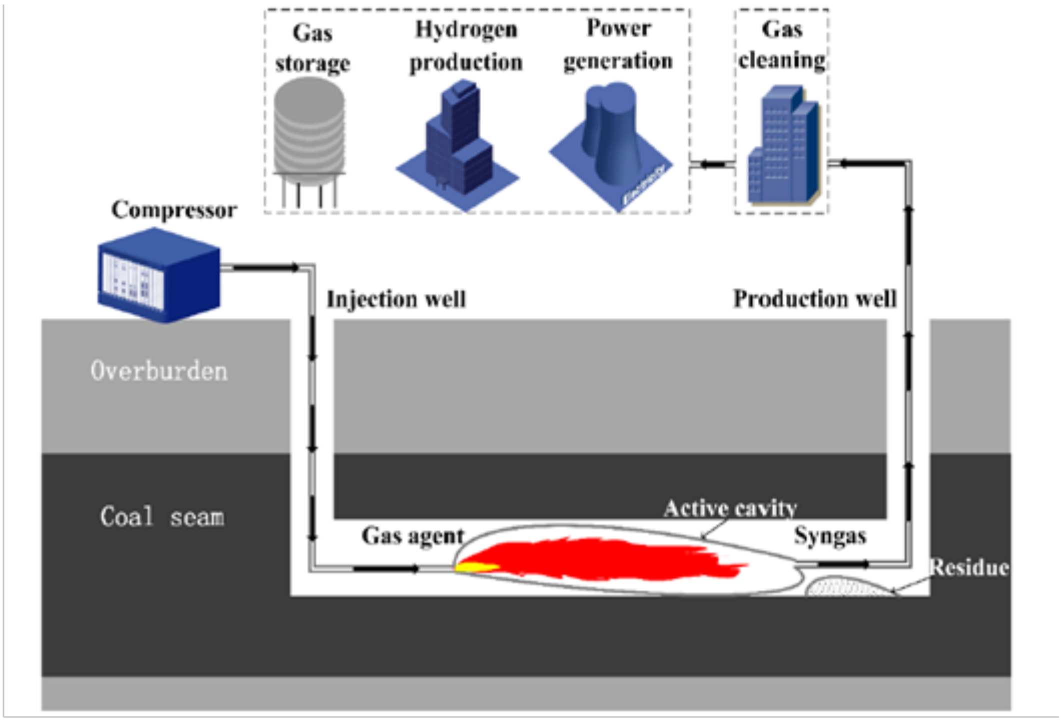

Fig.1: UCG Development diagram [6]

Underground coal gasification (UCG) technology is not only an effective method for producing syngas, but it also brings several compelling advantages. It optimally utilizes coal resources found in older mines and deep coal seams [7], while decisively eliminating emissions of sulfides and nitrogen oxides. UCG stands out for its minimal environmental impact and cost-efficiency, leveraging in situ water and coal during the gasification process to significantly lower operational costs. It's crucial to acknowledge that coal ash and residues from gasification remain underground [8], but this does not detract from UCG's status as one of the most promising sustainable technologies available. With broad application prospects, UCG offers substantial benefits for energy production, environmental health, and economic development.

Extensive research has been conducted worldwide to clearly define the essential criteria for selecting locations and specific coal types that effectively promote the development of underground coal gasification (UCG) [9-14]. These criteria include critical geological conditions such as hydrogeology, geotechnical factors, the dip of the coal seams, and geological structure. Additionally, assessing the chemical and physical properties of the coal—such as depth, thickness, and rank—is vital. A thorough evaluation of coal reserves, including the quantity of resources and their distance from the mine opening, is also necessary. While these criteria are well-founded, it’s important to adapt them to suit the unique geological characteristics of each region. This tailored approach will help ensure that UCG is implemented effectively and sustainably, fostering innovation within the energy sector.

Research on Underground Coal Gasification (UCG) in Indonesia, while still in its early stages, presents significant opportunities due to the currently limited availability of UCG data, technology, and geological conditions [15, 16, 17]. The Sajau Formation coal in the Berau Basin stands out as an exemplary case study, showcasing exceptional coal properties and geological characteristics that meet the critical requirements for UCG development. This study decisively establishes robust criteria for site selection, ensuring the effective implementation of UCG technology in the Sajau Formation coal. Backed by a thorough series of advanced geological and coal property investigations, our findings and recommendations provide a strong foundation for advancing UCG initiatives in Indonesia.

2. Materials and methods

We will expertly identify the essential requirements for optimal UCG development locations and the most suitable coal seams through a comprehensive, three-stage process.

