

# **INTRODUCTION OF CATALYTIC FLOW-REVERSAL REACTOR (CH4MIN) TECHNOLOGY AND ITS POTENTIAL IN CHINA COAL MINES**

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## **ABSTRACT**

In 1995, researchers at Canadian Mineral and Energy Technologies (CANMET) in Varenes, Quebec, Canada, conceived and developed the CH4MIN technology exclusively for the treatment of methane in coal mine ventilation air. The development comprised computer simulations, large pilot-scale trials and catalyst compatibility tests at the Phalen coal mine (Nova Scotia, Canada).

With its catalyst, CH4MIN technology reduces the auto-ignition temperature of methane by several hundred degrees Celsius (i.e. to as low as 350°C). A regime of operation at a low temperature can process economically large flow of dilute (0.1 – 1.0 % v/v) of methane emissions, while recovering up to 90% of the reaction heat as a high-quality hot air stream at 600-800°C.

This paper gives an in-depth introduction of CH4MIN technology: process principle and prospect of potential thermal energy recovery and utilization. In addition, the paper also examines the project economic viability of using CH4MIN reactors in China coal mines, and different scenarios of project revenue streams and financing options. Finally, the paper outlines the future prospect of commercializing CH4MIN technology and potential of deploying CH4MIN technology in China.

## **1.0 INTRODUCTION**

Methane is a greenhouse gas, approximately 21 times more harmful than carbon dioxide in terms of causing global warming over a 100-year period [IPCC, Climate Change 2001 [1]]. In terms of anthropogenic gas that enhances the greenhouse effect, methane is 2<sup>nd</sup> (17%) after carbon dioxide (55%) as a contributor to global warming. Except coalbed methane, which is concentrated at 50–90% (v/v) methane in air, the underground coal mines around the world release ventilation air containing methane at concentrations generally below 1.0 percent, which is defined as ventilation air methane (VAM). With few exceptions, the mines operators allow the release of methane to the atmosphere without attempting to capture and use it. Methane emissions from mine ventilation air comprise the largest portion (about 70%) of all Coal Mines Methane (CMM) liberated worldwide [USEPA (2002) [2]]. World total VAM emissions estimated at year 2000 were 15.2 Billion m<sup>3</sup> or 211

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Mt<sub>equiv.</sub> CO<sub>2</sub>/y (Million metric tons of equivalent CO<sub>2</sub> per year) [USEPA (2002a) [3]]. In light of ever-increasing pressure for reducing GHG emissions and meeting the reduction targets set in the Kyoto Protocol, reducing VAM emissions is becoming a very important task in the 21st century.

The CH<sub>4</sub>MIN technology was developed exclusively for use on treatment of methane in coal mine ventilation air. With its catalyst, the CH<sub>4</sub>MIN technology reduces the auto-ignition temperature of methane by several hundred degrees Celsius (i.e. to as low as 350°C). It provides a great potential for the use of VAM as a principal fuel source because the technology is able to oxidize diluted methane in coal mine ventilation air and produce useable energy from heat exchangers operating at an optimal temperature. Consequently, the new technology not only provides a feasible solution to eliminate methane in ventilation air, but also could generate value through recovered energy (hot air, water and steam) during the process.

## **2.0 CH<sub>4</sub>MIN OPERATING PRINCIPLES**

The schematic of a typical CH<sub>4</sub>MIN process is shown in Figure 1. It consists of a reactor, two pairs of valves and a heat removal system in the central region separating the catalyst bed in two parts. At both ends of the reactor, an inert material bed is present and acts as a thermal accumulator. Flow reversal is controlled by the two sets of valves. During the first half-cycle, the methane-air mixture, which is originally at ambient temperature, is heated as it passes through the upper inert bed. It enters the upper catalyst bed at a temperature sufficient for exothermic methane oxidation to occur, which produces heat in the reactor. The stream then passes through the lower catalyst bed and finally heats the lower inert bed before exiting to atmosphere. During this first half-cycle, the upper part of the reactor, which was initially hot, cools down, while the lower part, which was initially cool, heats up. After a certain period of time, the flow direction is reversed by inverting the position of the valves in order to use the heat available in the lower inert bed. At the end of the second half-cycle, downward flow is re-established. The heat generated in excess by the exothermic chemical reaction is withdrawn by the heat removal system in the mid-section of the reactor.

## **3.0 NUMERICAL SIMULATION AND EXPERIMENTATION**

A mathematical model and computer programs were developed for the study and design of CH<sub>4</sub>MIN reactors. A transient two-dimensional heterogeneous model is combined with a numerical method allowing the fast formulation of new reactor designs, [Aube and Sapoundjiev, 2000, [4]]. The program has been validated with experiments performed with a 500-mm reactor. The comparisons between the experimental data (circles) and predictions by the model (lines) are shown in Figure 2(a-d). Good agreement with the experiments was observed. The dynamic behaviour of the CH<sub>4</sub>MIN can be predicted accurately by the model for a wide range of conditions including small reactor diameter and low air flow rate.

