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Optimizing Borehole Diameter for Maximum Gas Extraction Efficiency in Coal Seams

Junming Zhang[1,2], Lei Tan[1,2], Xuan Zhang[1,2], Hai Wu[1,2*], Zhen Hu[1,2], Haohua Chen[3]

[1] Work Safety Key Lab on Prevention and Control of Gas and Roof Disasters for Southern Goal Mines, Hunan University of Science and Technology, 411201 Xiangtan, China
[2] School of Resources, Environment and Safety Engineering, Hunan University of Science and Technology, 411201 Xiangtan, China
[3] Department of Civil and Architectural Engineering and Mechanics, University of Arizona, Arizona, USA

[*] Correspondence: Hai Wu (wuhai@hnust.edu.cn)

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Abstract: In mines characterized by high gas concentrations, the process of extracting natural resources frequently precipitates coal and gas outbursts, positioning borehole gas extraction as a pivotal preventative strategy. Investigations aimed at identifying an optimal borehole diameter for gas extraction were undertaken within the Puxi Mine, entailing the drilling of boreholes across a spectrum of diameters and subsequent comparative analysis of the resultant data. This study meticulously evaluated the influence of seven distinct borehole diameters on gas concentration and pure flow rate, per unit length of coal hole and per unit of applied negative pressure. It was discerned that boreholes with larger diameters significantly enhance gas extraction efficacy. Specifically, boreholes of 113mm and 94mm diameters were noted for their exceptional performance, delivering pure flow rates of gas at 0.0215 m^3/min and 0.0428 m^3/min, respectively. Through a detailed examination of borehole diameters that presented considerable advantages, notably 113mm, 105mm, and 94mm, it was ascertained that the 94mm borehole diameter achieved the highest utilization efficiency, registering a gas pure flow rate of $1.62 \times 10^{-4}\ \mathrm{m}^3/\mathrm{min}$ per unit diameter. Consequently, this diameter was identified as the most advantageous for gas extraction purposes. The insights garnered from this investigation are instrumental for the selection of borehole diameters tailored to gas extraction in coal seams of varying thicknesses, and they significantly contribute to the formulation of rationalized gas extraction methodologies.

Keywords: Gas extraction diameter; Coal hole; Extraction negative pressure; Extraction efficiency; Optimal borehole diameter

1 Introduction

China's abundant coal resources, characterized by a widespread distribution, confront a significant challenge with a substantial number of mines susceptible to gas outbursts, posing frequent and high-risk incidents [1, 2]. The technique of borehole gas extraction has emerged as the foremost strategy for mitigating such hazards [3]. Critical parameters in the drilling process for gas extraction include the borehole diameter, the negative pressure applied during extraction, and the length of the coal hole [4]. Investigating the influence of coal hole length and negative pressure on the efficacy of gas extraction across boreholes of varied diameters, alongside the determination of an optimal borehole diameter, holds paramount importance for the enhancement of gas extraction results and the minimization of drilling expenses. The specialization in the deployment of a novel outburst prediction position sampler, featuring a borehole diameter of Φ42mm, underscores the innovative approaches being explored in this domain [5].

Recent years have witnessed a proliferation of research by a myriad of experts and scholars focusing on variables such as borehole diameter, gas extraction concentration, and the effective radius of extraction. Sharma et al. [6] delved into the present and future prospects of gas extraction within Indian coal mines. Bressan and Deshaies [7] accentuated the pivotal role of gas extraction within the context of the energy transition. Aziz et al. [8] elaborated on the strategies implemented for the secure mining of outburst-prone mines in Australia. Viney et al. [9, 10] offered modeling illustrations depicting the repercussions of coal mining and coal seam gas extraction on runoff within five Australian research catchment areas. Taheri et al [11] engaged in the examination of gas flow within coal masses to ascertain gas pressure and molecular velocity amid gas emission operations. Aghighi et al. [12] elucidated the analytical principles governing both surface vertical and subterranean gas extraction methodologies. Frank et al. [13] acknowledged the establishment of directional drilling techniques as the industry benchmark for efficacious gas emission drilling. Deng [14], through the utilization of COMSOL numerical simulations and field trials, deduced that an augmentation in borehole diameter favorably impacts coal seam gas extraction efficiency. Fan et al. [15] pursued an examination of the impacts exerted by large diameter boreholes on the efficiency of gas extraction from coal seams.

In the investigation into gas extraction from the No. 3 coal seam at Yicheng Coal Industry, Wei et al [16] analyzed the relationship between borehole diameters of 94mm and 75mm, and the corresponding gas concentration and pressure. It was observed that a correlation exists between extraction concentration and pressure, yet the borehole diameter exerts a minimal impact on both gas extraction pressure and concentration. Zhang et al. [17], employing similar simulations and numerical modeling techniques, explored the effect of negative pressure on gas permeation within the borehole. Their findings suggest that an extraction negative pressure within the range of 25-35Kpa is conducive to efficient gas extraction, albeit with a diminishing effectiveness over time. Further, Cao et al. [18] undertook a statistical evaluation of layout parameters and extraction data for 53 high-level boreholes, thereby optimizing both borehole diameter and extraction negative pressure for the gas extraction efforts at Wangjialing Coal Mine. Through numerical simulation, Xue [19] established an optimum diameter for extraction boreholes. Similarly, Cheng et al. [20] utilized COMSOL software to delve into the mechanisms through which negative pressure influences gas extraction. Zhao et al. [21] amalgamated engineering practices with FLUENT software simulations to ascertain the ideal negative pressure for gas extraction at the Zhaozhuang mine's 1309 working face, pinpointing it at 20Kpa. Gao et al. [22] posited that the plastic zone and effective influence zone of a borehole expand in tandem with an increase in borehole diameter, thereby enhancing the interaction among adjacent boreholes. Specifically, when the borehole diameter reaches 1.0m, the radius of the effective influence zone is augmented to 4m, which is 2.67 times greater than that of standard boreholes.