This meticulous and structured approach ensures an in-depth assessment, enabling informed decision-making and setting the stage for outstanding project outcomes.

1) First Stage: We will conduct a thorough literature review that focuses on the development and implementation of UCG across various regions of the world. This review will include a detailed examination of case studies that highlight both successful projects and those that faced significant challenges or failures. By analyzing the methodologies, technologies, regulatory environments, and socio-economic impacts involved, this research aims to provide a clear understanding of the factors contributing to the success or failure of UCG initiatives globally. The insights gained will be instrumental in guiding future projects and informing policymakers and stakeholders in the energy sector.
2) Second Stage: The second stage involves exploration activities to assess a site's suitability for underground coal gasification (UCG). This phase reveals important geological conditions, structures, and coal deposit characteristics. We use advanced techniques such as precision exploration drilling for direct geological samples and geophysical wireline recording to measure the density, porosity, and resistivity of subsurface materials. This data helps geologists and engineers create detailed subsurface models, enabling informed decisions about the location's compatibility for UCG. This thorough exploration process also identifies and mitigates potential risks, ensuring successful UCG implementation.
3) Third Stage: In the final stage, we focus on key geological and coal characteristics necessary for UCG implementation. This includes assessing coal seam depth, geological stability, gas permeability, and the chemical composition of the coal. To streamline decision-making, we will apply the Analytic Hierarchy Process (AHP) [18], a method that allows us to evaluate and prioritize alternatives through pairwise comparisons. This will help us identify the most suitable geological settings and coal types for UCG, enhancing the overall process's effectiveness and efficiency.

3. Results & Discussion

3.1The global journey of underground coal gasification (UCG) over time

In the 1800s, the Siemens Brothers boldly pioneered the use of underground coal mining waste as a critical material for underground coal gasification (UCG) [19]. By 2000, the esteemed Russian chemist Dmitri Mendeleev made remarkable advancements by developing a comprehensive design and operational framework for UCG [20]. Since then, Australia, Europe, Canada, and, more recently, South Africa have become powerhouses in advancing UCG technology. Their significant contributions have established a robust foundation for innovation in this field, inspiring further global development, as demonstrated in Figure 2.

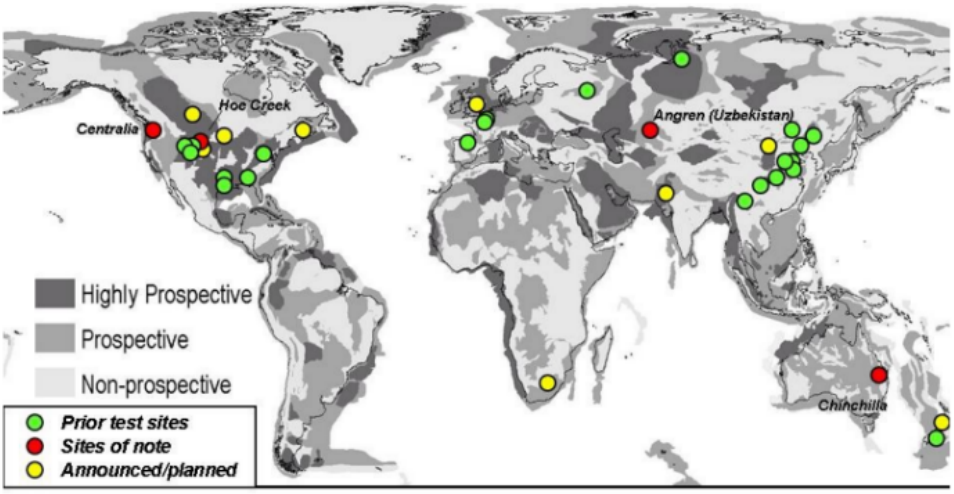

Fig. 2: Worldwide underground coal gasification: a snapshot [21]

Table 1 provides an in-depth overview of the development of Underground Coal Gasification (UCG), detailing a range of projects that have either achieved significant success or are currently undergoing trials. Notably, in Russia[22], research efforts have concentrated on maximizing gas production efficiency while addressing the environmental implications of UCG, such as groundwater contamination and emissions control. In Europe[22], various countries have launched pilot projects designed to test UCG's viability in generating sustainable energy; these projects aim to evaluate the technology's effectiveness in reducing greenhouse gas emissions compared to traditional fossil fuel extraction methods. South Africa[22, 23] is actively assessing UCG as a strategy to capitalize on its abundant indigenous coal resources, intending to minimize the ecological disruption caused by surface mining practices, which often result in land degradation and habitat loss. Australia[22, 23, 24, 25] is particularly noted for its pioneering approaches that aim to synergize UCG with renewable energy systems, promoting a more integrated energy framework that enhances overall efficiency and sustainability. In China[22, 23], substantial investments are being directed toward advancing UCG technology, driven by the need to meet the country's soaring energy demands while implementing strategies to significantly reduce carbon emissions and combat air pollution. This detailed presentation of data not only highlights the global acknowledgment of and investment in UCG but also serves as a comprehensive framework for guiding future research and development in this innovative and crucial energy sector.

