DEVELOPMENT OF AN ULTRA-LIGHTWEIGHT COCONUT SHELL-BASED PROPPANT FOR HYDRAULIC FRACTURING OF SUBTERRANEAN FORMATIONS

ABDOULLATIF GHARIBI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Petroleum Engineering)

Faculty of Chemical and Energy Engineering
Universiti Teknologi Malaysia

SEPTEMBER 2016

Dedicated to my beloved family

ACKNOWLEDGEMENT

I am heartily expressing my greater gratefulness to Allah s.w.t for His blessing and strength that He blessed to me during the completion of the research.

My sincere thanks goes to my supervisor Dr. Manssor Zooveidavianpoor for his continuous motivation, advices, encouragement and support from the starting to the end of my studies. I would like to thank Dr. Mohd Zaidi Bin Jaafar for his tremendous support.

I am ever grateful to my family for their support and encouragement from psychological and financial. And the very genuine appreciation goes to my father whom I owe my very existence to the world, whom always gave me motivation and courage to look on the bright side every time I felt unmotivated, whom that never let me down and whom I respect the most in my heart.

At the end, I would like to thanks to FKT Lab members in Universiti Teknologi Malaysia for their helps and supports.

ABSTRACT

Hydraulic fracturing (HF) has seen a considerable increase in interest for the purpose of improved oil recovery. HF creates high conductive conduits between wellbores and reservoirs by a pressurized fluid mixed with proppants. The problem of most popular fracturing fluid (i.e., slickwater) is the high settling rate of common proppants, e.g. sand, which results in small effective propped fractures. Ultra-lightweight (ULW) proppants are easily transported by slickwater and can cover further fracture area. However, ULW proppants cannot provide enough strength at high closure pressure. This study developed a moderately high strength, chemically modified and reinforced composite proppant (CMRCP) which is composed of chemically modified coconut shell, composite material, and epoxy resin. Investigating the performance of new ULW proppant was conducted using laboratory and simulation works such as characterization, quality and mechanical evaluation, simulation mechanical response of particles under compression, fracture conductivity, and HF design. Characterization indicated that the coating layers of CMRCP provide thermal stability of 297.5 °F. Also, quality tests revealed that CMRCP is a neutral buoyant proppant with lower bulk density than frac sand, glass beads, ULW-1.75, and ceramic. Desirable strength (i.e., 8,000 psi) and conductivity (i.e., 791 mDft) from mechanical tests and fracture conductivity were observed, respectively. The results showed an improved performance than Brady sand and its counterpart (i.e., ULW-1.25). The results of strength tolerance and fracture conductivity of CMRCP were 25% and 77% higher than ULW-1.25. Furthermore, experimental and simulation of proppant’s mechanical response with different geometries approved that round geometry provides further strength. Finally, HF design shows that the new product can realise high cumulative production, net present value, and return on investment. This study introduced a new ULW proppant that has moderately high strength, resistant to high temperature, easy to get, light, and cost effective, and it can be used as proppant for HF of subterranean formations.

