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Study on Generating Acoustic Emission with Heating Coal for Application as Monitoring System for Underground Coal Gasification

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Abstract. Underground Coal Gasification (UCG) is a technology to recover combustible gases by drilling holes and in-situ gasification. The establishment of a safe UCG system requires monitoring of the gasification reaction area because the gasification process that occurs in the underground is an invisible event. It is considered that Acoustic Emission (AE) monitoring is an effective technique for monitoring the underground gasification area since many fracturing activities occur in the coal seam due to coal heating. Therefore, the temperature condition of AE generations is investigated using the coal heating experiments and examines the applicability of AE measurement as a monitoring method for UCG. Measurements of temperature change and AE events with the thermocouples and the acceleration transducers during the coal specimen were heated. As a result, many AE events are found when the temperature of coal is changed and detected in the sensor where its location was near the heat source. Additionally, AE sources are expanded widely with the expansion of the high-temperature region based on the analysis results of the AE source location. It is possible to monitor the temperature change of coal and the expansion of the high-temperature region by applying AE measurement monitoring during UCG.

1. Introduction

Underground Coal Gasification (UCG) is a method of recovering combustible gases from coal by in-situ gasification of unused underground coal resources. This technique enables the utilization of coal resources that remain unrecoverable in the underground due to either technological or economic reasons. Most coal mining in Japan was closed by 2001 because of complicated geological conditions for mining development and the high prices of domestic coal. However, abundant unused coal resources remain underground, but they are not recoverable because of technical and economic reasons. For that reason, UCG has a great potential to recover vast amounts of energy from these coal resources.

In UCG process, the gasification process that occurs underground is the invisible process and the temperature during UCG is over 1,000°C, indicating that the excessive expansion of the gasification area causes a significant impact on the surrounding environment, including gas leakage, land subsidence, and groundwater contamination [1-3]. On the other hand, if the gasification area is widely expanded, the gasification reaction of UCG is accelerated in a wide area, and the combustible components in the product gas are expected to increase. These facts mean the visualization of the gasification region of UCG plays an important role in the development of safe, low environmental impact, and high-efficiency

UCG systems because the expansion of the gasification region in UCG is important for both the risk of environmental problems and the improvement of gasification efficiency.
It is assumed that the gasification area of UCG can be predicted by monitoring the temperature of the coal [4, 5]. However, it is practically difficult to measure many temperatures of coal seams in the actual UCG site. Since fracture activity in the coal seam occurs due to thermal stress in the high-temperature region in the UCG, acoustic emission (AE) measurement is considered to be one of the effective methods to monitor the fracturing activity in the underground gasification region [6-9]. AE measurement and source location analysis during UCG model experiments have revealed that many AE activities occur in the high-temperature region of the UCG and contribute to the estimation of the gasification zone [10, 11]. However, it has not been clarified the temperature conditions these AE activities occurred.
From these backgrounds, this paper describes the results of coal heating experiments conducted to collect the fundamental data to understand the temperature conditions to occur AE event and to examine the applicability of AE measurement as a monitoring technique during UCG.

2. Materials and methods

The coal heating experiment was carried out by heating coal block and sandstone which is a size of 200 mm × 200 mm × 100 mm using a cartridge heater. The sandstone was selected as a sedimentary rock around the coal seam to investigate the AE generation due to the heating other than the coal seam. Thermocouples were installed at 15 mm intervals up to a distance of 60 mm from the cartridge heater, and several acceleration transducers were installed on the end faces of the coal block to detect AE events. Figure 1 shows the experimental setup of the coal heating experiment. Tables 1 and 2 show the industrial and elemental analysis values of the coal and mechanical properties of the samples used in this study. The different temperature distributions were formed to arrange the temperature input of a cartridge to investigate the effect of the AE activities on the coal temperature. AE waveform and the number of AE events were measured during the experiment. Figure 2 shows the temperature setup of a cartridge heater. Besides, the relationship between the AE source and temperature distribution was investigated by conducting source location analysis using the AE waveform data and the temperature distribution of the coal specimen obtained by thermocouples.