Table 1: Summary of UCG data showing successful outcomes and trial results in Russia, European countries, South Africa, Australia.

Location	Year	Coal Type	Seam	
			Thickness (m)	Depth (m)
Russian				
Podmoskova	1940-1962	Lignite	2 – 4	40 – 60
Yuzhno-abinsk	1955-1989	Bituminous	2 – 9	-
Ukraine				
Lischansk	1934-1963	Bituminous	0,4 – 1.4	400
Gorlovka	1937-1939	Bituminous	1.9	40
Uzbekistan				
Angren	1962-1989	Lignite	4 - 24	110 - 250
European				
Belgium (Bos-la-Dame)	1948	Anthracite	1	400
UK (Newman Spiney)	1949-19959	Sub Bituminous	1	76
France (Bruary Artois	1981	Anthracite	1,2	1200
Belgium (Thulin)	1982-1984	Anthracite	6	800
France (Haute – Deule)	1985-1986	Amthracite	2	850
Australia				
Chinchilla	1999 - 2004	Anthracite	8 – 10	130
South Africa				
Majuba	2007	Bituminous	2.8 – 4.5	250 - 380

3.2Geology of Sajau Coal

The coal within the Sajau Formation demonstrates exceptional potential for underground coal gasification (UCG) in the Berau Basin, a crucial part of the stable block of the Greater Tarakan Basin. This region is strategically positioned in the northeastern part of Kalimantan Island. The geological conditions of the Berau Basin are comprehensively documented, providing a solid foundation for understanding its attributes.

The detailed surface geological map of the Tanjung Redeb Sheet vividly showcases the orientation of the region's structural features. The predominant northwest-southeast (NW-SE) and north-northwest-southeast (NNW-SSE) orientations of the anticlines and synclines reflect the dynamic tectonic processes that have significantly shaped the landscape. Furthermore, the normal faults in the area are consistently aligned along the NNW-SSE axis, underscoring the region's geological vitality [28].

The stratigraphic sequence of the Berau Basin is distinguished by its diversity and is arranged from the oldest to the youngest formations. This sequence includes the Sembakung Formation, consisting of continental and marine deposits from the Early Eocene; the Birang Formation, characterized by fluvial sediments; the Lati Formation, renowned for its volcanic ash layers; the Labanan Formation, which showcases coal deposits indicative of a rich paleoenvironment; and the Domaring/Sajau Formation, representing the youngest deposits from the Pleistocene epoch, primarily composed of coal. Collectively, these formations encapsulate a geological timeline that spans from the Early Eocene to the Pleistocene, vividly illustrating the intricate interplay of sedimentation and tectonics that has defined the geological history of the Berau Basin.

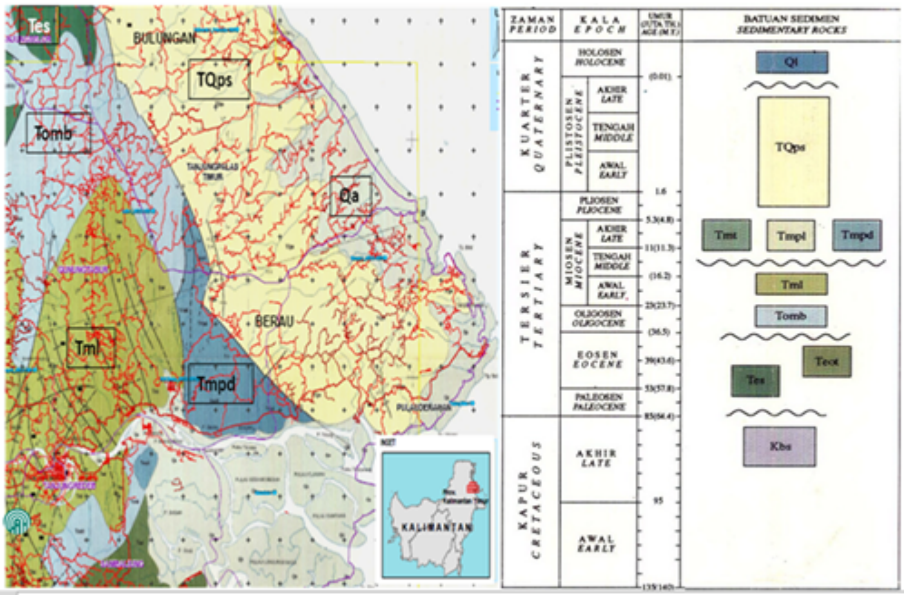

Fig. 2: The geological map of the Tanjung Redeb Sheet includes the stratigraphic sequence of the Berau Basin [28]