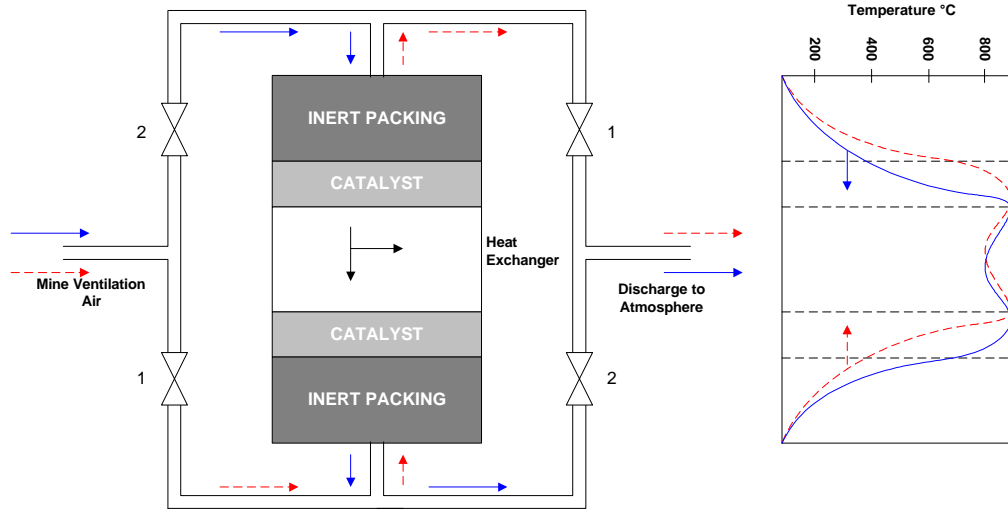


Figure 1. Flow diagram of the CH4MIN technology

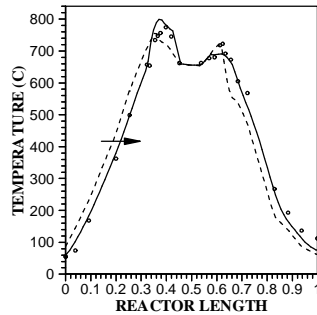


Fig. 2 (a): beginning (---) and end ( $\circ, \frac{3}{4}$ ) of the first semi-cycle.

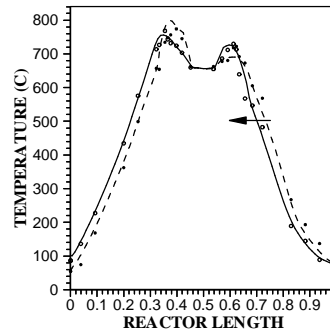


Fig. 2 (b): beginning (---,  $\cdot$ ) and end ( $\circ, \frac{3}{4}$ ) of the second semi-cycle.

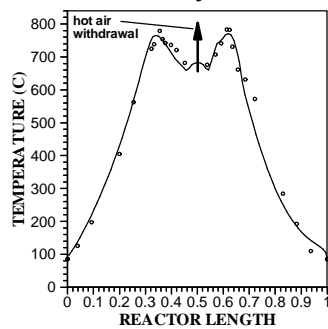


Fig. 2 (c): temperature profile along the reactor length after 10 cycles.

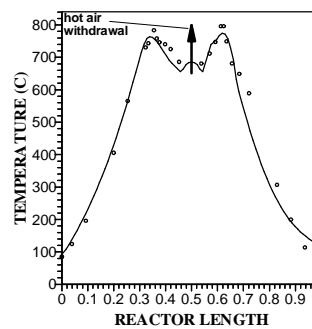


Fig. 2 (d): temperature profile along the reactor length after 15 cycles.

Figure: 2 (a-d) Temperature profiles along the reactor length and time evolution of the temperature distribution in the reactor. Experimental results (circles) and prediction by the model (lines). Methane concentration 0.3 v/v %.

#### 4.0 HEAT RECOVERY EFFICIENCY AND BENEFITS

The heat recovery efficiency of the CH4MIN technology, based on experimental results is illustrated in Figure 3 as a function of methane concentration. Results show that the reactor operates in autothermal regime (with no need for external heat) even when the methane concentration is as low as 0.1% v/v. Significant heat recovery is possible at higher concentrations. For concentrations between 0.3 and 1.0% v/v of methane, the heat recovery efficiency of the CH4MIN technology is between 50 and 95%. For a typical coal mine concentration, 0.5% v/v of methane, the efficiency is 75%.