ABSTRAK

Peretakan hidraulik (HF) telah menarik banyak perhatian bagi tujuan pengeluaran minyak tertingkat. HF mewujudkan saluran konduktif yang tinggi di antara lubang telaga dengan reservoir menerusi pengaplikasian cecair bertekanan tinggi yang dicampurkan dengan penyangga. Masalah yang dihadapi bendalir peretak yang paling popular (iaitu air licik) ialah kadar pemendapan tinggi yang dialami penyangga biasa, misalnya pasir, yang hanya menghasilkan retakan kecil yang kurang berkesan. Penyangga lampau ringan (ULW) mudah diangkut oleh air licik dan boleh menyanggah kawasan retakan secara menyeluruh. Walau bagaimanapun, penyangga ULW tidak mempunyai kekuatan yang cukup untuk menahan tekanan penutupan yang tinggi. Kajian ini telah menghasilkan penyangga komposit berkekuatan tinggi, terubah suai secara kimia dan diperkukuh (CMRCP). Penyangga itu diperbuat daripada tempurung kelapa yang diubah suai secara kimia, bahan komposit, dan resin epoksi. Kajian terhadap prestasi penyangga ULW baharu melibatkan kerja-kerja di makmal dan penyelakuan misalnya pencirian, penilaian kualiti dan mekanikal, penyelakuan respons mekanikal zarah bawah mampatan, kekonduksian retakan, dan reka bentuk HF. Pencirian menunjukkan bahawa lapisan-lapisan CMRCP menghasilkan kestabilan terma setinggi 297.5 °F. Ujian kualiti turut mendedahkan bahawa CMRCP ialah penyangga apung neutral yang mempunyai ketumpatan pukal lebih rendah daripada pasir peretak, manik kaca, ULW-1.75, dan seramik. Kekuatan (iaitu 8000 psi) dan ujian kekonduksian (iaitu 791 mDft) yang dikehendaki masing-masing diperoleh daripada ujian mekanikal dan kekonduksian retakan. Keputusan kajian telah menunjukkan prestasi yang lebih baik daripada pasir Brady dan bahan setaranya (iaitu ULW-1.25). Keputusan toleransi kekuatan dan kekonduksian retakan CMRCP ialah 25% dan 77% lebih tinggi daripada ULW-1.25. Selanjutnya, kajian di makmal dan kajian penyelakuan terhadap respons mekanikal penyangga dengan geometri yang berbeza membuktikan bahawa geometri bulat memberikan kekuatan tambahan. Akhir sekali, reka bentuk HF menunjukkan bahawa produk baharu itu mampu merealisasikan pengeluaran kumulatif, nilai bersih kini, dan pulangan ke atas pelaburan yang tinggi. Kajian ini memperkenalkan penyangga ULW baharu yang mempunyai kekuatan yang tinggi, kalis suhu tinggi, mudah diperoleh, ringan, dan kos efektif. Penyangga itu boleh diguna dalam operasi peretakan hidraulik formasi subpermukaan.

TABLE OF CONTENTS

3 RESEARCH METHODOLOGY 94

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

D - Depth of Reservoir (ft)

E - Modulus of Elasticity (psia)

F - Contact Force (lbf)

k - Permeability (mD)

P - Reservoir Pressure (psia).

R - Radius of the Sphere (ft)

C_b - Bulk Compressibility (psia)

D_I - Test liquid density, (lb/ft^3)

D_p - Specific gravity of proppant (lb/ft^3)

$E_{infiltration}$ - Infiltration Elasticity (psia)

h_f - Fracture height (ft)

k_f - Fracture Permeability

P_p - Pore Pressure (psia)

P_{bd} - Breakdown Pressure (psia)

q_i - Production Rate (ft^3/s)

w_o - Width of the Fracture(ft)

$W_{f,l}$ - Weight of flask filled with test liquid (lb)

W_f - weight of empty flask (lb)

W_p - Weight of proppant (lb)

$W_{f,l,p}$ - Weight of flask, liquid and proppant (lb)

U_{avg} - Linear Velocity (ft/s)

$P(r)$ - Hertzian distribution of pressure (psia)

xf - Fracture half-length, (ft)

μe - Effective viscosity of fracturing fluid (cp)

ρ_b - Bulk Density (lb/ ft^3) or (gr/cm^3)

μ - Fracturing fluid viscosity, (cp)

ν - Poisson’s ratio, dimensionless

LIST OF ABBREVIATIONS

API - American Petroleum Institute
ASTM - American Standard
CBD - Chemical Bath Deposition
CE - Chain Extender
CMRCP - Chemically Modified and Reinforced Composite Proppant
CP - Conventional Proppant
CPs - Conventional Proppant Systems
CS - Cold Spray
EDX - Energy Dispersive X-Ray Spectrometry
FESEM - Field Emission Scanning Electron Microscope
FEM - Finite Element Method
FC - Fracture Conductivity
FML - Full Monolayer
FTIR - Fourier Transform Infrared Spectroscopy
FTU - Formazin Turbidity Units
HF - Hydraulic Fracturing
HVPC - High Velocity Particle Consolidation
HSP - High Strength Proppant
IOR - Improved Oil Recovery
ISO - International Standard Organization
ISP - Intermediate Strength Proppant
KGD - Khristianovich-Zheltov-Geertsmadeklerk
LW - Lightweight
LRS - Liquid Resin System
LPCS - Low-Pressure Cold Spray
LPTA - Lembaga Perlesenan Tenaga Atom