The reconstruction and interpretation of petrophysical data from drilling wells and seismic surveys are instrumental in accurately characterizing coal composition both vertically and laterally within specific geological formations. This study highlights the significant geological features found in the Tanah Kuning Block, Mangkupadi Block, and Kasai Block, where extensive geological drilling has identified a total of 13 distinct coal seams.

To promote clarity and ease of identification, each coal seam has been assigned a letter designation, beginning with Seam A at the lowest level and continuing through to Seam M (as illustrated in Fig. 3). The identification process is reinforced by a comprehensive analysis of data gathered from multiple sources. Geological drilling yields essential insights into the depth and thickness of the seams, while seismic data interpretation reveals crucial information regarding their lateral extent and structural relationships. Furthermore, outcrop data serves as a valuable reference, affirming the presence and characteristics of the seams at the surface level.

This integrated approach not only deepens our understanding of the coal seams within these blocks but also establishes a solid foundation for prospective exploration and exploitation initiatives [29, 30]. By effectively synthesizing these diverse datasets, we can better assess the available resources and devise strategies for their sustainable development, ensuring that the opportunities presented by these coal seams are maximized for future generations.

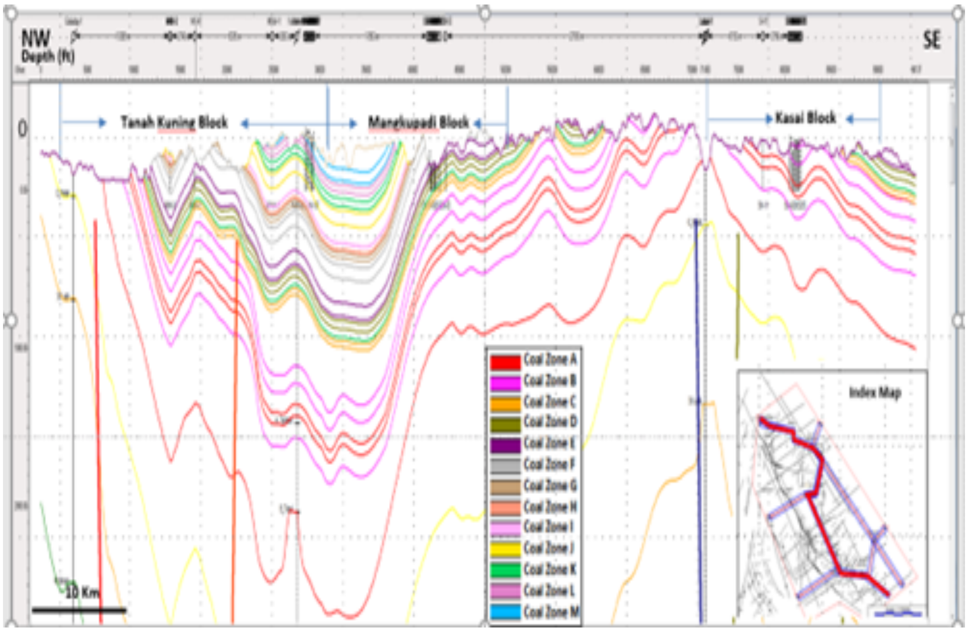

Fig. 3: Regional NW–SE Cross Section of Sajau Coal Seam Distribution

3.2 Criteria for UCG Site Selection in Berau Basin, North Kalimantan

Experts in underground coal gasification (UCG) from around the world have developed various site selection criteria aimed at optimizing UCG development [10, 22, 31, 32, 33, 34, 35]. These criteria include geological assessments, environmental impact considerations, economic feasibility, and technological requirements. However, it is important to note that the application of these criteria is not uniform across all locations due to the distinct geological conditions found in different regions. Drawing on the unique geological features and specific coal characteristics of the Sajau Formation, the author has developed a comprehensive set of criteria. This framework will be used to evaluate the potential of Sajau Formation coal in the Berau Basin for UCG development. The evaluation will consider factors such as coal composition, calorific value, and geological stability, ensuring a thorough analysis to determine the viability and efficiency of utilizing this resource for sustainable energy production.As a result, it is essential to customize these selection criteria to align with the specific geological and environmental characteristics of each UCG prospect area. By doing so, we can ensure a more effective integration of UCG technologies, enhance safety measures, and maximize the benefits of UCG projects while minimizing potential risks and environmental impacts.

