MICROWAVE-ASSISTED CATALYTIC UPGRADING OF HEAVY OIL

Mohamed Adam* [a], Abarasi Hart [b], Joseph Wood [b], John P. Robinson [a] and Sean P. Rigby [a]
[a] Faculty of Engineering, University of Nottingham, Nottingham NG7 2RD, UK
[b] School of Chemical Engineering, University of Birmingham, Birmingham B15 2TT, UK

Abstract

Toe-to-Heel Air Injection (THAI) with its catalytic add-on (CAPRI, CAtalytic upgrading PRocess in-situ) is considered one of the promising technologies for simultaneous recovery and in-situ upgrading of heavy oils. Previous studies suggest that the temperature of the oil reaching the catalyst pack in the THAI-CAPRI process is too low for a successful CAPRI operation. Microwave heating technique has been proposed as a possible option to provide the required extra heating. A lab-scale reactor was built and used to investigate the microwave-assisted catalytic upgrading of heavy oil. It was possible to heat a THAI produced oil directly with microwaves to 400 °C, which is the temperature needed for a successful CAPRI operation. An increase in the specific gravity of up to 2.75° API was achieved. This study establishes that microwave heating can be used to provide the extra heating needed for a successful CAPRI operation by targeting the oil surrounding the horizontal producer well. This suggests microwave heating would resolve the issues with the previously disappointing field trials of THAI-CAPRI.

Keywords

Microwave heating, Catalytic upgrading, Enhanced oil recovery

Introduction

Despite the rapid growth in sustainable energy sources, oil and gas are projected to need to satisfy up to 55% of the world's energy demand in 2040 (EIA, 2017). With the decline in light oil reserves attention has been shifting towards unconventional oil such as heavy oils and bitumen.

Toe-to-Heel Air Injection (THAI) with its catalytic add-on (CAPRI, CAtalytic upgrading PRocess in-situ) is considered one of the promising technologies for simultaneous recovery and in-situ upgrading of heavy oils. In THAI, air is injected to the reservoir to burn a small fraction of the oil. The generated heat thermally-cracks and mobilizes the oil ahead of the combustion front which, then, drains into a horizontal producer well. The catalytic add-on, CAPRI, provides an in-situ upgrading by surrounding the horizontal producer with a catalyst packing. Previous studies showed that a minimum operating temperature of ~400 °C is required for successful CAPRI operation (Shah et al., 2011). However, simulations suggested that the temperature of the mobilized oil passing through the horizontal well in the THAI process does not exceed 300 °C (Rabiu Ado et al., 2017). Microwave heating is one of the possible options to fill this gap and provide extra heating to increase the temperature at the catalyst packing and/or the oil in its immediate vicinity to 400 °C or more.

Microwave heating is a selective and volumetric heating technique. Unlike conventional conductive and convective heating methods, heating is achieved instantaneously as a result of the interaction of the electromagnetic field with the material at the molecular level. Crude oils, in general, are considered poor microwave absorbers, and heating them may require adding microwave susceptors. However, we have recently (Zhang et al., 2018) shown that at high temperatures, which is the case in THAI-CAPRI, heavy oils are more susceptible to being heated directly with microwaves. We have also shown, in another work (Adam et al., 2018), that it is possible to produce a microwave susceptor in-situ which can improve the efficiency and effectiveness of the microwave heating.

* Email: Mohamed.Adam@nottingham.ac.uk

The aim of the current study was to develop a lab-scale microwave-heated reactor and use it to examine if heavy oils can be heated directly with microwaves up to 400 °C to achieve catalytic upgrading.

Results and Discussion

Figure 1 is a schematic of the microwave heating system which was built to investigate the catalytic upgrading of the heavy oils. It involves a flanged 30 mm i.d quartz tube inside a single-mode microwave applicator.

