Fuel 191 (2017) 486–494

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Technological aspects for underground coal gasification in steeply inclined thin coal seams at Zhongliangshan coal mine in China

Lin Xin [a,b], Zuo-tang Wang [c,d], Gang Wang [a,b], Wen Nie [a,b], Gang Zhou [a,b], Wei-min Cheng [a,b,*], Jun Xie [a,b]

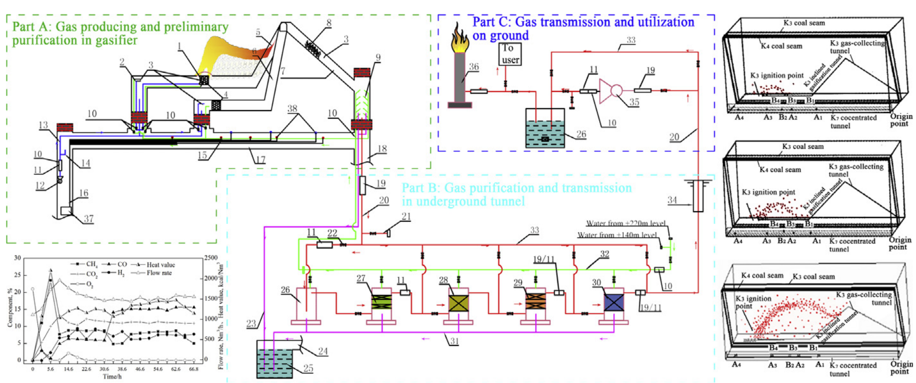
[a] College of Mining and Safety Engineering, Shandong University of Science and Technology, Qingdao, Shandong 266590, China
[b] Key Laboratory of Ministry of Education for Mine Disaster Prevention and Control, Shandong University of Science and Technology, Qingdao, Shandong 266590, China
[c] State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China
[d] Key Laboratory of Deep Coal Resource Mining, Ministry of Education, China University of Mining & Technology, Xuzhou, Jiangsu 221116, China

HIGHLIGHTS

- The hollow-bottom and wall-style gasifier and pinnate-pattern boreholes have been used.
- Two injection points were used for controlling the moving of flame work face.
- Multicomponent oxygen-rich was used to produce high calorific value gas.
- The combustion situation with an "S" form or arch shape was detected by micro-seismic detection system.

GRAPHICAL ABSTRACT

The hollow-bottom and wall-style gasifiers and pinnate-pattern boreholes have been used, and the controlled moving multipoint injection technology, gasification technology of multi-component oxygen-rich gasification agent and micro-seismic detection technology for flame working face have been carried out for the monitoring and control of combustion gasification, gas production and running state of gasifiers.



ARTICLE INFO

Article history:
Received 15 August 2016
Received in revised form 24 November 2016
Accepted 26 November 2016

Keywords:
Underground coal gasification
Coal
Oxygen-rich gasification agent
Hollow-bottom and wall-style gasifiers
Micro-seismic detection

ABSTRACT

In order to recover the abandoned coal resource of steeply inclined thin coal seams (SITCS), a field trial of underground coal gasification (UCG) with shaft method has been successfully carried out at Zhongliangshan coal mine in China. Many technological measures have been taken according to the geological conditions of coal seams. These technologies include the hollow-bottom and wall-style gasifiers, pinnate-pattern boreholes, the controlled moving multipoint gas injection, multi-component oxygen-rich gasification agent, and micro-seismic detection of flame working face. Some of the technologies were used for monitoring and controlling the UCG process, including gas-producing conditions and gasifier running states. The trial results show that it's feasible to recover the abandoned coal resource and produce clean gas energy. The gaseous product of gasification consists of 5–10% H_2, 14–16% CO and 5–8% CH_4 and generated at a flow rate of 1400–1600 Nm^3/h with a heat value of 1200–1400 $kcal/Nm^3$.

* Corresponding author at: Key Laboratory of Ministry of Education for Mine Disaster Prevention and Control, Shandong University of Science and Technology, Qingdao, Shandong 266590, China.
E-mail addresses: xinlincumt@cumt.edu.cn (L. Xin), cumtucgztwang@163.com (Z.-t. Wang), gang.wang@sdust.edu.cn (G. Wang), sdniewen@163.com (W. Nie), ahsdzhougang@163.com (G. Zhou), wmcheng@sdust.edu.cn (W.-m. Cheng), mrxie998@163.com (J. Xie).

http://dx.doi.org/10.1016/j.fuel.2016.11.102
0016-2361/© 2016 Published by Elsevier Ltd.

1. Introduction

Underground coal gasification (UCG) is a mining technology with which coal is gasified in a manually controlled manner under in-situ conditions to produce gas. It converts the useful components in coal (such as fixed carbon and volatile component) into gas fuel (such as CO, H_2, CH_4 and other hydrocarbons) by controlling the combustion between underground solid coal with gasification agent (such as O_2 and H_2O). The gas fuel can then be used for power generation, hydrogen production or feed gas synthesis (such as synthetic natural gas and synthetic oil) [1–5]. This technology was initially developed and applied in industry by the former Soviet Union in 1930s, and since around 20 countries, such as USA, Western Europe, Australia, China, Canada, India and South Africa, have conducted hundreds of industrial experiments and commercial demonstrations [6–9]. UCG has several safety, economic and environmental benefits over conventional coal mining and surface-based gasification methods – increased worker health and safety, no surface disposal of ash and coal tailings, low ash residues and fugitive emissions, low dust and noise pollution, low carbon emissions with carbon capture and storage [10,11], zero coal transport cost, zero coal handling cost, high coal reserve recovery ratio [7,12–15]. Nowadays, with more strict environmental requirements associated with excessive consumption of coal and high demands for alternative clean energy sources, UCG attracts strong interest in many countries, especially in China [16]. The low carbon economy is developing rapidly in China in recent years. As an important supplement to the traditional mining technologies, UCG can open up a new way for clean, safe and efficient coal mining, especially for exploitation and utilization of low-rank coal resources, abandoned coal resources and deep coal resources, it will promote the development of key industries such as coal and chemical engineering and will be a new economic growth point [17,18].

