INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 40 (2015) 3381–3387

Available online at www.sciencedirect.com

ScienceDirect

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

Catalytic oxidation of coal mine ventilation air methane in a preheat catalytic reaction reactor

Bin Zheng [1], *Yongqi Liu* *, *Ruixiang Liu*, *Jian Meng*

Shandong University of Technology, School of Transportation and Vehicle Engineering, 255049, China

ARTICLE INFO

Article history:
Received 23 November 2014
Received in revised form
2 January 2015
Accepted 6 January 2015
Available online 28 January 2015

Keywords:
Lean-methane
Preheat catalytic reaction reactor
Catalytic oxidation
Methane conversion rate

ABSTRACT

The results of experimental investigations on catalytic oxidation of coal mine ventilation air methane in a preheat catalytic reaction reactor is presented in this paper. The experimental system was located in the Energy Research Institute of Shandong University of Technology, which has been applied to investigate the effects of startup conditions such as the startup flow coefficient (0.3–0.5) and the startup power (10 kW–20 kW) on the startup process within the preheat catalytic reaction reactor. The average temperature distribution of catalytic oxidation bed and the minimal startup power were measured and the effects of operating conditions such as the space velocity (2600 h^{-1} to 11,500 h^{-1}) and the methane concentration (0.8%–1.2%) were experimentally investigated. Moreover, the methane conversion rate and the average temperature of the catalytic oxidation bed were discussed and the critical space velocity value and the critical methane concentration value were determined.

Introduction

Coal mine methane emissions make up approximately 8% of the world's anthropogenic methane emissions, and the quantity of methane emissions from coal mining alone is over 25 million tons every year. Roughly 70% of methane emissions come from coal mine ventilation air methane (VAM), which is not only a greenhouse gas but also a wasted energy resource if not utilized. As a greenhouse gas, CH_4, which (17%) is the second largest contributor to global warming after CO_2 (55%), is over 21 times more effective at trapping heat in the atmosphere than carbon dioxide over a 100-year period. As the air volume is large and the methane resource is diluted and varies in concentration and flow rate, ventilation air methane is the most difficult source of CH_4 to be used as an energy source. Because methane concentration in coal mine ventilation air is usually below 1 vol.% [1], the combustion of lean methane–air mixtures combined with the recovery of the heat of reaction is an important problem for the mining industry.

A number of studies have been conducted to determine the most efficient way to utilize this lean methane via combustion as well as to recover the energy thus produced. Due to the pretty low CH_4 concentrations, the most promising solution seems to be auto thermal combustion in reverse-flow reactors. So far, most studies have focused on catalytic

* *Corresponding author*. School of Transportation and Vehicle Engineering, Shandong University of Technology, Zhangzhou Road 12, Zibo 255049, China. Tel.: +86 533 2782616 (office), +86 13969353396 (mobile); fax: +86 533 2782616.
E-mail addresses: sdutzb@163.com (B. Zheng), sdutliu@163.com (Y. Liu).
[1] School of Transportation and Vehicle Engineering, Shandong University of Technology, Zhangzhou Road 12, Zibo 255049, China. Tel.: +86 533 2782616 (office), +86 13665334629 (mobile); fax: +86 533 2782616.
http://dx.doi.org/10.1016/j.ijhydene.2015.01.020

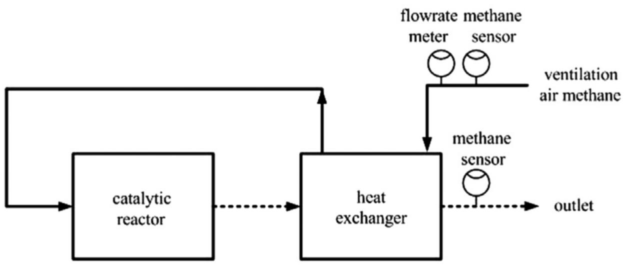

Fig. 1 – Preheat catalytic reaction reactor operating principle and experimental schema.