Yao et al. [23] delved into the complexities of borehole gas extraction in soft coal. Li et al. [24] embarked on a study to evaluate the outcomes of gas extraction processes. Through the lens of numerical simulations, Zhang et al. [25] scrutinized the stress alterations and the likelihood of damage failure, attributing these phenomena to the scouring of coal and the geometric configurations of boreholes. Utilizing Fluent software, Xu et al [26] undertook an analysis and simulation of disparate gas extraction effects under varied stratifications and negative pressure conditions across different roadway levels, subsequently optimizing the technological parameters pertinent to these environments. Saber et al. [27] investigated the partial differential equations governing gas flow within extraction mechanisms. Ahamed et al. [28] explored the ramifications of hydraulic fracturing on the efficacy of gas extraction. Danesh et al. [29] highlighted the significance of coal creep within the context of evaluating gas extraction performance. While a considerable volume of research has been dedicated to exploring the effective radius of gas extraction, the impact of large diameter boreholes, and the refinement of gas extraction methodologies—culminating in a spectrum of findings—a paucity of inquiry has been directed towards determining the optimal diameter for gas extraction boreholes. This analysis, predicated on empirical data derived from borehole gas extraction at the Puxi Well operated by Jiahe Mining Co., Ltd., assesses the influence of coal hole length and negative pressure on the efficiency of gas extraction across boreholes of varying diameters. The determination of an appropriate borehole diameter for gas extraction emerges as a critical consideration.

2 Experimental Scheme and Basic Conditions

2.1 Borehole Configuration

Within the context of Jiahe Coal Mine, a systematic drilling of boreholes was undertaken across the 2254 and 2454 floor roadways. This endeavor resulted in the establishment of seven sets of boreholes, encompassing three sets with diameters of 75mm and one set each for diameters of 87mm, 94mm, 105mm, and 113mm. Each set comprised five boreholes, uniformly matching in diameter. In a detailed arrangement, the 2254 floor roadway was designated for the construction of four experimental borehole sets, characterized as follows: the initial set was defined by a 75mm diameter, utilizing conventional sealing technology; a subsequent set, also of 75mm diameter, was distinguished by the integration of a two-plug-one-injection sealing process augmented by lower screen pipe protection technology; a third set, marked by an 87mm diameter, adhered to the aforementioned sealing methodology coupled with lower screen pipe protection; and a fourth set, with a 94mm diameter, similarly employed the two-plug-one-injection sealing approach alongside lower screen pipe protection. Additionally, the 2454 floor roadway witnessed the construction of three borehole sets: a fourth set of 94mm diameter, following the two-plug-one-injection sealing protocol with lower screen pipe protection; a fifth set of 105mm diameter, adhering to the same sealing method; and a sixth set of

113mm diameter, also utilizing the two-plug-one-injection sealing process with lower screen pipe protection. The fundamental parameters of these boreholes are systematically cataloged in Table 1.

Table 1. Basic parameters of boreholes by diameter

Borehole Diameter (d/mm)	75	75 − 2	75 − 3	87	94	105	113
Average Coal Hole Length (m)	5.98	5.775	5.98	7.2	2.6	2.1	3.5
Average Sealing Length (m)	21.4	16.75	21.4	21.6	14.8	14.4	14

2.2 Basic Conditions of Borehole Gas Extraction

In the investigation of borehole gas extraction, a detailed analysis was conducted on the fundamental aspects of gas extraction across seven distinct sets of boreholes, designated as 75, 75-2, 75-3, 87, 94, 105, and 113. The parameters scrutinized included mixed flow rate, concentration, negative pressure, and cumulative pure flow rate, with the findings systematically represented in Table 2 and illustrated through Figure 1, Figure 2, Figure 3, Figure 4.

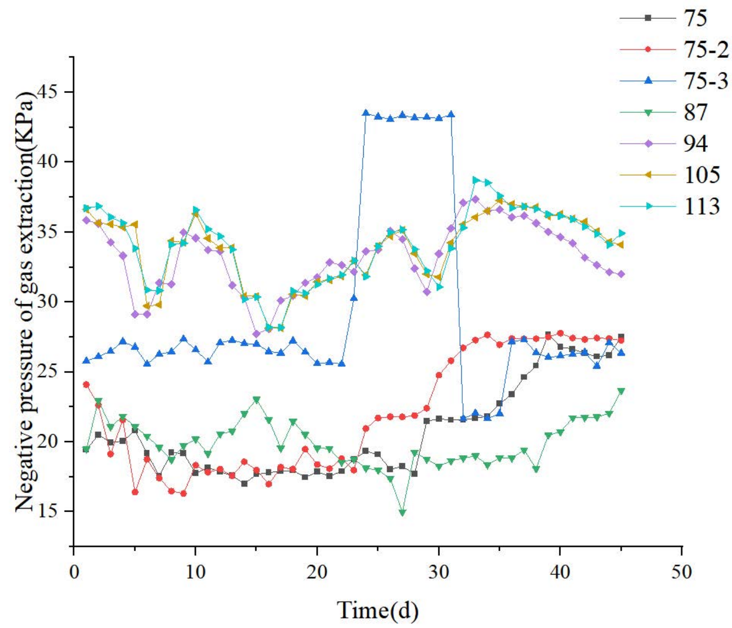

Figure 1. Variation curves of extraction negative pressure for different borehole groups