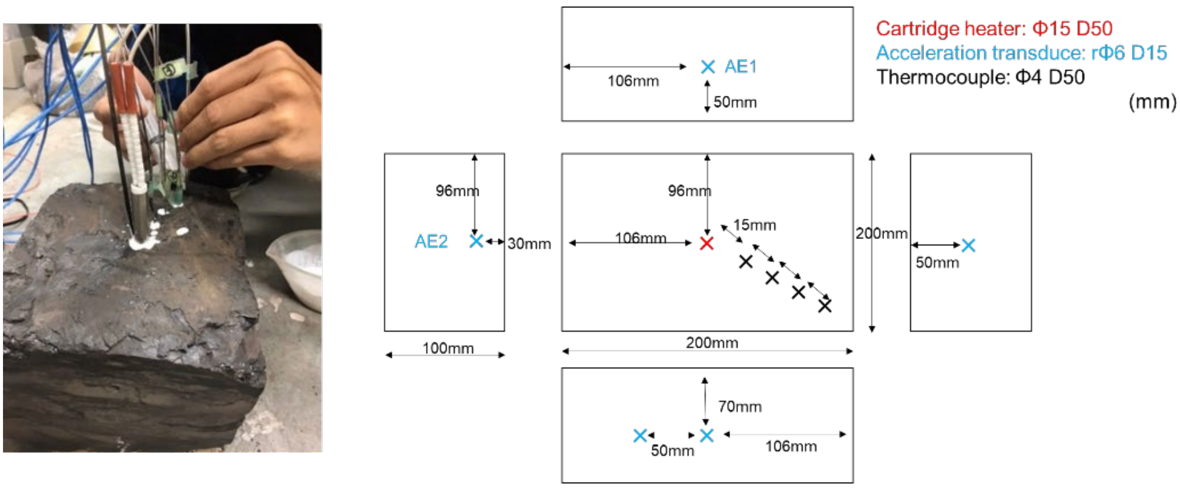


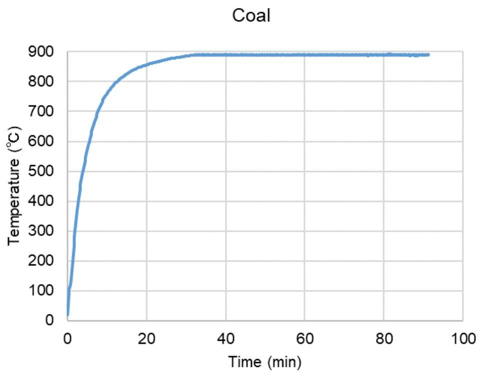
Figure 1. Experimental setup of the coal heating experiment.

Table 1. Proximate and ultimate analyses of the coal.

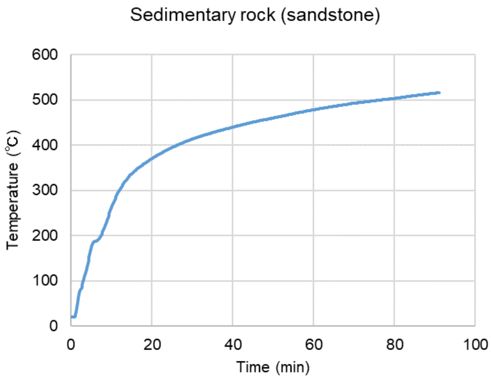
Calorific value (MJ/kg)	Proximate analysis (wt%)				Ultimate analysis (wt%)				
	Moisture	Ash	Volatiles	Fixed carbon	C	H	N	S	O
22.66	2.2	28.8	34.0	35.0	55.3	4.20	1.28	0.76	9.31

Table 2. Mechanical properties of samples.

	Density (g/cm^3)	Uniaxial compressive strength (MPa)	Young's modulus (MPa)
Coal	1.15	8.95	808
Sedimentary rock (sandstone)	2.21	35.69	2975



(a) Coal



(b) Sedimentary rock (sandstone)

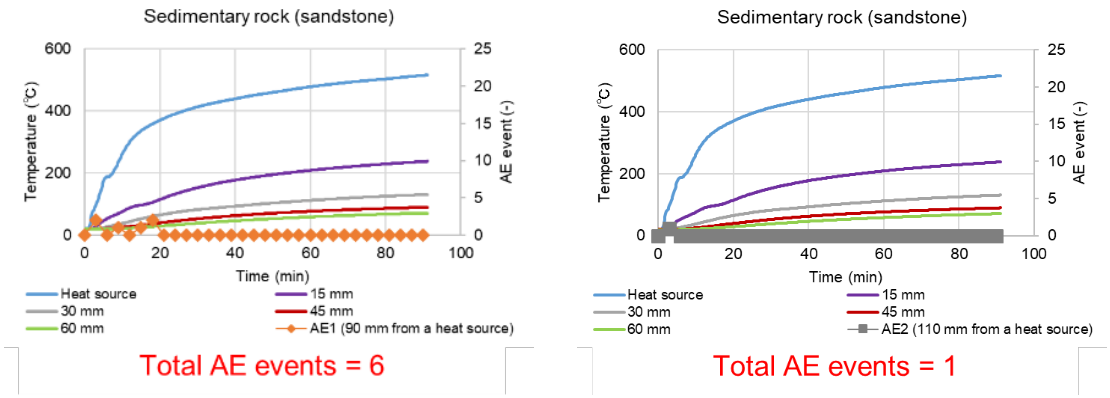
Figure 2. Temperature setup of a cartridge heater.