MPL - Multiple layer
NIOSH - National Institute for Occupational Safety and Health
NTU - Nephelometric Turbidity Units
NPV - Net Present Value
OSHA - Occupational Safety and Health Administration
PGMA - Poly Glycidyl Methacrylate Polymer
PKN - Perkins-Kern Width Equation
PU - Polyurethanes
PML - Partial Monolayer
RCP - Resin Coated Proppant
RCPs - Resin Coated Proppant Systems
RSE - Resource Engineering Systems
ROI - Return on Investment
SG - Specific Gravity
SEM - Scanning Electron Microscope
SSP - Self-Suspended Proppant
SPD - Supersonic Particle/Powder Deposition
SMA - Surface Modifying Agent
TGA - Thermo Gravimetric Analysis
ULW - Ultra-Lightweight
U.S - Unites States
VES - Viscoelastic Surfactant-Based

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Due to the decrease in oil discoveries in recent years, Improved Oil Recovery (IOR) methods will be capable of playing an essential role in replying to demand in the years to come. IOR processes consist of all techniques that are employed to enhance hydrocarbon production (Surguchev *et al.*, 2005). Well Stimulation as one of these techniques is composed of various operations to maintain or improve productivity of wells. It creates new channels or eliminates the obstacles in the pay zone to facilitate the flow of oil and gas from the formation to the wellbore (Pershikova, 2007). Hydraulic fracturing (HF) is known as the main method to stimulate oil and gas wells, and it begins with pumping a fracturing fluid into a well to enhance pressure above fracturing pressure of the subterranean formation that contains entrapped oil or gas (Soane *et al.*, 2010). This process results in cracks and breaks that disrupt the underlying layer to allow the transfer of hydrocarbon products to the wellbore at a significantly higher rate. Once the fracture is created, a slurry composed of fracturing fluid and proppant is injected to open and maintain a path flow from the fracture to the wellbore (Soane *et al.*, 2010). Fracturing fluids used to transport proppant inside the fracture include water based fluids, linear gels, cross-linked gels, oil based fluids, and foam/ poly emulsions fluids (Montgomery, 2013). Further information about history of the fracturing fluid, composition, economical issue, methods of utilization, and cost of the fracturing fluid can be found in the technical literature (Montgomery, 2013).

Another part of the slurry is proppant, and it is defined as any non-liquid material that is used to provide structural support for created fracture and to keep it open (Windebank *et al.*, 2013). Proppant demand for HF treatment of the unconventional reservoirs has been increased from 5 billion pounds in 2004s to 60–70 billion pounds in 2012s (Palisch *et al.*, 2012). In accordance to a report, the oil and gas industry supplied over 135 billion pounds of various proppants in 2015s, close to 50 percent growth over 2012s (McEwen, 2015).

The proppant can be frac sand, nut hulls, ceramics, bauxites, glass beads, RCP, and combinations thereof (Lesko *et al.*, 2008). These types of proppants are known as conventional proppant (CP). In the recent years, a new generation of proppants with low specific gravity, high strength, and low settling velocity that are known as Lightweight (LW) and Ultra-Lightweight (ULW) proppant have been introduced to the market. One aim of proppant industry has been to reduce proppant density without sacrificing strength. Thus, the ULW proppant with specific gravity of 1.25-1.75 made from a substrate material such as a walnut hull or porous ceramic and two layers of polymers as coating was introduced to the market to satisfy this aim (Wood *et al.*, 2003).

Therefore, a chemically modified and reinforced composite proppant (hereafter it is called CMRCP) that is comprised of the coconut shells as substrate and two layers of polymer (reinforced and coating layers) is introduced in this study. The new proppant is produced at three stages. First, substrate surface is modified with a solution of sodium hydroxide to improve its capability for reinforcement. Then, the modified substrate is reinforced with a composite material to improve its strength. Thereafter, coating of the reinforced coconut shell is performed with a thin layer of polymer. The epoxy resin is chosen as polymer because the reinforced layer contained the poly glycidyl methacrylate (PGMA) polymer, and the epoxy group of the PGMA polymer is capable of providing a strong bond with epoxy resin. In this study, experimental and computational analysis methods are used to characterize and investigate the capability of the new ULW proppant. Narrowing down of the study is shown in Figure 1.1.