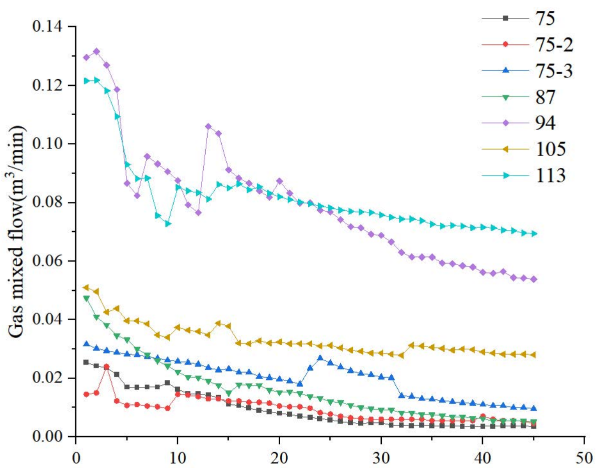

Figure 2. Variation curves of mixed flow rate for different borehole groups

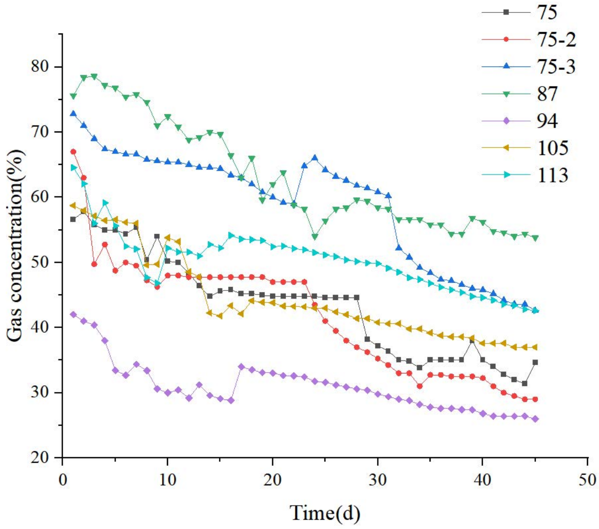

Figure 3. Variation curves of extraction concentration for different borehole groups

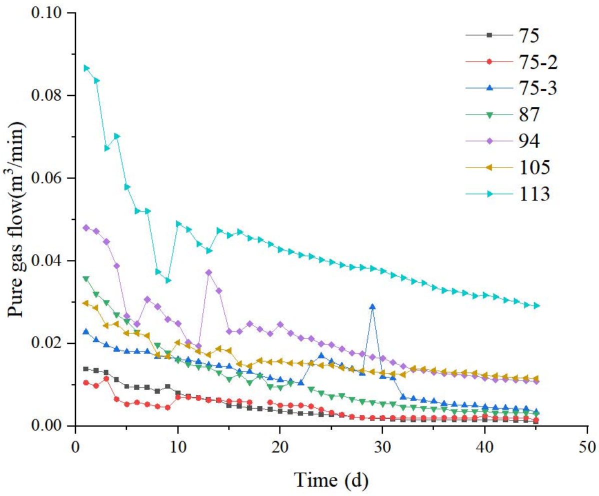

Figure 4. Variation curves of pure flow rate for different borehole groups

Table 2. Conditions of gas extraction across borehole diameter groups

Borehole Diameter $(\mathrm{d/mm})$	75	$75-2$	$75-3$	87	94	105	113
Average Negative Pressure (Kpa)	20.68	22.02	29.12	19.93	33.19	33.83	34.01
Average Mixed Flow Rate $(\mathrm{m}^3/\mathrm{min})$	0.0094	0.0093	0.0202	0.0161	0.0791	0.033	0.0817
Average Concentration $(\%)$	51.6	50.56	66.54	73.17	33.39	51.82	53.88
Average Pure Flow Rate $(\mathrm{m}^3/\mathrm{min})$	0.0046	0.0043	0.0124	0.0110	0.0215	0.0162	0.0428

The analysis revealed that borehole groups with diameters of $\varphi 94\ \mathrm{mm}, \varphi 105\ \mathrm{mm}$, and $\varphi 113\ \mathrm{mm}$ experienced relatively uniform changes in negative pressure, which were observed to be higher than those of the $\varphi 75\ \mathrm{mm}$ and $\varphi 87\ \mathrm{mm}$ borehole groups. It was noted that the extended sealing lengths associated with the $\varphi 75\ \mathrm{mm}$ and $\varphi 87\ \mathrm{mm}$ borehole groups resulted in higher average concentrations when compared to the larger diameter groups of $\varphi 94\ \mathrm{mm}, \varphi 105\ \mathrm{mm}$, and $\varphi 113\ \mathrm{mm}$. Furthermore, the average mixed flow rates and pure flow rates for gas extraction were more pronounced within the $\varphi 94\ \mathrm{mm}$ and $\varphi 113\ \mathrm{mm}$ borehole groups. Prior to the 20^{th} day of extraction, significant fluctuations in mixed flow rate were recorded for both; however, the pure flow rate of the $\varphi 113\ \mathrm{mm}$ boreholes demonstrated a rapid decline while still retaining a commendable level of extraction efficiency. Among the groups, the $\varphi 87\ \mathrm{mm}$ boreholes exhibited the lowest average mixed flow rate, with the $\varphi 75\ \mathrm{mm}$ borehole group recording the lowest average pure flow rate, thereby indicating the efficacy of larger borehole diameters in augmenting gas extraction efficiency.

