Fuel 185 (2016) 468–477

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Experimental study on sonic vibrating effects of cavitation water jets and its promotion effects on coalbed methane desorption

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HIGHLIGHTS

- A technique method based on sonic vibrating effects to promote methane desorption was proposed.
- The sonic vibrating effects of cavitation water jets can cause mechanical vibration and thermal effects.
- The mechanical vibration effect played a dominant role in promoting the methane desorption.
- The sonic vibrating effects had an obvious accelerating impact on coalbed methane desorption.

ARTICLE INFO

Article history:
Received 5 June 2016
Received in revised form 31 July 2016
Accepted 1 August 2016
Available online 8 August 2016

Keywords:
Cavitation water jets
Sonic vibrating effects
Promotion of methane desorption
Mechanical vibrating effect
Thermal effect

ABSTRACT

To enhance the desorption of coalbed methane and increase the efficiency of gas extraction, a technique method based on the sonic vibrating effects of cavitation water jets to promote methane desorption is proposed. With proper devices, we conduct an experiment of using sonic vibrating effects of cavitation water jets to accelerate methane desorption. This is based on experiment tests on the mechanical vibration and thermal effects caused by the sonic vibrating effects. During the collapse phase of cavitation bubbles, the strong sonic vibrating effects may cause intense mechanical vibration and thermal effects. The vibration acceleration root-mean-square value presents an approximate positive linear correlation with the total volume of methane desorption. The mechanical vibration effect plays a dominant role in promoting the methane desorption, while the facilitation of thermal effect is relatively weaker. There is an obvious accelerating impact of sonic vibrating effects on coalbed methane desorption and the ultimate methane desorption volume increases by from 13.4 to 42.1% respectively, while desorption time shortens by between 12.5 and 21.5%. The study results bear an important significance on revealing the mechanism of promoting the methane desorption by sonic vibrating effects and field application of the technique method to CBM development.

1. Introduction

CBM (coal-bed methane) which is a clean, cost-efficient and environmentally friendly energy, has gradually become an important viable alternative source to conventional fuel. As an unconventional gas resource and strategic reserve resource, CBM is attracting increasing attention worldwide [1,2]. Among the abundant coalbed methane resources on earth, the America has the largest volume (3017×10^{12} m^3) and the greatest output (over 1.91 TCF of gas sold in 2009). It is estimated that China has a quantity of 36.8×10^{12} m^3 in CBM resources buried 2000 m under the ground. By the end of 2014, the quantity of proved reserves had surpassed 6200×10^8 m^3 and 10 CBM development projects had been activated with an output of 57×10^8 m^3 each year in China.

The key component of CBM is methane that takes shape during the coal-forming process and exists in coalbed in an adsorption and unbound state [3]. The CBM reservoir character is fundamentally different from that of conventional gas reservoir [4]. CBM reservoirs are dual porosity systems consisting of coal matrix, pores and fracture network [5]. In the reservoirs, coalbed methane is adsorbed mostly in micropores (pore diameter < 2 nm) of matrix, accounting for over 90% of the total CBM reserves, while only a small amount contributing less than 10% is stored in pores and fracture systems as free gas and solution gas [6].

For adsorbed state methane in the reservoir, only after being changed into unbound state through desorption can it be extracted

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http://dx.doi.org/10.1016/j.fuel.2016.08.024
0016-2361/

with the help of exogenic action. Increasing the desorption rate and desorption volume of coal gas is of vital importance to improve the extraction rate of coalbed methane. Study shows coalbed methane desorption is mainly affected by factors of coalmass structure (component: moisture, ash content, pore structure) [7,8] gas characteristic parameters (gas content, coalbed pressure) [9,10] external environmental conditions (gas component, temperature, stress field, electric field and acoustic field) [11–13]. Based on these factors, and to promote the coalbed methane desorption and increase the CBM extraction efficiency, many methods have been put forward, mainly including hydraulic cutting seam [14], hydraulic fracturing [15,16], gas injection [17–19], blasting vibration [20] and physical field (electric filed, temperature field, emagnetic field, acoustic field, etc.) excitation [21–23].

For the methods of increasing the CBM output, hydraulic cutting and fracturing, because of their such strengths as technical maturity of equipments, wide field application and strong anti-reflection capacity, have been widely applied in the CBM development in China. Lu et al. [24] has not only established a fluid-solid coupling model for CBM seepage of low permeability by high-pressure water jet cutting, but also verified its engineering adaptability. It is reported that the hydraulic slotted bore gives a gas concentration three times higher and has a more effective range twice as long as conventional techniques [25]. The research of Huang et al. [26] shows that the permeability of gassy coal seams can be improved by hydraulic fracturing, which can form a network of original joint cracks, hydraulic wing cracks, and main hydraulic cracks in the coal seams. Yan et al. [27] demonstrates a novel ECBM (enhanced coal-bed methane) extraction technology which is a very promising method for improving the effect of the CBM extraction and the technology joins the hydraulic slotting and hydraulic fracturing together.