combustion in catalytic flow-reversal reactors (CFRRs) and thermal flow-reversal reactors (TFRRs). The earliest attempt at ventilation air methane (VAM) combustion in CFRR was supposedly carried out at the Boreskov Institute of Catalysis. At present CANMET in Canada is the most advanced in terms of the development of the technology of lean air–methane mixtures combustion [2,3]. Pablo [4] systematically compared the performance of particle beds and monolithic beds in catalytic reverse flow reactors. Shi [5] classified the existing technologies for coal mine methane mitigation and utilization. Tischer [6] developed transient two- and three-dimensional simulations of catalytic combustion monoliths. Shahamiri [7] developed a one-dimensional model to investigate the effects of operational conditions on CFRR. The authors in Refs. [8,9] studied the combustion of preheated lean mixtures of hydrogen with methane in a catalytic packed-bed reactor. Some investigations [10,11] carried out a comparative assessment of TFRR and CFRR. It has been shown that both solutions have advantages and drawbacks. Dobrego [12,13] and Jeon [14] studied the combustion of lean methane in a reverse flow reactor. TFRRs is regarded as an attractive alternative in a number of articles [15–18]. Such reactors have long been employed, e.g. for the homogeneous (thermal) combustion of volatile organic compounds (VOCs) [19].

The common characteristic of CFRRs and TFRRs is reverse-flow in reactors. The drawbacks of their reactors are as follows:

(1) The device occupies a large area because the reactor is packed with a large number of ceramic monolith blocks.
(2) After a long time operation, a high maintenance cost is needed due to the damage of ceramic monolith blocks.
(3) The pressure drop is high and more energy is required to supply ventilation air methane.
(4) The control machine of the time-varying airflow direction is quite large and complex, and as a result, the control system is really complex.

This paper presents a preheat catalytic reaction reactor to catalytic oxidation coal mine ventilation air methane [20]. The reactor adopts a new working principle and different CFRRs and TFRRs, which isn't reverse-flow. The employment of a preheat catalytic reaction reactor for the catalytic oxidation of lean methane mixtures therefore requires detailed studies to determine the reasonable startup and operating conditions. The objective of the present study is to investigate the effects of key operational parameters on startup and catalytic oxidation processes within the preheat catalytic reactor, including the effect of fuel composition. It can be used to gain much needed data for preheat catalytic oxidation operations when employed in industry.

Operating principle

A schematic diagram of the preheat catalytic reaction reactor being considered in the experiment is shown in Fig. 1. VAM flows into the heat exchanger, where it is heated by high temperature flue gas from the catalytic reactor until it reaches the temperature of methane catalytic oxidation. Then preheated VAM flows outlet from the heat exchanger, and flows into the catalytic reactor, where VAM is catalytic combusted. The high temperature flue gas from catalytic reactor flows into the heat exchanger to preheat VAM, then the cooled flue gas is emitted into the atmosphere.

Experimental reactor system

Tests of methane catalytic oxidation were carried out in a preheat catalytic reaction reactor built at the Energy Research Institute of Shandong University of Technology. A general view of the experimental apparatus is shown in Fig. 2, while a simplified flowsheet of the apparatus is given in Fig. 3.

The designed rated flow rate of the experimental system is 1000 $Nm^3\ h^{-1}$. The experimental system is divided into six parts: the gas supply system, the parameter acquisition system, the startup system, the gas composition analysis system, the heat exchanger and the catalytic oxidation bed. A schematic diagram of the experimental apparatus is shown in Fig. 3. Mine ventilation air used in the experiment was a mixture of air and natural gas, of which the CH_4 purity is 99.9%. Compressed air from the air compressor through the gas regulating valve and pressure-relief valve mixes with the methane from methane cylinder in the mixer, which is then

Fig. 2 – General view of the research & demonstration preheat catalytic reaction reactor apparatus.