The benefits of CH4MIN technology are shown on base of single mine. The calculations were performed using a flow rate of 100 m<sup>3</sup>/s of coal mine ventilation air at 0.5% v/v of methane. In the current situation, mine ventilation air is rejected to the atmosphere. The greenhouse gas emissions are equivalent to 238 kilotons of CO<sub>2</sub> per year. Gases rejected to the atmosphere contain a large amount (17.9 MW or 560 GJ/y) of potential thermal energy, which is not utilized. The proposed treatment of this mine ventilation air with the CH4MIN technology provides the following benefits: heat recovery: 14 MW<sub>therm.</sub> or 425 000 GJ<sub>therm.</sub>/ year and reduced greenhouse gas emissions: 208 kilotons equivalent CO<sub>2</sub>/year.

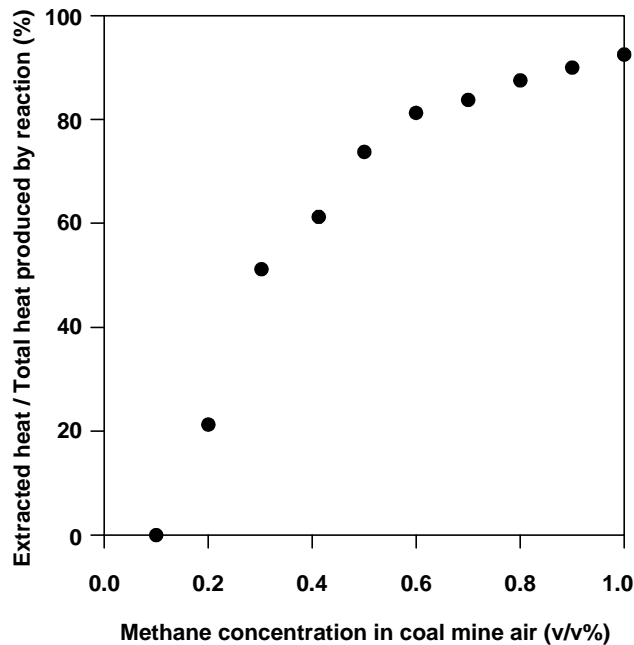


Figure 3. Efficiency of the extracted heat as a function of methane concentration.

## 5.0 ECONOMICS

A preliminary economic assessment has been performed to estimate the value of the thermal heat produced by the CH<sub>4</sub>MIN technology, as applied to the treatment of underground coal mine ventilation air. The results are shown in Table 1. The main conclusions are:

The cost of producing 1 GJ of thermal energy with the CH<sub>4</sub>MIN technology is US\$ 1.97. When the environmental effect is taken into account with basic CO<sub>2</sub> credit rate of US\$ 1.5 per tonne of avoided CO<sub>2</sub> emissions (Canter Fitzgerald, 2001), the net unit cost to produce 1 GJ of energy is decreased to US\$ 1.15.

The CO<sub>2</sub> credit value leading to a cost-revenue break-even point, for various energy prices is shown in Figure 4. A simple model was used, where revenues cover operating and financing costs (capital and interest) over a 15-year period. The following assumptions were made: the CH<sub>4</sub>MIN unit treats 100 cubic meters per second of ventilation air; the total cost of the unit is 3.5 million US\$ (including installation) and is financed entirely at 10%, over a 15-year period; the inflation rate is 2%. The results show that the CH<sub>4</sub>MIN technology becomes economically viable even if it is used only for methane destruction, when the CO<sub>2</sub> credits are over US\$ 6.0 per tonne.

Table 1: Economic assessment of the CH<sub>4</sub>MIN technology

<b>Basic assumptions:</b>	
Ventilation air flow rate	100 m <sup>3</sup> /sec.
Methane concentration in air	0.5 % v/v
Methane heating value	36 MJ/m <sup>3</sup>
Energy recovery efficiency	75 %
Life expectancy of the reactor	15 years
Catalyst replacement interval	4 years
Utilization factor	95 %
Ratio of GWP CH <sub>4</sub> /CO <sub>2</sub>	21
Currency	US Dollars
<b>Net recovered energy by CH<sub>4</sub>MIN</b>	405 000 GJ/Year
<b>Greenhouse gas reduction:</b>	
Amount of methane oxidized	10 700 tonnes/year
CO <sub>2</sub> equivalent	208 000 tonnes/year
<b>Costs:</b>	
<b>Capital costs</b> (reactor; blower; construction costs; engineering)	3.5 M\$
<b>Operating costs over 15 years</b> (catalyst; operation and maintenance; electricity for fan operation)	4.4 M\$
<b>Total costs (capital and operating)</b>	7.9 M\$
<b>Unit costs:</b>	
<b>Energy value (over 15 years)</b>	1.97 \$/GJ
<b>CO<sub>2</sub> value (CO<sub>2</sub> credit rate: \$1.50/tonne)</b>	0.82 \$/GJ
<b>Net unit cost</b>	1.15 \$/GJ