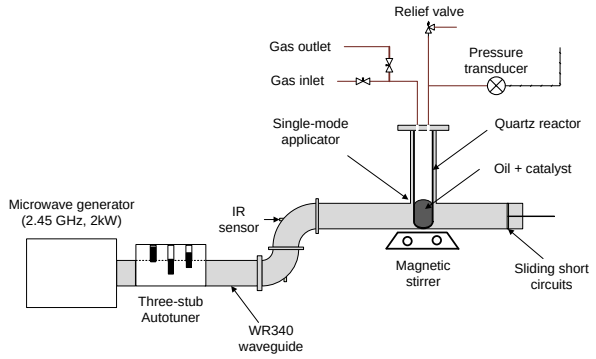

Figure 1. Schematic of the microwave heating system

The system provides many advantages over the similar commercially-available microwave heating systems as it allows study of a wider range of powers and temperatures. The reactor has a maximum operating temperature and pressure of 450 °C and 20 bar, respectively. The heavy oil used in this study was supplied by Touchstone Exploration Inc. Canada, and was produced through THAI technology. The properties of the oil are listed in Table 1.

Table 1. Properties of the oil used in this work

Property	Value
API gravity at 20 °C	14.29
Viscosity at 20 °C (cP)	1360
Sulfur content (wt. %)	3.2

During the experiments, typically 15 g of the oil was mixed with 1.0 g solid catalyst in the quartz reactor. The catalyst used was a commercially available $CoMo/Al_2O_3$. The microwave power was used to control the oil temperature. It was possible to heat the oil up to 400 °C with no need for a microwave susceptor. Experiments were run under similar conditions with and without a catalyst. Figure 2 shows the increase in the API specific gravity with the holding time at 400 °C. The increase in the specific gravity without a catalyst is thought to be caused by thermal cracking. Holding time of more than 6 minutes resulted in a significant increase in the catalytic effect, as opposed to thermal cracking, as can be seen in the gap between the two plots in Figure 2. An increase in the API specific gravity of up to 2.75° was achieved after 15 minutes holding time when the catalyst was used.

This study establishes that, in principle, microwave heating can be used to provide the extra heating needed for a successful CAPRI operation by targeting the oil surrounding the horizontal producer well. Future studies to focus on optimizing the process parameters to maximize the degree of upgrading keeping in mind the requirements and constrains of the THAI-CAPRI process.

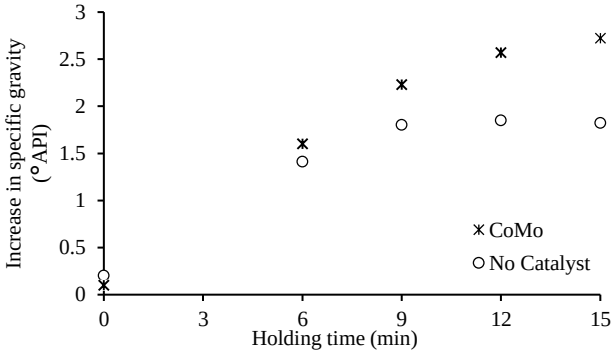

Figure 2. Effect of holding time on the specific gravity of the THAI oil.

Conclusions

This study demonstrated that heavy oils can be heated directly with microwaves to 400 °C which is the temperature needed for a successful CAPRI process. Upgrading with an increase in the API of up to 2.75° was achieved. Future studies to focus on optimizing the process and to investigate field-scale settings.

Acknowledgements

This research was supported by the Engineering and Physical Sciences Research Council [grant number EP/N032985/1].

References

Adam, M., Hart, A., Stevens, L. A., Wood, J., Robinson, J. P. & Rigby, S. P. 2018. Microwave synthesis of carbon onions in fractal aggregates using heavy oil as a precursor. *Carbon,* 138**,** 427-435.

Eia 2017. International Energy Outlook 2017. U.S. Department of Energy, Energy Information Administration

Rabiu Ado, M., Greaves, M. & Rigby, S. P. 2017. Dynamic Simulation of the Toe-to-Heel Air Injection Heavy Oil Recovery Process. *Energy & Fuels,* 31**,** 1276-1284.

Shah, A., Fishwick, R. P., Leeke, G. A., Wood, J., Rigby, S. P. & Greaves, M. 2011. Experimental Optimization of Catalytic Process In Situ for Heavy-Oil and Bitumen Upgrading. *Journal of Canadian Petroleum Technology,* 50**,** 33-47.

Zhang, Y., Adam, M., Hart, A., Wood, J., Rigby, S. P. & Robinson, J. P. 2018. Impact of Oil Composition on Microwave Heating Behavior of Heavy Oils. *Energy & Fuels,* 32**,** 1592-1599.