This approach not only promotes the advancement of UCG as a viable energy solution but also supports sustainable practices in resource extraction.

3.2.1 Coal Rank

Coal gasification offers a versatile method for converting coal into useful gaseous fuels, and nearly all types of coal can be employed in this process. However, specific coal rankings can significantly influence the effectiveness of gasification. The gasification process requires reactive coal, as this reactivity is crucial for achieving effective chemical conversions. Low-rank coals, such as lignite and sub-bituminous coal, are typically more reactive than their high-rank counterparts, making them particularly desirable for applications like underground coal gasification (UCG). These types of coal not only have higher reactivity but also exhibit properties that enhance their gasification efficiency, such as lower carbon content and higher moisture levels.

Research indicates that low-rank coal possesses favorable qualities, as highlighted by studies conducted by [36, 37]. Bituminous coal can also be a viable option for gasification; however, its suitability hinges on its ability to maintain structural integrity during the process. Bituminous coal mustn't undergo cooking or caking, as this can impede gasification efficiency and complicate the overall process.

3.2.2 Coal Depth

Coal depth plays a vital role in the successful development of underground coal gasification (UCG), influencing both operational efficiency and environmental safety. UCG sites worldwide exhibit considerable variation in coal depth, ranging from 24 meters to depths of up to 880 meters [6].

Given these considerations, the optimal range for conducting UCG is from 150 meters to 900 meters [13, 14, 33]. Specifically for lignite, a depth of 150 meters is recommended to ensure the best results. Targeting these deeper coal deposits not only enhances the efficiency of the gasification process by tapping into less volatile seams but also reinforces environmental safeguards.

3.2.3 Coal Thickness

There are differences in the literature regarding the thickness of coal layers suitable for UCG development, for example, the Lisichansk location, Russia (0.4 m), and Angren in Uzbekistan (22 m). Although it is reported that thin coal thicknesses, under 1 meter, are found in various places, such as Lisichansk (0.4 - 0.75 m), Newman Spinney (UK) (0.75 m), and Highveld, South Africa (0.5 - 1 m) [6, 12]. However, considering the possibility of problems related to the thinness of the coal in the form of heat loss to the surrounding formation. Therefore, in the UCG process, it is recommended that the coal thickness be more than 2 meters.

3.2.3 Coal Seam Dip

A critical physical and geological parameter when assessing coal for energy projects of UCG is the dip of the coal seam. Specifically, coal seams with a dip greater than 70 degrees are generally considered more flammable, presenting increased risks in combustion processes compared to seams with a slope of less than 20 degrees. This distinction is important for project planning and safety protocols.

Several gasification projects in Bulgaria and Ukraine have successfully employed coal seams with dips ranging from 0 to 70 degrees, demonstrating the viability of utilizing coal in various geological settings. For instance, these projects have highlighted the importance of seam orientation in optimizing gas production and minimizing environmental impacts.

3.2.4 Roof and Floor Coal Layer

Underground coal seams are surrounded by an overburden roof, which consists of rock material above (roof layer), and an underburden or floor, which is the rock layer beneath. To ensure success in UCG, both the roof and floor rocks need to meet certain criteria:

1. The rocks should be permeable, such as claystone or siltstone, to effectively prevent gas leaks and protect groundwater from potential pollution.
2. To ensure proper structural integrity, the roof layer should be designed to be at least twice the thickness of the coal. Additionally, the floor layer should be equivalent to match the thickness of the coal for optimal support.
3. Lastly, a density typically falling within the range of 1.2 to 1.8 g/cm³ is preferable to ensure proper containment and efficiency during the gasification process.

3.2.5 Coal Resources

Determining the quantity of coal resources available for the Underground Coal Gasification (UCG) process is a critical task that hinges on several factors. These factors include the specific industrial applications the gas produced will serve, the anticipated electricity generation capacity, and the planned operational duration of the UCG system. Consequently, the assessment of coal resources or reserves is inherently relative and may vary based on these criteria.

To provide a more effective framework for resource assessment, experts in UCG recommend a minimum resource estimate of 2.5 to 3.5 million tons of coal per square kilometer, for more than 20 years of operation. This guideline helps ensure that the coal deposit is sufficient to meet both immediate and long-term energy needs while supporting efficient gasification processes [12, 13, 38].