3 Comparative Analysis of Gas Extraction Efficiency Across Borehole Diameters

3.1 Comparison of Gas Extraction Efficiency Across Borehole Diameters

In the comparative analysis of gas extraction efficiency across a range of borehole diameters within the Jiahe Coal Mine, the $\varphi 75\ \mathrm{mm}$ borehole group served as a baseline for examining the interplay between borehole diameter and two pivotal metrics: gas extraction concentration and cumulative pure flow rate.

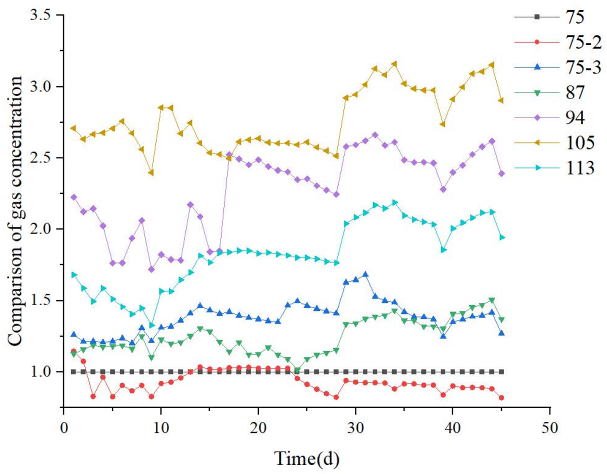

Figure 5. Comparison of gas extraction concentration

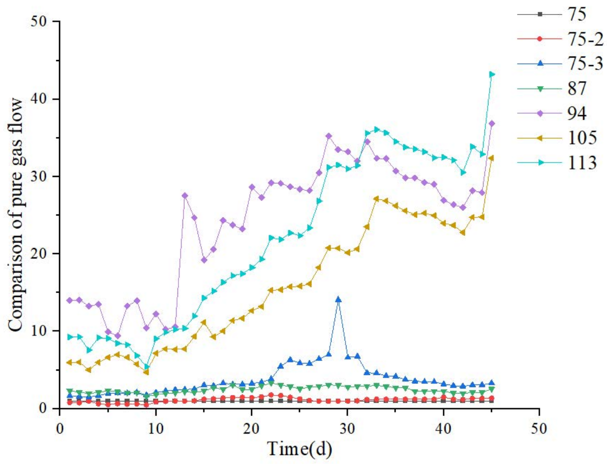

Figure 6. Comparison of pure gas flow rates

Figure 5 and Figure 6, derived from the core data on gas extraction, serve to visually articulate the differential outcomes in gas extraction efficiency as influenced by borehole diameter. These graphical representations provide insight into the variance in gas extraction concentration and pure flow rates among the studied borehole groups. The comparative results are presented in Table 3.

Table 3. Efficiency of gas extraction across diverse borehole groups under uniform gas occurrence conditions

Borehole Diameter (d/mm)	75	$75-2$	$75-3$	87	94	105	113
Concentration (Multiple)	1	1	1.4	1.3	2.4	2.8	1.8
Pure Flow Rate (Multiple)	1	1	3.5	2.5	37	18	25

Under homogeneous gas occurrence conditions, a pattern of similarity in average gas concentration trends was discerned across boreholes of varying diameters. Notably, the $\varphi 87\ \mathrm{mm}$ borehole group's concentration exceeded that of the $\varphi 94\ \mathrm{mm}$ and larger diameter groups, as evidenced by a comparative analysis between Figure 3 and

Figure 5. Conversely, under identical gas occurrence conditions, the gas concentration attributed to the $\varphi 87\ \mathrm{mm}$ borehole group was observed to be lower than that of the $\varphi 94\ \mathrm{mm}$ and larger diameter groups. This discrepancy underscores the propensity of larger borehole diameters to facilitate an enhancement in gas extraction concentration.

Further examination of Figure 4 and Figure 6 revealed a marked enhancement in the extraction efficiency of the $\varphi 94\ \mathrm{mm}$ borehole group. Despite the presence of shorter coal hole lengths in borehole diameters of $\mathrm{d} \geq 94\ \mathrm{mm}$ relative to those of $\mathrm{d} < 94\ \mathrm{mm}$, an elevated pure flow rate was recorded, suggesting an absence of correlation between the gas's pure flow rate and the coal hole length at the extraction site. Consistent with the conditions of gas occurrence, an augmentation in gas extraction efficiency was associated with the application of high negative pressure extraction and the utilization of larger borehole diameters. Specifically, the $\varphi 94\ \mathrm{mm}$ borehole group was distinguished by its superior extraction efficiency.

3.2 Comparison of Borehole Diameter Utilization Rates

To ascertain the relative contribution of various borehole diameters to gas extraction under uniform gas occurrence conditions, an analysis was conducted on the efficiency of gas extraction per millimeter of borehole diameter within a specified coal hole length. This analysis focused on two pivotal metrics: the concentration of extracted gas and the pure flow rate of gas extraction. The outcomes of this investigation are depicted in Figure 7and Figure 8, offering a visual representation of the concentration variation and pure flow rate variation per unit diameter, respectively. The synthesized data, providing a quantitative measure of gas extraction per unit diameter, are systematically presented in Table 4.