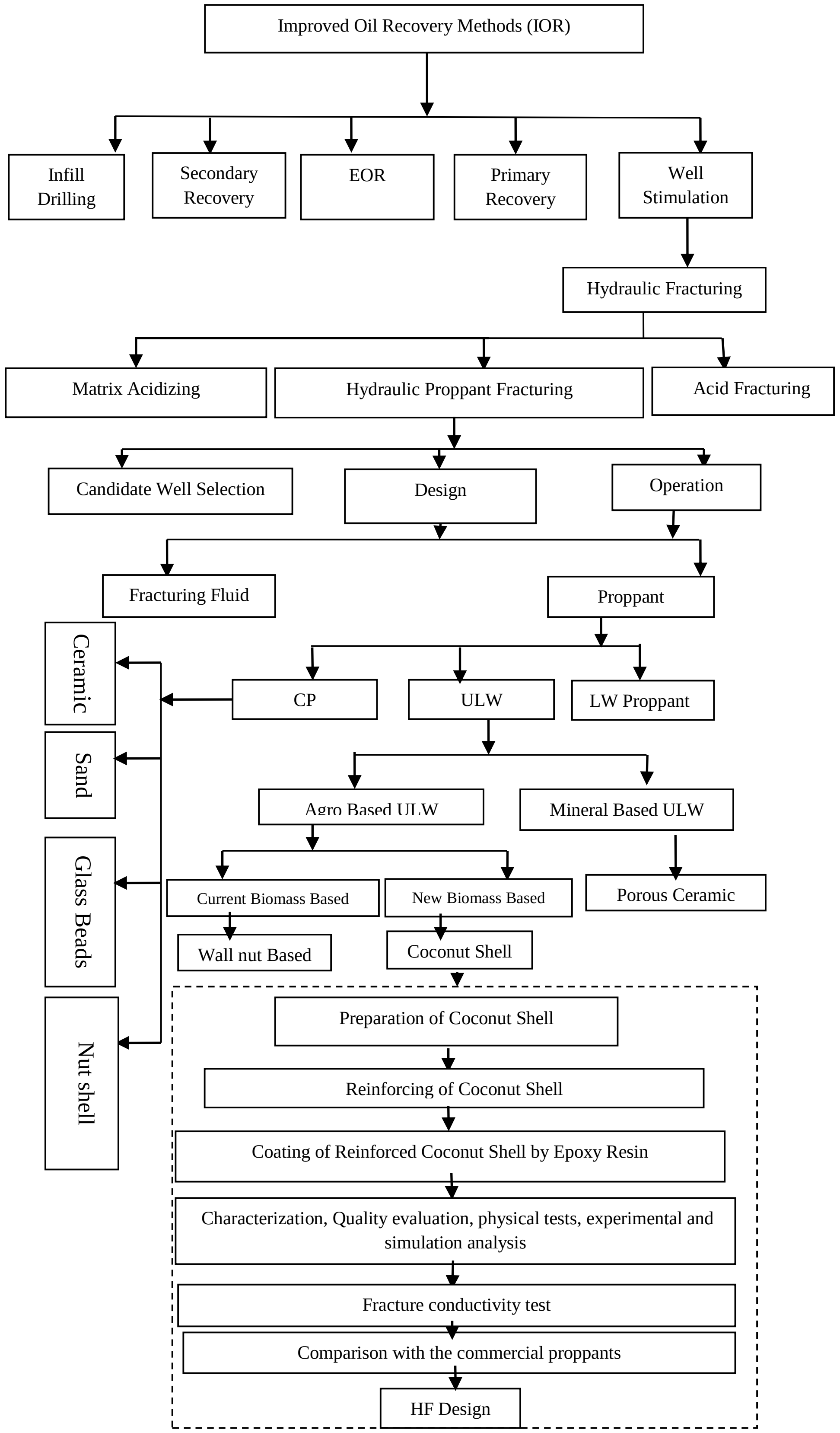

Figure 1.1 Narrowing down of the study

1.2 Background of the Problem

Researchers are trying to improve the quality of proppant to remove the drawbacks of CP for HF treatment. For example, the widespread use of frac sand as propping agent with an average specific gravity of 2.5-2.70 (Luo *et al.*, 2011) is common because of the low cost and ready accessibility (O'Brien and Haller, 2014). However, frac sand is not capable of providing sufficient strength to resist crushing (Li *et al.*, 2014). The high embedment pressure of the formation causes proppant embedment, and exceeding the load bearing capacity of the frac sand leads to crushing of the frac sand. As a result, fines produced from the crushed frac sand plug the fracture leading to proppant flowback. Proppant flowback is the transfer of proppants back into the wellbore with the production of formation fluids from formation (Nguyen, 2004), and it causes reduction of the fracture conductivity, restriction of production, and erosion of tubular and wellhead equipment as well as surface facilities. In addition, proppant flowback fills treating vessels that cause failure in the treating process (Ellis and Surles, 1998).