3.2.6 Structural Geology

UCG (Underground Coal Gasification) locations should feature uncomplicated geological structures, ensuring that there are no significant faults that would disrupt coal distribution and accessibility. The presence of cleats—natural fractures within the coal—plays a crucial role in enhancing coal permeability, allowing for more efficient gas movement and extraction. Furthermore, a syncline structure at the UCG site is particularly advantageous, as it typically indicates a greater concentration of coal reserves, providing a more effective environment for the gasification process and maximizing energy output.

Table 2: Key factors to evaluate when identifying suitable UCG sites.

.No	Parameters	Standard Requirements for UCG Site
1	Coal Rank	All types of coal are acceptable, but we strongly prefer low-rank coal with a low free swelling index for optimal results. Lignite to subbituminous
2	Coal Depth	For optimal conditions, a depth of more than 100 meters is advised. Specifically for Lignite, a depth of 150 meters is recommended to ensure the best results
3	Coal Thickness	Coal Seam of greater than 2 metres thick
4	Depth/Thickness ratio	Depth 120–200-meter ratio 22, depth 200–300-meter ratio 18, Depth 300–400-meter ratio 15, depth >400 ratio 15.
5	Coal Dip	A preferred dip of 20°, while ensuring that the maximum dip does not exceed 70°.
6-7	Roof and Floor layer, and thickness	The rock must be impermeable; specifically, types like siltstone and claystone are ideal choices. The roof layer must be twice the thickness of the coal, and the floor layer should be equivalent to the coal layer.
8	Density	Typically falls within the range of 1.2 to 1.8 g/cm³
9	Coal resources (MT)	The estimated resource ranges at least from 2.5 to 3.5 million tons of coal per square kilometer, providing a robust supply that can support operations for over 20 years.
10	Geological structure	A simple geological structure without major faults is preferred. A developing syncline fold and cleat structure is ideal.

3.3 Evaluation Site Selection UCG for Sajau Coal Formation

The Sajau Formation coal exploration work, which includes geological mapping, exploration drilling, and laboratory analysis, has yielded significant data. This data was rigorously compared against predetermined criteria (refer to Table 2). The results of this thorough evaluation are presented in Table 3.

Table 2: Evaluation consideration site selection of UCG

Well Name	Coal Seam	Coal Rank ((Btu/Lb)	Top Depth (m)	Bottom Depth (m)	Thickness (m)	Depth/Thickness Ratio	Dip (0)	Rock Roof Type	Rock Roof Thickness (m)	Rock Floor Type	Rock Floor Thickness (m)	Density (gr/cm3)	Stuctural Geology	Resources (MT/Km2)
Kasai Block														
AH-101	E	4810	87,24	90,26	3,02	29,89	15	1	1,24	1	1,24	1.265	1	1,950
	D	7818	118,30	121,42	3,12	38,92	10	1	2,86	1	2,18	1.265	1	1,356
	C	8015	152,10	161,80	9,70	16,68	15	1	20,34	2	13,80	1.264	1	1,450
	B	7815	172,50	178,62	6,12	29,19	13	1	18,21	1	9,18	1,318	1	1,458
	A	8172	195,20	202,00	6,80	29,71	20	1	12,24	1	4.28	1,268	1	1,280
AKH-108	D	7926	79,30	82,10	2,80	29,32	15	1	2,18	2	1,10	1,265	1	2,850
	C	8082	85,10	90,28	5,18	17,43	18	1	2,12	1	2,06	1,265	1	1,750
	B	7284	100,38	112,80	12,42	9,08	20	1	5,24	1	4,28	1,272	1	1,640
	A	8232	148,92	154,84	5,92	26,16	20	1	12,80	1	5,34	1,642	1	3,260
Mangkupadi Block														
AMH-11	E	5180	76,62	80,2	3,58	22,40	15	1	2,15	1	3,92	1.265	2	1,350
	D	8102	88,21	97,15	8,94	10,87	15	1	1,80	1	9,21	1.264	2	1,410
	C	8062	114,72	118,24	3,52	33,59	18	1	2,78	1	2,10	1,308	2	0,980
	B	8126	124,82	130,26	5,44	23,94	21	2	2,86	2	6,32	1,286	2	0,740
AMH-18	E	7523	83,98	68,12	- 15,86	- 4,30	10	1	3,12	1	2,82	1,274	2	1,645
	D	5320	72,28	76,24	3,96	19,25	15	1	2,46	1	1,80	1,258	2	1,280
	C	7928	82,43	90,42	7,99	11,32	14	1	1,86	1	2,18	1,266	2	1,915
	B	8120	110,26	115,23	4,97	23,19	20	1	2,88	1	3,24	1,256	2	1,880
Tanah Kuning Block														
MNH-1	E	7215	51,28	60,34	9,06	6,66	15	1	2,12	1	1,86	1,264	2	1,710
	D	4818	65,68	78,12	12,44	6,28	10	1	1,68	1	1,76	1,252	2	1,026
	C	8170	82,82	88,28	5,46	16,17	12	1	0,88	1	3,24	1,261	2	0,810
MNH-3	H	7815	73,28	80,24	6,96	11,53	18	1	1,46	1	4,2	1,258	2	1,650
	G	7524	91,28	109,26	17,98	6,08	14	1	2,42	1	3,26	1,254	2	1,425
	F	5812	117,35	121,79	4,44	27,43	12	1	2,68	1	2,13	1,258	2	1,680
	E	7982	129,42	135,2	5,78	23,39	10	1	3,18	1	4,32	1,251	2	2,820
	M	7624	116,26	120,14	3,88	30,96	14	1	1,24	1	1,14	1,268	2	1,805
	L	5645	124,18	125,26	1,08	115,98	15	1	2,12	1	1,36	1,264	2	1,088
	K	7786	132,32	134,10	1,78	75,34	12	1	2,18	1	2,21	1,262	2	1,625
KAH-1	J	8760	139,26	145,16	5,9	24,60	10	1	2,46	1	3,52	1,251	2	1,025
MKAH-1	M	7602	112,26	123,14	10,88	11,32	15	1	3,24	1	3,24	1,252	2	1,710
	L	5612	127,18	135,26	8,08	16,74	15	1	1,12	1	4,28	1,252	2	1,025
	K	7528	145,32	148,10	2,78	53,27	10	1	3,28	1	2,86	1,254	2	1,820
	J	8562	151,26	155,16	3,9	39,78	12	1	4,64	1	6,62	1,256	2	3,160