3. Results and discussion

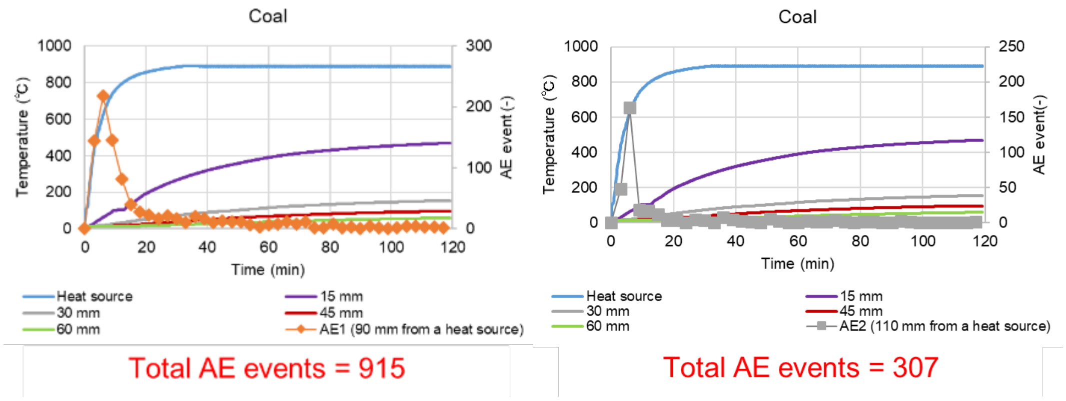
3.1. Relationship between coal temperature and AE events

The results of temperature and AE events for sandstone and coal block are respectively shown in Figures 3 and 4. From the figures, it can be seen that the closer to the heat source, the higher the temperature of the thermocouple for both samples: the thermocouples of 15 mm, 30 mm, 45 mm, and 60 mm show respectively 229 ℃, 125 ℃, 86 ℃, and 67 ℃ in sandstone after the 80 minutes elapsed while they show 430 ℃, 133 ℃, 81 ℃, and 49 ℃ in coal block. The total AE events for sandstone are only 6 AE events for AE1 and 1 AE event for AE2 in sandstone while they are more AE events in coal block. This means that the AE events that occurred due to the heat during UCG process are mainly from the coal not from the surrounding sedimentary rocks. The results of AE events also show that many AE events are found when the temperature of the heat source changes dramatically at the initial stage of the experiment. This indicates that the occurrence of AE activities is related to the temperature change of the coal, indicating that it is possible to understand the temperature change of the coal by AE monitoring. In addition, it is confirmed that more AE events can be detected in the closer the distance from the heat source in the coal block according to the AE events measured at different distances from the heat source: 915 AE events when the distance is 90 mm while 307 AE events when the distance is 110 mm. In other words, the AE events can be used to identify the location of the temperature change in the coal from the position of the sensors.

In summary, AE monitoring can be used to predict the location of coal temperature changes during UCG. Besides, a significant increase in the AE events may indicate that the temperature has increased to the point where coal gasification occurs.



(a) AE1 (90 mm from a heat source) (b) AE2 (110 mm from a heat source)
Figure 3. Temperature and AE events (sandstone).



(a) AE1 (90 mm from a heat source) (b) AE2 (110 mm from a heat source)
Figure 4. Temperature and AE events (coal block).

3.2. AE source location

In this study, the source location of AE activities is calculated by the least-squares travel-time-difference method [12]. As an example of the results, the results of the source location analysis in the experiment are shown in Figure 5. The dark color box shows the coal block and the cylinder in the center is a cartridge heater which is a heat source in the experiment. The red spheres depict the results of AE source location. Figure 6 shows the results of AE source location and the ratio of source locations depending on the distance from the heat source when the temperature of the elapsed time is 0~30 min and 30~120 min. AE sources are dispersed from a heat source although the temperature dramatically changes near the cartridge heater. This result suggests that precise estimation of AE activities by coal heating is seemingly difficult due to the heterogeneous of coal, the properties changes of the coal with temperature changes, and other unknown factors. However, a rough estimation of AE activities can be done if the results are analyzed statistically: more than 50% of AE sources are located within 30 mm from a heat source and more than 50 % of them are located above 30 mm from a heat source. The AE sources are located farther away from the heat source for 30~120 min and the high-temperature region extends over a wider area of the coal block in the latter stage of the experiment, meaning that the distribution of AE sources agrees with the temperature distribution as shown in Figure 7. In other words, this result suggests that it is possible to monitor the expansion of the high-temperature region by AE measurement.