Another main problem of using frac sand proppant for the HF treatment is related to enhancement of frac sand mining across the bank river. Frac sand mining has created a considerable public health threat in the region possibly due to the negative effects of mining, processing and transporting of frac sand.

By surface coating the frac sand proppant with a thin layer of resin, the brittle frac sand proppant becomes resistant to acid and crushing (Droppert et al., 2002). Also, the coated sand is capable of consolidating, and it has great potential to minimize proppant flowback. This is because coating layers retain the small particles that are generated from the frac sand due to the increase of the closure pressure (Barmatov et al., 2010). Although coating layers have eliminated some of the drawbacks of frac sand but utilization of sand coated proppant is restricted to wells with certain closure stress (less than 8,000 psia) (Ellis and Surles, 1997). Also, phenolic acid and formaldehyde that are known as dangerous chemical materials are used for sand coating that cause health problems for those who are exposed to this type of proppant (Malone, 2012).

Since application of frac sand and coated sand are restricted to a certain closure pressure (less than 8,000 psia), ceramic proppant with a specific gravity of 3.3-3.6 (Jones and Cutler, 1985) was introduced to stimulate formation with higher closure pressure (Smith *et al.*, 2011). Although conventional ceramic proppant has shown exceptional crush strength, it has exhibited extreme density that requires viscous fluids to carry within the fracture (Smith *et al.*, 2011). When it transfers with a low-density fluid (e.g., slickwater), it settles before reaching the end of the fracture. Consequently, using viscous fluids creates problems such as damage to the formation and surface equipment and increase in the cost of the HF treatment during propped fracturing treatment.

Also, environmental problems that are related to ceramic factories cause a lot of damage to human beings. These factories cause emissions that are released into air, water and land, and they make noise and undesirable smells during production of the ceramic products (IPPC, 2007). All involved parts of the ceramic industry are consuming higher amounts of energy, and they consume natural gas, liquefied petroleum gas and fuel oil for firing. Utilization of these materials as feed leads to the production of high amounts of carbon dioxides and other harmful gases (IPPC, 2007).

Other proppants which have been used in proppant industry are agro-based materials such as nutshells which were introduced in the proppant industry in the 1960s. In contrast to frac sand, nutshells cause less damage when exposed to the surface equipment because these hard fibrous products are deformable. In addition, nutshells are free from the silica that causes inhalation health concerns (Kramer, 2015). It was found that when agro-based materials are used in proper concentration and size, they yield high fracture capacities relative to frac sand (Fast *et al.*, 1961). However, utilization of agro-based proppant such as nutshells has reduced fracture conductivity, and nutshells that are made naturally have limited application as closure pressure increases (Liang *et al.*, 2015). It is due to the high tendency of nutshells to deform even in lower closure stress.

Accordingly, reinforcing and coating of nutshells with polymers can improve their strength to high closure stress, protecting particles from crushing, help resist embedment, and prevent the liberation of fines (Rickards *et al.,* 2003, Schein *et al.,* 2004, Abbott *et al.,* 2008, Brannon *et al.,* 2010). Since specific gravity of these coated materials is lower than CP, they are called ULW proppant. ULW proppant is defined as a proppant with the specific gravity less than or equal to 2.45 while its particle size is ranged in a mesh size of 12/20 to about 40/70 (Brannon *et al.*, 2010).

ULW Proppants are ideally suited to slickwater fracturing treatments because they have light weight, and they do not settle before reaching the end of the fracture (Brannon *et al.*, 2009). Slickwater is a cost saving fracturing fluid with low viscosity. Most of the slickwater fracturing fluid is water while other additives such as friction reducer, acid, surfactant, potassium chloride, scale inhibitor, pH adjusting agent, iron control agents, corrosion inhibitors, and biocides are added to the fluid (Barati and Liang, 2014).

Transferring ULW proppants with slickwater have indicated more benefits such as reducing proppant settling and creating more effective fracture length (Rickards *et al.*, 2003; Schein *et al.*, 2004). The performance of ULW proppants was great in reservoirs with closure pressures up to 5,000 psia and bottom hole temperatures up to 225 ºF (Posey, 2007).