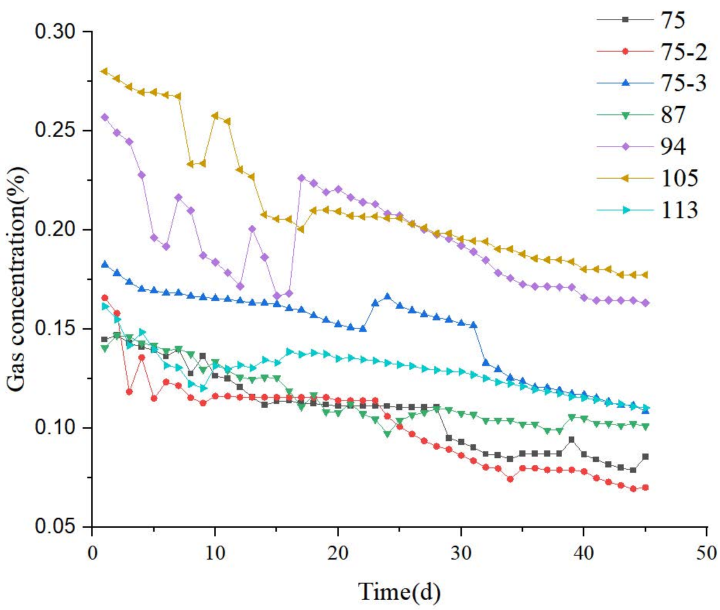

Figure 7. Variation curve of gas extraction concentration per unit diameter

Table 4. Gas extraction efficiency per unit diameter of borehole

Borehole Diameter $(\mathrm{d/mm})$	75	$75-2$	$75-3$	87	94	105	113
Concentration $(\%)$	0.108	0.102	0.149	0.116	0.194	0.213	0.129
Pure Flow Rate $(\mathrm{m^3/min})$	1.10×10^5	1.06×10^5	3.09×10^5	2.17×10^5	1.62×10^{-4}	8.04×10^5	1.04×10^{-4}

Analysis of Figure 7 reveals that the highest concentration of gas extraction per unit diameter was attained by the $\varphi 105\ \mathrm{mm}$ borehole group. Over the course of the study, the disparity in gas extraction concentration per unit diameter between the $\varphi 105\ \mathrm{mm}$ and $\varphi 94\ \mathrm{mm}$ borehole groups was observed to diminish after the initial 16 days.

Furthermore, Figure 8 demonstrates that the $\varphi 94\ \mathrm{mm}$ borehole group secured the maximum pure flow rate of gas extraction per unit diameter, effectively doubling the rate observed in the $\varphi 105\ \mathrm{mm}$ borehole group. Despite witnessing a marked reduction in the pure flow rate of gas per unit diameter over time, the $\varphi 94\ \mathrm{mm}$ borehole group maintained a position of superiority in comparison to other borehole groups. Consequently, under equivalent

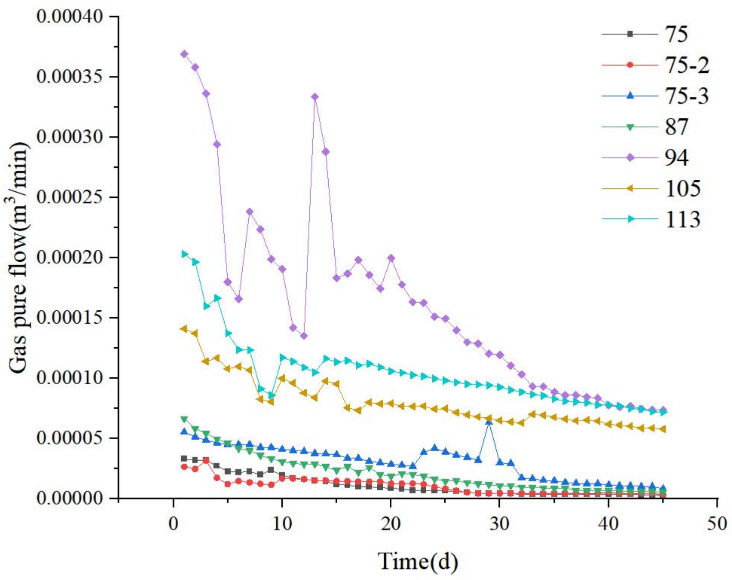

Figure 8. Variation curve of pure flow rate per unit diameter

conditions of gas occurrence, the extraction efficiency of the $\varphi 94$ mm borehole group was markedly superior, showcasing the highest utilization rate per borehole diameter among the groups analyzed.

3.3 Comparison of Gas Extraction Efficiency Across Borehole Diameters Per Unit of Negative Pressure

Accounting for the variations in extraction pressure observed across each borehole, an investigation was conducted to assess the efficiency of gas extraction among different borehole diameters under a range of negative pressures. The efficiency of gas extraction was quantified based on the negative pressure applied, with an analysis of the variations in gas concentration and pure flow rate per unit of negative pressure (1 Kpa) for the various borehole groups being undertaken. The outcomes of this investigation are depicted in Figure 9 and Figure 10, which illustrate the comparative analysis of average concentration and average pure flow rate, respectively. The comparative results of this study are succinctly tabulated in Table 5, presenting the gas extraction effects under identical extraction negative pressures across different borehole groups.

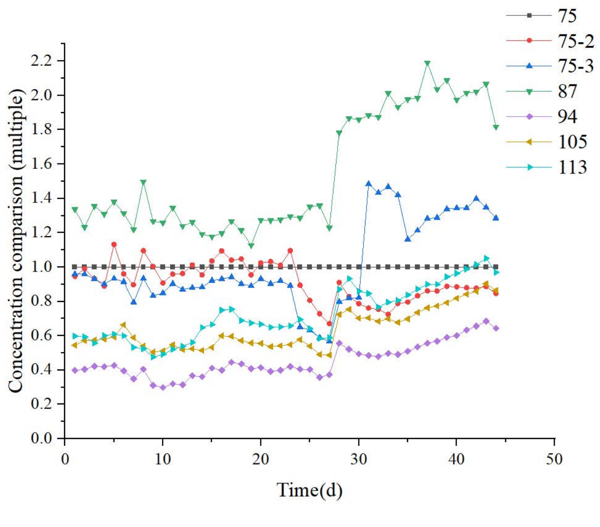

Figure 9. Comparative analysis of average concentration

Under the application of a unit of negative pressure, it was discerned from Figure 9 that the $\varphi 87$ mm borehole group exhibited the highest average concentration effect among the groups studied. Following closely, the $\varphi 113$ mm group demonstrated a commendable average concentration effect, while the $\varphi 94$ mm group's performance was noted to be lower, achieving only 90% of the extraction effect observed in the $\varphi 75$ mm group.

