A non-conventional model to assess the production potential of the Waipawa Formation – a possible hydrocarbon source rock in the East Coast Basin

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy in Earth Science at Massey University, Palmerston North, New Zealand

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Sadaf

2013

Abstract

Since the early part of the 20^{th} century, many countries have attempted to diversify their energy resources through exploiting their unconventional hydrocarbon reserves. These include oil shales, native bitumen, oil sands and tar sands. Oil shale, in particular, has received significant interest over recent decades due to the potentially huge reserves stored within this type of resource. Traditional assessment of oil shale deposits is dependent on the analytical technique Source Rock Analysis (SRA), but there are recognised limitations to this technique.

The hypothesis of the current study was that a novel and non-conventional analytical tool would be better suited to assess the hydrocarbon potential of oil shales than conventional SRA. The overall objective of the study was to define a scientifically comprehensive production potential model for non-conventional source rocks using a suite of physical (XRD, organic petrography), thermal (LOI, LECO, TGA) and chemical analytical techniques (FTIR and GC-MS of the solvent-extracted bitumen phase). These techniques were used to characterise international reference shales from the USA (Green River Formation, GRF), Pakistan (Salt Range oil shale, Mir Kalam Kala and Speena Banda oil shale) and China Qianjiang Formation), and shales from New Zealand (Waipawa Formation and Orepuki oil shale). Analysis of each rock by SRA allowed for ranking of the petroleum potential, with the GRF, Orepuki oil shale, and two of four locations from the Waipawa Formation, being inferred as good potential source rocks.

Physical characterisation of the rocks showed that the content of illite in an oil shale is inversely proportional to the hydrocarbon content of the rock. The absence of illite can therefore be used as an index of production potential, and allowed ranking of the petroleum potential of the rocks which was in good agreement with SRA. Organic petrography linked production potential to the presence of macerals in polished sections prepared from selected rocks of the study and provided strong evidence for the environment of deposition of these samples.

Thermal analysis showed that the abundance of organic matter and total organic carbon (TOC) are directly proportional to the oil production potential of an oil shale provided the oil shale is not post mature. Samples with good SRA-defined production potential had LOI and TOC values in excess of 5% and 2.5% respectively, and a weight loss due to decomposition of kerogen (W_B) of 7%. There was a clear distinction between the good and

poor production potential source rocks, with the Pakistan samples showing low values in each of these parameters. The TOC of the Chinese oil shale provided fan ambiguous interpretation, but further investigation defined this rock as post-mature.

Chemical analysis showed that the relative aliphaticity and aromaticity of the bitumen phase extracted by dichloromethane was higher for the highly SRA-ranked shales. No aromatic bands were identified in the low to non-producing oil shales. A direct relationship between the relative content of the constituent chemical compounds of bitumen (alkanes, cycloalkanes, aromatics and heteroatom compounds) and production potential was also observed, and the GC-MS data provided information on the likely quality of oil that might be extracted from an oil shale. The trend in relative aliphaticity and aromaticity of the rocks was consistent under both FTIR and GC-MS analysis.

To formulate the non-conventional production potential model, cut-off values were selected using the SRA-defined production rankings. Good production potential is inferred through LOI >5%, TOC >2.5% and W_B >7%. The presence or absence of illite in the clay fraction, and the presence of both aliphatic and aromatic bands (FTIR) and the four constituent chemicals in the bitumen extract (GC-MS), were defined as qualitative cut-off values. Organic petrography is not integrated into the model at the current time, but provided strong data on the origin of deposition of a shale rock. These cut-off values were integrated into a model that defines a sequence of analytical steps. The analytical techniques become progressively more complex as the potential of a sample becomes more certain. A sample is defined as having good production potential if it meets all criteria.

The non-conventional production potential model was then used to interpret the analytical results obtained through analysis of the Orepuki oil shale and Waipawa Formation shale rocks. The Orepuki oil shale was found to be an oil shale, rich in organic matter with excellent production potential. The Waipawa Formation was similarly found to be an oil shale, with good petroleum potential for two of the four outcrop locations analysed.

The conclusions from the non-conventional production potential model were consistent with those inferred by SRA. But the model yields superior understanding regarding the production potential of the Orepuki oil shale and Waipawa Formation. The low illite content, origin of deposition of these formations, degree of richness of the constituent organic content, and the inferred quality of oil which may be derived from its bitumen, are key information that cannot be obtained from SRA.

Acknowledgements

Undertaking this PhD has been a truly life-changing experience for me, which would not have been possible without the support and guidance of many people. I am deeply grateful to all of them and wish to render my sincerest thanks to them.

I would like to thank my supervisor Dr Christopher Anderson for his scholarly support, encouragement, guidance and patience throughout this project. Without his continuous help and valuable guidance, this PhD would not have been possible.

Thanks to my supervisor Julie Palmer, for her continuous guidance and support throughout my doctoral studies.

I am immensely grateful to the Higher Education Commission (HEC), Pakistan, for granting me a full-time doctoral scholarship which made it possible for me to pursue and complete my doctoral studies at Massey University.

I would like to thank Richard Sykes from GNS for sharing his ideas through discussions with me, sending me publications and reports and helping me with Source Rock Analysis and identifying different macerals under a microscope using polished grain mounts. I greatly appreciate help of Todd Ventura with discussion of GC-MS data.

I am indeed thankful to Associate Professor Bob Stewart for running all the XRD samples. I greatly appreciate his help by critically reading some parts of the manuscript and rendering invaluable advice and guidance from time to time throughout my PhD.

I would like to acknowledge the help and support of Graham Freeman, Senior Technician, Chemistry Department, Massey University. I am indebted to him for his useful discussion and helping me with the FTIR analysis and Soxhlet Extractions. I am immensely grateful to John Sykes from School of Engineering and Advanced Technology, Massey University, for the GC-MS analysis.

I greatly appreciate the assistance I received through my research from the staff of the Soil and Earth Science section, Institute of Agriculture and Environment, especially Professor Mike Hedley, Lance Currie, Peter Bishop, Clel Wallace, Ian Furkert, Glenys Wallace, Ross Wallace, Anja Mobis, Mike Bretherton and Liza Haarhoff.

Thanks to all my friends and research colleagues , especially Saman, Tomoko, Tao, Neha, Reddy, Saleem and Amandeep who always added colour to dull routine through their chat or laughter. I cherish all the beautiful moments spent with them and the help and support they gave me.

I can’t find words to express my gratitude and thanks to my parents. Heartfelt respect to my parents who always loved me, were so proud of me, believed in me, supported me and were always there for me through this journey. I thank my dad for allowing me to proceed with my PhD studies. My special thanks to my brothers and sisters, Rashid, Sheema, Danish and Shumaila for their continuous love, encouragement and help in whatever way they could provide me during this challenging period. To my son – Zaid – your love, your presence and future ahead has been my inspiration and motivation!!!. Zaid is only two years old and will not remember these days when he is grown up. I am sorry that I could not play with you more during this period. I love you.

Last but not the least; I am greatly indebted to my loving, encouraging and patient husband – Amjad – whose unfailing support during this PhD is so appreciated. When I was down you were always there to pick me up. I have always kept taking out my frustration on you. Thank you so much for always understanding and believing in me during such times, checking my health, motivating me to complete this study and for all the little things that made me feel secure and cared for. THANK YOU.

This thesis is dedicated to my abbu and ammi for their love, endless support and encouragement.

Table of Contents

List of Tables

List of Figures