Placement of ULW proppant within the fracture is usually performed with various arrangements including partial monolayer (PML), full monolayer (FML), and multiple layers (MPL) of proppants. As previously mentioned by Economides *et al.,* (2000), the PML is the best arrangement because of providing further fracture conductivity related to other arrangements. In a properly engineered fracture treatment, ULW proppant could form PML arrangement (Brannon *et al.*, 2009). Also, the ULW proppants provide further fracture conductivity compared to conventional frac sand proppant. As reported by Brannon *et al.* (2009), adding small amounts of ULW proppant to pad leads to great improvement in the fracture conductivity. In addition, the settling rate of ULW proppants is less than CP (Brannon *et al.*, 2004). It means that they are transported easily within the fracture with lower proppant settling that leads to the provision of further effective propped fracture length. As the result of more propped fracture length for low permeability reservoirs, the production is improved (Wood *et al.*, 2003). However, the ULW proppant cannot provide high strength under closure stress. It seems that using higher strength substrate and reinforcing of substrate with composite material before coating can improve strength of ULW proppant.

Since nutshells are always subjected as a good substrate for ULW proppant, and coconut shell is classified as a part of nutshells, it is obvious that it has potential to convert to a good substrate of ULW proppant. Advantages of coconut shell including light weight with specific gravity of 1.25-1.33 (Reddy *et al.*, 2014) , high strength to withstand closure stress with Young modulus of 9.2 GPa, renewable, ready accessible with low price, and good capability for coating with a less expensive method have qualified it as a good substrate of ULW proppant in tropical countries such as Malaysia. Some advantages of coconut shell have qualified it to apply in various industries. For example, inherent mechanical properties of coconut shell such as high strength and high modulus (Sapuan *et al.*, 2003) enable it to be applied as fillers in the composition of new composites. In addition, the excellent shock-absorbing capability of coconut shells accounts for its robustness (Martone *et al.*, 2010). Also, coconut shell provides low specific gravity which has been used as a coarse aggregate for light weight concrete (Reddy *et al.*, 2014)

Since the ULW proppants must provide appropriate strength to withstand high closure pressure (Brannon *et al.*, 2004), are light to buoyant on the fracturing fluid (Wood *et al.*, 2003), deform to prevent breaking (Brannon and Starks, 2009), inexpensive, and safe to reduce damage to the workers who are exposed to propping agent, it is obvious that coconut shell that is reinforced with a composite material before coating has all of these requirements, and it can be used as ULW proppant.

1.3 Problem Statement

Using renewable resources, saving cost of HF treatment, improving hydrocarbon recovery and pollution preservation are essential needs in today’s oil and gas industry. Expense of the propping agent alone could be 67 % of the total stimulation costs, and it has converted proppants as an important parameter for technological research (Economides *et al.*, 2000).

Although CPs have wide application in the HF treatment, some of the drawbacks that they have shown during the HF operation impose extra cost to HF treatment. As indicated by Li *et al.* (2013), frac sand proppant does not provide sufficient strength to resist crushing of the high closure stresses. When frac sand proppant is exposed to high closure stress (further than 5,000 psia), it produces fines that will plug the formation and fracture path flow (Economides *et al.*, 2000). It also causes damage to the surface equipment and adds extra cost to HF treatment (Ellis and Surles, 1998).

In contrast to frac sand, high strength tolerance is the main characteristic of ceramic proppants and resin coated proppant (RCP) but their extreme density have restricted their utilization in a wide range (Smith *et al.*, 2011). It means that they require viscous fracturing fluids and high pumping rates to suspend into fracturing fluid. Also, they cause greater than normal wear on fluid carrying and pumping equipment (Li *et al.*, 2013).

Slickwater fracturing treatment has indicated great success for stimulating of numerous formations because it does not require viscous fracturing fluid. However, higher settling rate of frac sand, RCP, and ceramic proppant have restricted its utilization (Liang *et al.*, 2015). In contrast to CPs, ULW proppants were ideally suited to slickwater fracturing treatments because they have light weight, and they do not settle before reaching the end of the fracture (Brannon *et al.*, 2009). However, ULW proppants had indicated low strength, proppant embedment, high price and difficult placement within the fracture (Wood *et al.*, 2003). Utilization of common ULW proppants are restricted to closure pressure of 5,000-6,000 psia (Wood *et al.*, 2003; Brannon *et al.*, 2004). The major advantage of ULW proppants is their low specific gravity, not strength. They will deform easily under high closure pressure and reduce the fracture conductivity.