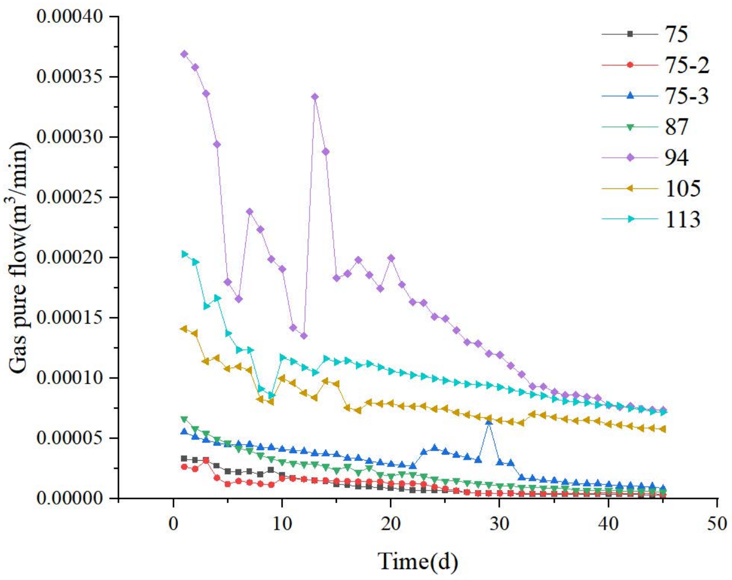

Figure 10. Comparative analysis of average pure flow rate

Table 5. Effects of gas extraction under uniform extraction negative pressure by different borehole

Borehole Diameter $(\mathrm{d/mm})$	75	$75-2$	$75-3$	87	94	105	113
Concentration (Multiple)	1	1	2	3	0.9	1.3	1.5
Pure Flow Rate (Multiple)	1	1	2.5	2.7	5	4.3	11

Figure 10 delineated a comparison where the $\varphi 113$ mm group's pure flow rate extraction effect was significantly superior to that of other groups, especially when compared to the $\varphi 75$ mm group. The pure flow rate extraction effect of the $\varphi 94$ mm group was also noteworthy, surpassing that of the $\varphi 87$ mm group in efficiency.

Through the analysis of variation curves pertaining to each borehole group's extraction effect, coupled with the comparative results under a single unit of negative pressure, several conclusions have been drawn. It was found that the gas flow rate for borehole groups with diameters $\mathrm{d} \geq 94$ mm surpassed those of groups with diameters $\mathrm{d} < 94$ mm. Conversely, the gas concentration for borehole groups with diameters $\mathrm{d} \geq 94$ mm was observed to be lower than that of groups with diameters $\mathrm{d} < 94$ mm. This phenomenon can be attributed to the fact that borehole groups with diameters $\mathrm{d} \geq 94$ mm were subjected to higher extraction negative pressures compared to the $\varphi 75$ mm and $\varphi 87$ mm groups, leading to increased leakage and subsequently lower gas concentrations in the larger diameter boreholes. Nonetheless, employing a suitably high extraction negative pressure has been recognized as conducive to enhancing gas extraction efficiency.

3.4 Utilization Rate of Borehole Diameter Per Unit of Negative Pressure

To explore the utilization rates of borehole diameters among different groups under uniform negative pressure conditions, with the objective of optimizing gas extraction efficiency while minimizing operational costs, an analysis was undertaken. This analysis evaluated the volume of gas concentration and pure flow rate extractable per millimeter of borehole diameter for each 1 Kpa of extraction negative pressure applied. The results of this study are depicted in Figure 11 and Figure 12, presenting the variation in gas concentration and pure flow rate per unit diameter, respectively. The compiled data, quantifying gas extraction per unit diameter of borehole, are methodically summarized in Table 6.

Table 6. Gas extraction efficiency per unit diameter of borehole

Borehole Diameter $(\mathrm{d/mm})$	75	$75-2$	$75-3$	87	94	105	113
Concentration $(\%)$	0.02	0.03	0.03	0.035	0.01	0.012	0.013
Pure Flow Rate $(\mathrm{m^3/min})$	3.67×10^{-6}	7.36×10^{-7}	1.72×10^{-6}	7.55×10^{-6}	6.83×10^{-6}	4.41×10^{-6}	1.07×10^{-5}