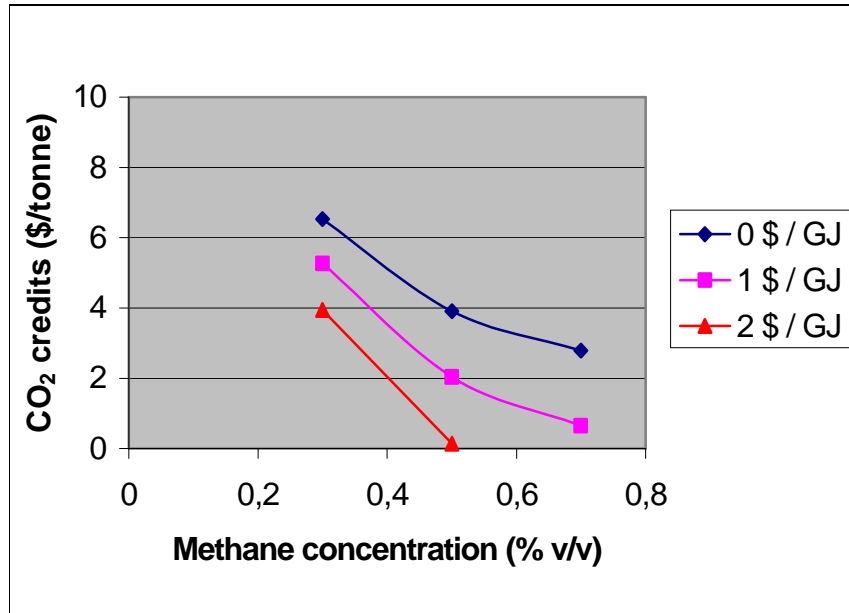


Figure 4. CO<sub>2</sub> credit value leading to cost-revenue break-even point for various energy selling prices

## 6.0 NEXT STEPS

Since the beginning of 2003, Lefebvre Frères Ltée, a Canadian equipment manufacturer based in Montréal, has begun to work on commercializing the CH4MIN technology

The commercialization plan is to build a demo CH4MIN reactor, which could process about 5.0 m<sup>3</sup>/s ventilation air methane flow, and conduct field testing in a China coal mine. In addition, various thermal energy extraction and utilization applications, including co-generation by gas or steam turbines, will be developed by CETC-Varenes and Lefebvre Frères Ltée.

Lefebvre and CETC-Varenes will verify the design parameters, engineering and various operation issues during the demonstration process. Lefebvre plans to put the demonstration project in a Sino-Canadian Clean Development Mechanism (CDM) in order to prepare for future carbon credits trading related to CH4MIN reactors.

After the demo process the next step is a full scale CH4MIN reactor and a co-generation plant in a China coal mine. Each full scale CH4MIN reactor will oxidize methane equivalent to 117,500 tons CO<sub>2</sub> per year and recover 7 MW thermal energy, including 2 MW electricity through a co-generation plant.

At present, Lefebvre and CETC-Varenes are discussing with the other partners in Canada and abroad to finalize the technology transfer.

## **7.0 CONCLUSION**

The development of the CH<sub>4</sub>MIN technology and its application on elimination of dilute methane emissions, along with heat recovery, has been shown to be a technically and economically viable solution to a major global warming problem. The technology has significant and multiple impacts on greenhouse gas reduction. First, it produces thermal energy using mine ventilation air containing dilute methane (0.1-1.0% v/v), which was previously emitted to atmosphere. Every 100 m<sup>3</sup>/s of mine ventilation air (0.5% v/v of methane) treated with the CH<sub>4</sub>MIN technology reduces greenhouse gas emissions by 208 kilotons equivalent CO<sub>2</sub>/year. Second, it converts the dilute methane gas at a temperature below 850°C, and the exhaust gases contain no NO<sub>x</sub>, another important greenhouse gas. Using the CH<sub>4</sub>MIN technology as an external heat source for a gas turbine is beneficial to the turbine operation since no NO<sub>x</sub> is produced. Third, the thermal energy produced is environmentally friendly. The same amount of energy produced by other technologies, using coal or liquid fuels would additionally pollute the atmosphere with NO<sub>x</sub> and SO<sub>x</sub> gases. The recovered heat can be used near the mine site or be converted to electrical power, which can then be transmitted to user sites.

With increasing energy need and coal mining activity, China has vast resources in ventilation air methane with large average shaft ventilation airflow and high concentration. Apply CH<sub>4</sub>MIN technology in China coal mines will not only eliminate methane emission, but also bring useable clean thermal energy to local market as well as generate considerable carbon credits through CDM with developed countries. In addition, it would be a great interest for local manufacturing industry to produce CH<sub>4</sub>MIN reactors in China through licensing or technology transfer in future.

## **8.0 REFERENCES**

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