Development of science and technology is beneficial to use new materials (e.g., high strength substrate, composite material,…) and techniques (e.g., surface modifying, reinforcing, new coating methods,…) for development of a new generation of ULW proppants which can tolerate higher closure pressure. Therefore, using a substrate that has better properties than walnut hull can improve the strength of agro-based ULW proppants. Also, application of surface modification technique and composite material show promising results for strength improvement. If the surface of coconut shell is modified by sodium hydroxide and reinforced with a composite material then coated properly with epoxy resin, it is capable of providing higher strength under closure pressure. The new ULW proppant (i.e., CMRCP) that is light, strength, safe, inexpensive, easy to get, and reliably delivered can be used and developed as an economic proppant to improve the quality of HF treatment

1.4 Research Objectives

The main objectives of this study are as follows:

1. To develop ultra-lightweight and a high strength proppant through reinforcing and coating of the coconut shell with a composite material and polymer.

2. To characterize the mechanical response of CMRCP particles under compression.

3. To evaluate the performance of CMRCP for providing fracture conductivity, and to simulate its performance in the field using HF design.

1.5 Scope of Research

In this study, CMRCP that is comprised of coconut shells as substrate and two coating layers of composite and polymer is produced at three-step process. First step includes modifying the surface of the coconut shell for the reinforcement. Second step is reinforcing of closely sized coconut shell particles (20/40 US mesh) with a composite material composed of the flax fiber and poly glycidyl methacrylate polymer (PGMA). The aim of reinforcing coconut shell with the composite material is to improve its strength to resist closure pressure. Similar to the procedure that is used for most RCP, the third step includes coating of reinforced particles with a thin layer of epoxy resin. Scope of the study includes the following procedures:

1- Preparation of the coconut shell particles to use as a substrate in the composition of ULW proppant. The process of preparing coconut shell particles includes drying, crushing, grinding, and sieving.

2- Reinforcement of coconut shell particles with a composite material that is comprised of the flax fiber & PGMA polymer by using chemical bath deposition method.

3- Coating of the reinforced coconut shells with epoxy resin by using chemical bath deposition method.

4- Evaluating the quality of the uncoated coconut shell and CMRCP based on the standard procedure (API RP 60).

5- Investigation of physical properties of the uncoated coconut shell and CMRCP using crush resistance test.

6- Evaluation of mechanical behavior of the uncoated coconut shell, reinforced coconut shell and CMRCP using single compression test (Dag series 4000). In addition, simulation and experimental results of mechanical behavior of single particles of the uncoated coconut shell, reinforced coconut shell and CMRCP under compression are developed and compared.

7- Control quality evaluation of the uncoated coconut shell and CMRCP by using commercial proppants.

8- Characterization of the uncoated coconut shell, reinforced coconut shell and CMRCP to find microstructure, compounds and functional groups, elements, and thermal stability of particles. Field emission scanning electron microscope (FESEM), scanning electron microscope (SEM), energy dispersive X-ray spectrometry (EDX) test, Fourier transform infrared spectroscopy (FTIR), and thermo gravimetric analysis (TGA) tests are used to characterize the uncoated coconut shell, reinforced coconut shell and CMRCP.

9- Simulation of mechanical behavior of the uncoated coconut shell and CMRCP under compression using ABAQUS software.

10- Evaluation of flow capacity of the uncoated coconut shell and CMRCP using fracture conductivity test according to the standard procedure (ISO13503-5). Sandstone core from Kuala Terengganu were used in the fracture conductivity tester.

11- Performing HF design with using FracproPT (version 10.824-2015) simulator to investigate the performance of CMRCP in San Juan basin formation. This field is chosen because Brady sand and ULW-1.25 have been widely used as proppant to stimulate wells in San Juan basin formation.

1.6 Significant of the Study

1- Provision of the coconut shell is cost saving, and it is available in tropical countries like Malaysia. Thus, more economic benefits can be obtained during utilization of coconut shells as substrate of ULW proppant, and it has great capability to convert as an economical product especially for tropical countries like Malaysia.

2- Coconut shells appear to be the best natural role model as proppant agent if reinforced and coated in order to increase impact-resistance. As presented in this study, CMRCP has high strength compared to the current commercial ULW proppants (ULW-1.25) that are introduced into the market.