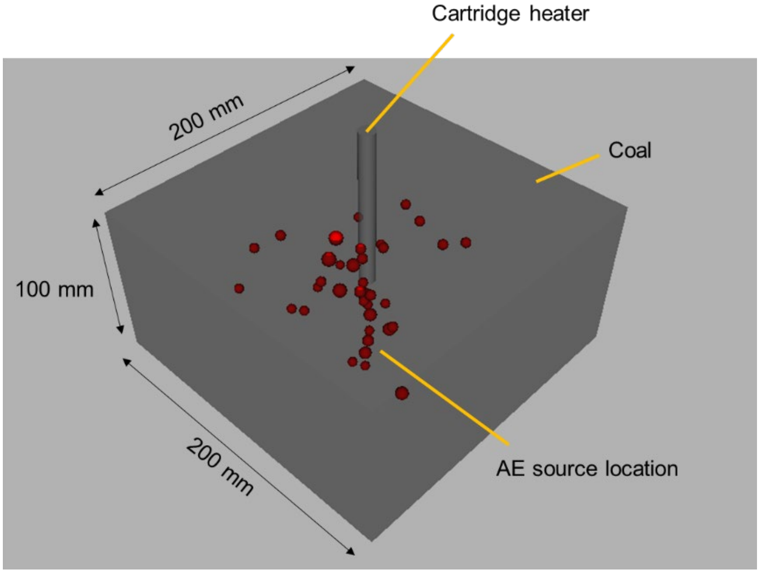
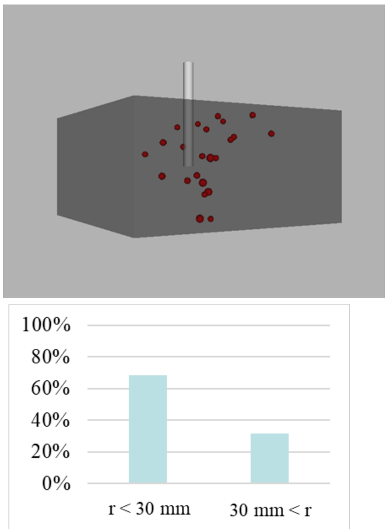
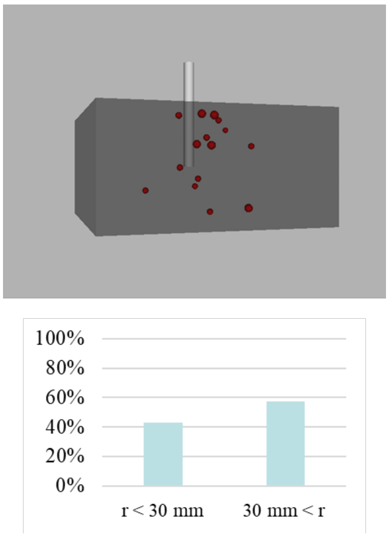


Figure 5. Example results of AE source location analysis.

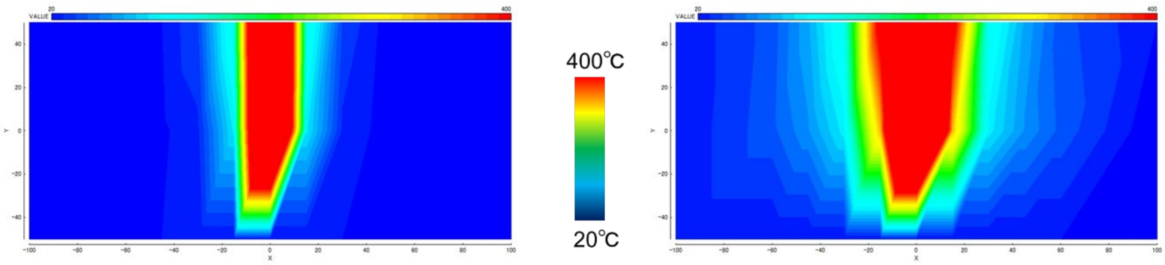


(a) 0~30 min



(b) 30~120 min

Figure 6. AE source location and its distribution ratio based on the distance from a heat source ("r" means the distance from a heat source).



(a) 15 min elapsed

(b) 75 min elapsed

Figure 7. Temperature distribution.

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4. Conclusion

In this study, the coal heating experiment has been conducted to investigate the relationship between temperature distribution and AE activities. As a result, the AE events that occurred due to the heat during UCG process are mainly from the coal not from the surrounding sedimentary rocks because AE activities are not detected when the sandstone is heated although a large number of AEs are generated when there is a temperature change in the coal. Besides, the closer the distance between the acceleration transducers and the heat source, the larger the number of AE events. This suggests that it is possible to identify the location where the temperature change is occurring to some extent by comparing the number of AE events using multiple sensors. In addition, the AE source location analysis is effective to monitor the expansion of the high-temperature region because the static analysis results of AE sources and the temperature distribution show the same trend, meaning that the AE sources are located far from the cartridge heater with expanding the high-temperature region. These results suggest that the application of AE measurement monitoring during UCG can capture the temperature change of coal and the expansion of the high-temperature region.

Acknowledgments

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