🟨	Suitable	Roof and Floor Type		Structural Geology	
🟧	Not Suitable	1: Claystone	2: Sandstone	1: Simple	2: Complexc

3.3.1 A Potential UCG of Block Kasai

In the Kasai area, extensive exploration for subsurface coal deposits suitable for underground coal gasification (UCG) has shown significant potential.

Detailed drilling operations were conducted at drill points AH-101 and AKH-108, reaching a total depth of 354.84 meters.

During these operations, five coal seams were identified: Seam A, located at the lowest depth, followed by Seams B, C, D, and the topmost, Seam E. The measured thickness of these seams varies between 2.80 meters and 9.70 meters, with Seam C notably being the thickest at 9.20 meters, indicating a substantial volume of coal.

In-depth laboratory analysis of the collected coal samples classified all of them as Lignite A, a type of coal known for its relatively low carbon content and high moisture levels but still holds potential for UCG due to its combustibility. The evaluation process revealed that Seam A stands out as the most suitable option for UCG development when compared to the other seams, as highlighted in Table 3. This assessment is based on factors such as thickness, coal quality, and gasification potential.

3.3.2 A Potential UCG of Mangkupadi Block

Coal drilling in the Mangkupadi Block was executed to thoroughly assess the coal potential of the Sajau Formation for Underground Coal Gasification (UCG). The drilling took place at two strategic sites, AMH-11 and AMH-18, achieving a combined total depth of 260.40 meters. Through this drilling effort, we successfully identified four distinct coal seams: Seam B, located at the lowest depth, followed by Seam C, Seam D, and the topmost layer, Seam E. The thickness of these coal seams varied significantly, ranging from 3.58 meters to 15.8 meters, indicating the diversity of coal deposition within the formation.

Comprehensive laboratory analyses revealed that nearly all coal samples were classified as Lignite A, characterized by a calorific value ranging from 7,692 to 8,126 BTU/Lb. This classification indicates reasonable potential for energy generation. However, it is noteworthy that the rock samples from Seam E taken from the AMH-11 well and those from Seam D were classified as Lignite B, with a calorific value between 5,180 and 5,320 BTU/Lb, which is lower and suggests reduced energy efficiency.

While the Gross Calorific Value (GCV), the thickness of the seams, and the dip of the rock layers met the specified criteria for potential UCG development, it is essential to highlight that several other geological and coal quality criteria were not satisfied. This thorough evaluation leads us to a solid conclusion: there are currently no coal seams within the Mangkupadi Block that are suitable for UCG development. This finding will guide future exploration and resource development efforts in the region.