China learnt UCG technology of tunnel blasting method from the former Soviet Union in 1950s and set up 16 UCG experiment points in Shanxi and Anhui provinces during 1958–1962. Since 1984, Yu [19] in China University of Mining and Technology pioneered a new UCG technology called ‘long-tunnel, large-section, and two-stage UCG’ and conducted many field tests with the technology [4,18,20–22]. Since the 21st century, with further technological innovation and field trials, two kinds of UCG technologies, i.e. well-type [23–25] and well-less-type [26,27] gradually become dominant, and both of them have laid a solid technical foundation for industrial demonstration.

A key to a successful UCG technology is to control the combustion gasification, combustion space area extension [28,29] and surrounding rock stability. Improper control will cause low gas quality, gas leakage, groundwater influx and pollution; even worse, it will lead to coal fire spreading out of control, large area of subsidence and harmful gas escape which will bring serious economic and ecological damage. Therefore, the UCG trial was conducted to optimize the gasifier structure, combustion gasification and process control appropriate to the geological conditions of coal seams.

In Zhongliangshan (ZLS) coal mine, due to the conditions of high seam gas content, serious coal-gas outburst proneness, and seam steepness and thinness, about 25 Mt abandoned coal resources are not minable by the conventional mining method due to the technical and economic issues. In order to improve the utilization of coal resources and meet the needs of clean gas energy, Chongqing Zhongliangshan Coal-Electricity-Gas Co., Ltd., the owner and operator of ZLS mine, intends to develop a clean utilization method of abandoned coal resources by UCG technology. This paper describes a field trial of UCG at ZLS coal mine which was conducted from June to September 2005. The paper focuses on the technological aspects, experiment process, gas production and operating characteristics. The trial explores a new way of SITCS mining and clean utilization by UCG, it also provides a way for abandoned coal mining through UCG with similar geological conditions.

2. Experimental

2.1. Geological conditions at ZLS coal mine

The surface elevation of ZLS gasification area is approximately +600 m, and the coal seams are located in +150 m level or 450 m below the surface ground. In the trial area, there are totally six coal seams (K_1, K_2, K_3, K_4, K_5 and K_7) with the inclination of 65–70°. The coal seams K_1 and K_2 have been mined out without goaf water. There are two large faults F_0 and F_{10} above and on the west side of the trial area. In this trial, the proposed coal seams for gasification are K_3 and K_4 with the thickness of 1.15 m and 1.45 m respectively, the roof of K_3 is mudstone and its floor is clay rock, while the roof of K_4 is siltstone and its floor is clay rock. The geological structure of gasification trial area is shown as Fig. 1.

According to the proximate analysis and ultimate analysis of raw coal at ZLS coal mine (see Table 1), the coal of K_3 and K_4 are coking coal with the characteristic of medium ash, medium sulfur, low volatile and high ash melting point and weak caking property.

2.2. UCG production system and technological aspects

The trial had excellent production and monitoring systems (see Fig. 2), mainly including gas production and preliminary purification system in underground gasifiers (Part A in Fig. 2), gas purification and delivery system in tunnel (Part B), gas transportation and utilization system on ground (Part C) and the gasification process monitoring system. In order to produce good quality gas and control the gasifiers effectively, a series of technical measures on gasifier structure design, gas injection and exhaust control, gasifying agent proportion and gasifier monitor have been taken.

For the seam conditions at ZLS coal mine, the underground gasifiers were constructed with several tunnels and pinnate boreholes. The multi-component oxygen-rich gasification agent (MOGA) was

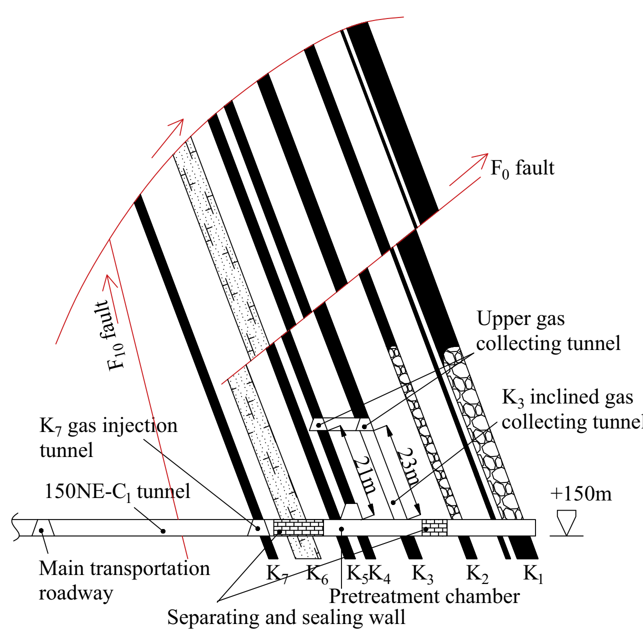


Fig. 1. Geological structure of gasification trial area.