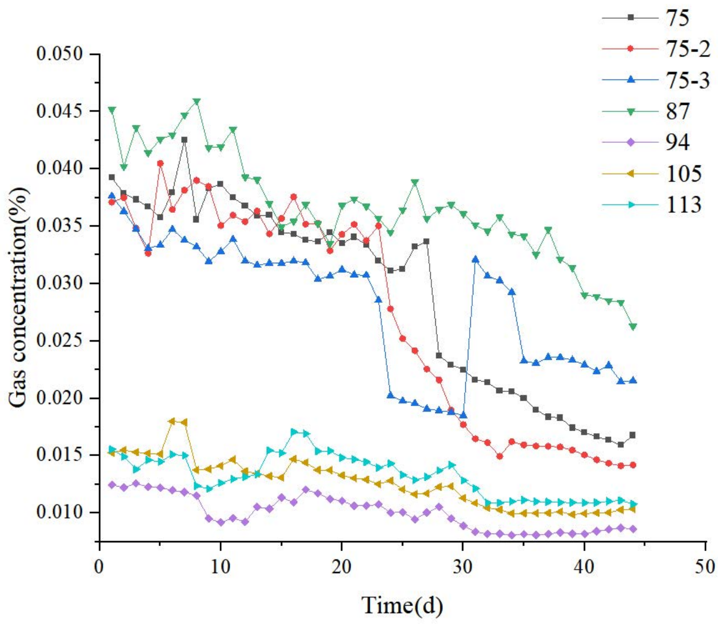

Figure 11. Variation curve of gas extraction concentration

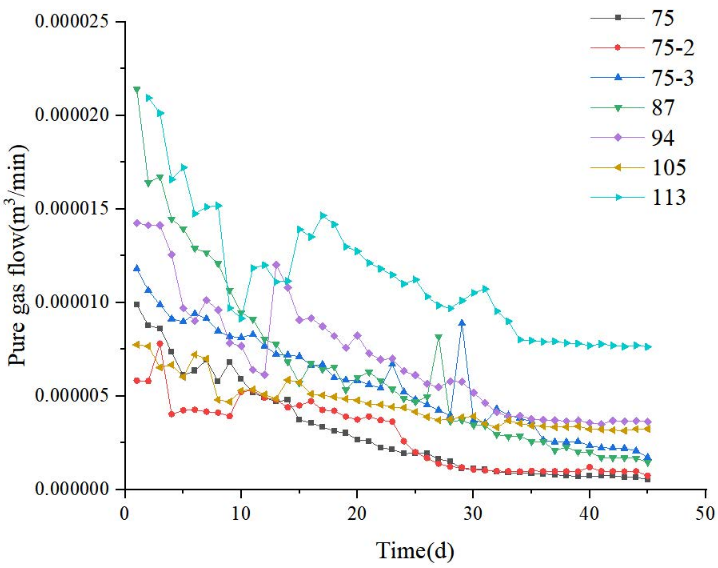

Figure 12. Variation curve of pure flow rate

As elucidated by Figure 11, under a negative pressure of $1\mathrm{Kpa}$, the highest gas concentration per unit diameter was achieved by the $\varphi 87$ mm borehole group, exhibiting a reduction rate of 48%. Conversely, the $\varphi 94$ mm group manifested the minimal concentration extraction effect, registering at 0.01%, with a negligible variance from the $\varphi 105$ mm and $\varphi 113$ mm groups, which displayed a reduction rate of 31%. The $\varphi 75$ mm group maintained a concentration around 0.02%, with a decrease rate of 24%; the $\varphi 105$ mm group at 0.012%, with a decrease rate of 30%; and the $\varphi 113$ mm group at 0.013%, with a decrease rate of 23%.

Figure 12 reveals that, under the same negative pressure of $1\mathrm{Kpa}$, the $\varphi 113$ mm group extracted the highest pure flow rate of gas per unit diameter, averaging $1.07 \times 10^{-5}\ \mathrm{m}^3/\mathrm{min}$, and witnessed a decrease rate of 62%. The $\varphi 94$ mm group's extraction rate stood at $6.83 \times 10^{-6}\ \mathrm{m}^3/\mathrm{min}$, with a decline rate of 74.5%, and the $\varphi 105$ mm group's rate was $4.41 \times 10 - 6\ \mathrm{m}^3/\mathrm{min}$, with a decrease rate of 57.2%. In comparison, the $\varphi 75$ mm and $\varphi 87$ mm groups attained lower pure flow rates per unit diameter under the same negative pressure, marked by a significantly steeper decline rate of 86%, indicative of less efficient extraction performance.

In conclusion, although the $\varphi 113$ mm borehole group demonstrated superior performance in terms of pure flow rate, analysis of gas concentration revealed lower concentrations for both the $\varphi 113$ mm and $\varphi 94$ mm groups compared to other diameters. This phenomenon is attributed to two principal factors: the observed gas extraction concentration parameters for the $\varphi 94$ mm, $\varphi 105$ mm, and $\varphi 113$ mm groups typically indicated lower concentrations relative to the smaller diameter groups, corroborating the premise that elevated extraction negative pressures engender diminished gas concentrations. Moreover, considering the construction locations of boreholes, the coal hole and sealing lengths for the $\varphi 113$ mm, $\varphi 105$ mm, and $\varphi 94$ mm groups were found to be shorter than those for the smaller diameter boreholes of $\varphi 75$ mm and $\varphi 87$ mm, potentially impacting the gas occurrence conditions. Furthermore, the abbreviated sealing lengths associated with these larger diameters may compromise gas tightness relative to the $\varphi 75$ mm and $\varphi 87$ mm groups, thus contributing to the reduced gas concentrations observed in larger diameter boreholes.

4 Determining the Optimal Borehole Diameter

In the evaluation of gas extraction efficiency across varying borehole diameters under identical environmental conditions and standardized units of negative pressure, it has been observed that borehole groups with diameters equal to or greater than 94 mm demonstrated superior performance. A focused examination was carried out on the efficiency of gas extraction for borehole diameters $\varphi 94$ mm, $\varphi 105$ mm, and $\varphi 113$ mm to ascertain the optimal diameter for gas extraction.