3.3.3 A Potential UCG of Tanah Kuning Area

To thoroughly evaluate the development potential of the Sajau Formation coal within the Tanah Kuning Block for underground coal gasification (UCG), an extensive drilling program was conducted at four strategically chosen locations: MNH-11, MNH-3, KAH-1, and MKAH-1. This drilling campaign reached a total depth of 523.80 meters, where we successfully identified ten distinct coal seams.

The lowest coal seam, seam C, was encountered in the MNH-1 well, indicating a complex stratigraphic profile.

The full sequence of identified coal seams includes seam D, seam E, seam F, seam G, seam H, seam J, seam K, seam L, and seam M, with seam M being notable for its presence in both the KAH-1 and MKAH-1 wells. The coal seams vary significantly in thickness; seam L is the thinnest at just 1.08 meters, while seam G emerges as the thickest, boasting a substantial thickness of 17.98 meters.

Comprehensive laboratory analyses of the coal samples revealed that seams D, G, and L fall under the classification of Lignite B, characterized by a calorific value ranging between 4,818 and 5,812 BTU/lb. Conversely, the samples from seams E, C, F, H, J, K, and M are classified as Lignite A, exhibiting more favorable calorific values from 7,215 to 8,170 BTU/lb, making them potentially more valuable for energy production.

Despite these findings, it is crucial to underscore that the Tanah Kuning Block does not present any coal reserves suitable for UCG. This conclusion stems from the failure to meet several critical criteria, including the depth of the seams, most of which exceed 150 meters—unfavorable depth-to-thickness ratios, insufficient thickness of the overburden and underlying rock layers, a complex geological structure that complicates extraction processes, and limited overall resource availability. These factors hinder the feasibility of developing UCG in this region, emphasizing the need for further exploration and analysis to identify more viable coal sources in the area.

3.3 Analytical Hierarchy Process Weight

Furthermore, the Analytical Hierarchy Process (AHP) analysis provided in-depth insights into the relative merits of the various seams identified in the region. Notably, Coal Seam A was ranked the highest, achieving an AHP weight of 92.30%, signifying its superior attributes and potential for energy production. Following, Coal Seam B received an AHP weight of 74.13%, indicating its viability but also highlighting the greater competitive advantage of Seam A. This ranking, detailed in Table 4, underscores the significant opportunity presented by Seam A for advancing underground coal gasification (UCG) initiatives.

The implications of this prioritization are substantial, as it suggests that focused development efforts on Coal Seam A could substantially optimize the processes involved in resource extraction, leading to increased efficiency and energy generation. By leveraging the strengths of Coal Seam A, the region can position itself as a leader in utilizing this promising energy source, which could ultimately contribute to meeting local and national energy demands sustainably and responsibly. Additionally, targeted investment in research and infrastructure related to Coal Seam A could enhance its development, paving the way for innovative approaches to energy production that capitalize on its unique attributes.

4. Conclusion

An in-depth assessment of the underground coal gasification (UCG) potential of the Sajau Formation coal was conducted in three distinct areas within the Berau Basin: the Kasai Block, the Mangkupadi Block, and the Tanah Kuning Block, all located in North Kalimantan Province. This evaluation aimed to identify suitable sites for UCG development by examining various geological and coal-specific factors.

The assessment utilized a range of critical criteria to determine the viability of each coal seam, including coal rank—an indication of the coal's carbon content and energy yield—coal seam depth, which affects both extraction feasibility and gasification efficiency, and coal thickness, essential for determining the volume of recoverable material. Additionally, the depth-to-thickness ratio was analyzed to evaluate potential operational challenges during gasification.

Further factors include the coal seam dip, which can influence the stability of the gasification process, as well as the types and thicknesses of the roof and floor rocks, which play a crucial role in the containment and control of gasification reactions.

Geological structures within each block were examined to identify any features that might affect gas flow and extraction efficiency.

The assessment also considered coal density, which correlates to the energy content, and the overall coal resources available in each block.

Among the three prospective locations, which collectively included eight coal seams, the Kasai Block emerged as the most promising site. Specifically, coal seam A demonstrated characteristics that align with the necessary parameters for successful UCG development, such as optimal depth, sufficient thickness, and favorable geological conditions.

Employing the Analytic Hierarchy Process (AHP) method, a structured decision-making framework, we identified coal seam A as the highest priority for further exploration and potential development, achieving an AHP weight of 97%. This strong prioritization underscores the seam's strategic significance and highlights a clear pathway for advancing UCG initiatives within the region. The promising results from this evaluation pave the way for future studies and investments focused on harnessing the UCG potential of the Sajau Formation coal in a sustainable manner.

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