While applying the hydraulic cutting for CBM extraction, we notice that the methane desorption speed and volume can be greatly increased, and the extraction efficiency also being improved by using cavitation water jets to shock and cut coal mass. Based on the special sonic vibrating effects of cavitation water jets, we put forward an idea of using sonic vibrating effects to promote the methane desorption and increase the extraction efficiency [28]. Sonic vibrating effects of cavitation water jets are able to trigger strong mechanical vibrating and thermal effects, giving itself a unique advantage in promoting coalbed methane desorption. What's more, it is very easy to produce cavitation water jets. The slots of drilling and cutting in the coalbed bear the function of cavitation chamber. If certain flow, pressure and jet range conditions exist, cavitation nozzle can produce a cavitation jet of high efficiency.

So far, there is still limited study on speeding up the methane desorption with sonic vibrating effects of cavitation water jets [29,30]. For this reason, we conducted an experiment test to study the mechanical and thermal effects caused by sonic vibrating effects. Later, a following experiment on promoting the methane desorption by using the sonic vibrating effects was conducted.

2. Cavitation phenomenon of high-pressure water jets and sonic vibrating effects

2.1. The occurrence of cavitation phenomenon

In the natural fluid, there are large quantities of microscopic bubbles whose diameter is 10^{-3}–10^{-4} cm, which is called gas nucleus or cavitation nucleus in technical terms. Should temperature remain constant, cavitation nucleus will generate tiny cavities while expanding if the pressure intensity of some part of the fluid decreases to or below one certain critical value and we call these global cavities cavitation bubbles. The bubbles, upon their birth, will continuously expand with the extension of time, but later on compressed when the pressure of fluid around goes up, and collapses finally. The non-condensing permanent gas in small numbers in the bubbles will enable them to stand the collapse for a while, during which several rounds of compression and rebounding takes place alternately until its final collapse. The whole process of the bubbles' coming into being, expansion, growth, contraction and collapse is called cavitation phenomenon.

2.2. Cavitation sonic vibrating effects

The collapse of the bubbles around the surface of target objects is able to cut and break the targets. The powerful impact force of the collapse will strengthen the water jets effects. In the collapse process of the bubbles emerges 5000 K high temperature and 500 atmospheric partial high pressures, with which also comes strong shock wave and high-speed microjet. There are large numbers of cavitation bubbles, whose birth, development and collapse phases all contribute to producing sonic vibrating effects. The sound radiation in the process can be generally grouped into pulsation source (monopole) type, which is the most effective source of sound radiation. Cavitation bubbles have a fairly large volume pulsation rate in the period between closing to the minimum radius and the minute of collapse. Although the volume of the cavitation bubbles is small in the collapse phase, the sound pressure of radiation is huge, which explains why the sonic vibrating effects in the collapse phase are the strongest. Because cavitation water jets will lead to strong cavitation sonic vibrating effects, when these jets impact the target surface, a violent energy transmission will take place, generating a strong mechanical vibration of the target and raising the temperature. These are the mechanical vibrating and thermal effects caused by sonic vibrating effects of the cavitation water jets.

3. Experimental method

3.1. Experimental device

3.1.1. Test device for mechanical vibrating and thermal effects

The test device consists of hydraulic pump system, main test system, data acquisition and analysis system. As shown in Fig. 1, the hydraulic pump system is the power source of cavitation water jets and it is mainly composed of a high-pressure pump, a water tank, a pressure maintaining valve, an overflow valve and a pressure gauge. The main test system which is made up of a cavitation cavity, a cavitation cavity base, a cavitation nozzle, a vibration acceleration sensor and 3 temperature sensors, provides an envi-

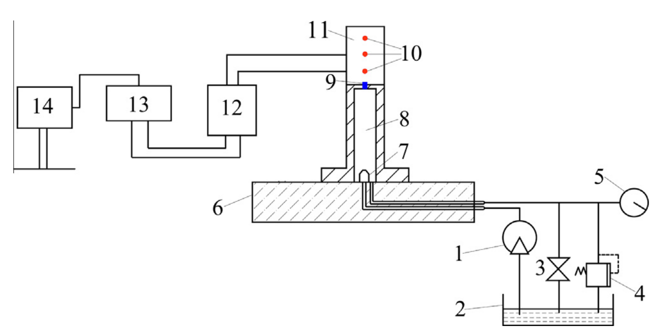

Fig. 1. Test device for sonic vibrating and thermal effects. 1 - Hydraulic pump; 2 - Water tank; 3 - Pressure maintaining valve; 4 - Overflow valve; 5 - Pressure gauge; 6 - Cavitation cavity base; 7 - Cavitation cavity; 8 - Cavitation nozzle; 9 - Acceleration sensor; 10 - Temperature sensor; 11 - Coal specimen; 12 - Signal receiver; 13 - Smart signal processor; 14 - Electronic computer.