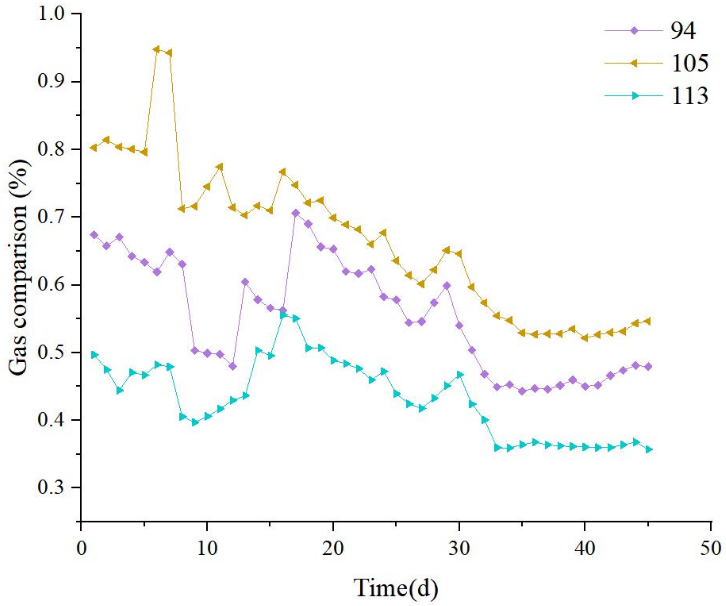

Figure 13. Variation curve of gas extraction concentration

Observations from Figure 1 indicated that the extraction negative pressures for borehole groups of diameters $\varphi 94$ mm, $\varphi 105$ mm, and $\varphi 113$ mm were substantially consistent, allowing for the exclusion of extraction negative pressure as a variable influencing extraction performance. To maintain uniform coal seam conditions across all seven borehole groups, an analysis centered on the variations in gas concentration and pure flow rate per unit of coal hole length was performed, as depicted in Figure 13 and Figure 14. The sequence of $\varphi 105\ \mathrm{mm} > \varphi 94\ \mathrm{mm} > \varphi 113\ \mathrm{mm}$ was established for gas concentration, whereas for pure flow rate, the order was determined as $\varphi 94\ \mathrm{mm} > \varphi 113\ \mathrm{mm} > \varphi 105\ \mathrm{mm}$. Consequently, under equivalent negative pressure and gas distribution conditions, the $\varphi 94$ mm borehole group was identified as exhibiting the most efficacious extraction performance. Although the $\varphi 105$ mm borehole group was characterized by a reduced presence of non-gas constituents and enhanced sealing properties, the $\varphi 94$ mm borehole group's pure flow rate markedly surpassed those of the $\varphi 105$ mm and $\varphi 113$ mm groups, establishing the $\varphi 94$ mm group as the most effective in terms of extraction efficiency.

5 Conclusion and Discussion

The examination of empirical data from seven borehole groups concerning gas extraction concentration and pure flow rate elucidates that an escalation in borehole diameter significantly enhances gas extraction efficiency. It has been observed that under uniform conditions of gas occurrence, the efficacy of gas extraction is augmented by employing high negative pressure techniques alongside larger borehole diameters. Notably, the borehole group with a diameter of $\varphi 94$ mm was distinguished as exhibiting superior performance, with its pure flow rate of gas extraction being 37 -fold higher than that of the $\varphi 75$ mm group, and its extraction concentration exceeding by a factor of 2.4 .

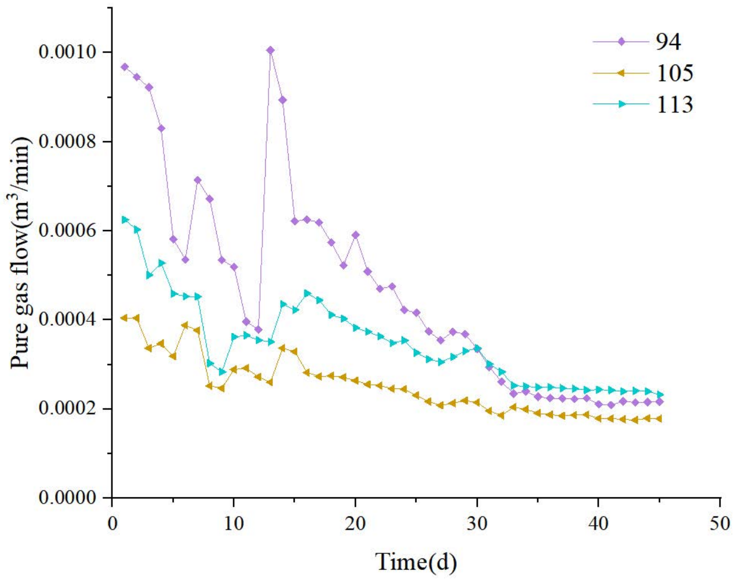

Figure 14. Variation curve of pure flow rate

In scenarios presenting identical gas distribution conditions, the $\varphi 94\ \mathrm{mm}$ borehole group was found to secure the highest average pure flow rate of gas extraction per unit diameter, achieving a rate of $4.67 \times 10^{-\ 4}\ \mathrm{m}^3/\mathrm{min}$ per $1\mathrm{KPa}$ of negative pressure per unit length of coal hole. Consequently, boreholes measuring $\varphi 94\ \mathrm{mm}$ in diameter have been identified as the most conducive for gas extraction, demonstrating optimal outcomes and efficiency in extraction processes. This study, however, did not incorporate the potential impacts of borehole wall collapse during drilling on gas extraction efficiency, which represents a limitation of the research presented.—

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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