3- Production process of CMRCP is safe because most of the elements that are used in the composition of CMRCP are organic materials which do not emit harmful gases, and they are degradable into nature.

1.7 Thesis Outline

The present thesis comprised of five chapters that are organized as follows:

Chapter 1: First chapter includes an overview of the study, background of the problem, problem statement, objectives, scopes and significance of the study.

Chapter2: A comprehensive review on the improved oil recovery methods, well stimulation, hydraulic fracturing and acid fracturing, HF models, HF design, proppant, history of proppant, various types of proppant such as CP and ULW proppant, physical properties of proppant, and evaluation of the quality of proppant are presented in the second chapter. In addition, this chapter is focused on the ULW proppant, historical background of ULW proppant, applications of ULW proppant, classification of ULW proppant, various arrangements of ULW proppant within the fracture, characterization of ULW proppant, simulation mechanical response of ULW proppant under compression, quality evaluation of ULW proppant, and advantages and disadvantages of ULW proppant, coated proppant and various methods of proppant coating, diverse types of polymers that are used for coating of proppant, and fracturing fluids.

Chapter 3: Third chapter describes the procedure of performing the study that is divided into main parts such as preparation of substrate material and evaluation of its quality as well as simulating mechanical response of the uncoated coconut shells under compression, the procedure of the reinforcing and coating of desirable particle size of coconut shells in addition to simulating mechanical response of CMRCP under compression, evaluating quality of CMRCP for possible use as proppant, the trend of setting up the fracture conductivity tester, and the procedure of performing HF design.

Chapter 4: Implementation, analysis, and discussion of the various parts of the study and a comparison with other available proppants are presented in this chapter.

Chapter 5: This chapter covered conclusions and future works.

REFERENCES

Abbott, J., Borisova, E. A., Kalinin, S. A., Matveev, A. V., Osiptsov, A. A., & Thiercelin, M. (2009). Elongated particles for fracturing and gravel packing, W.O. Patent 2009088317.

Achaw, O.-W., & Afrane, G. (2008). The evolution of the pore structure of coconut shells during the preparation of coconut shell-based activated carbons. *Microporous and Mesoporous Materials, 112*(1), 284-290.

Adachi, J., Siebrits, E., Peirce, A., & Desroches, J. (2007). Computer simulation of hydraulic fractures. *International Journal of Rock Mechanics and Mining Sciences, 44*(5), 739-757.

Agunsoyea, J., Talabib, S., Belloa, S. & Awec, I. 2014. The Effects of Cocos Nucifera (Coconut Shell) on the Mechanical and Tribological Properties of Recycled Waste Aluminium Can Composites. *Tribology in Industry*, 36.

Akbarningrum, F., Rudy, A., Carolina, A., & Yusnita, L. (2012). Enzymatic Hydrolysis of Alkaline Pretreated Coconut Coir. *International Conference on Chemical and Material Engineering.* September 12–13. Semarang, Indonesia.

Al-Ghazal, M., Al-Driweesh, S., & Al-Shammari, F. (2013). First Successful Application of an Environment Friendly Fracturing Fluid during On-The-Fly Proppant Fracturing. *Paper presented at the IPTC 2013: International Petroleum Technology Conference.* 26-28 March, Beijing, China, 1-12.

Al-Kanaan, A., Rahim, Z., & Al-Anazi, H. (2013). Selecting Optimal Fracture Fluids Breaker System and Proppant Type for Successful Hydraulic Fracturing and Enhanced Gas Production-Case Studies. *Paper presented at the SPE Unconventional Gas Conference and Exhibition.* 28-30 January, Muscat, Oman, 1-8.

Almlöf Ambjörnsson, H. (2013). Mercerization and Enzymatic Pretreatment of Cellulose in Dissolving Pulps. PhD Thesis. Karlstad University.

Anh Dung Ngo, J. D., Asami Nakai, Tohru Morii, Suong V. Hoa, & Hamada, H. (2010). *Design, Manufacturing and Applications of Composites Eighth Workshop 2010*.

API. (2014). Recommended Practice for Measurement of and Specifications for Proppants Used in Hydraulic Fracturing and Gravel-packing Operations.

API, (1989). Recommended Practices for Evaluating Short Term Proppant Pack Conductivity (pp. 27).

Ashcroft, W. (1993). Curing agents for epoxy resins *Chemistry and technology of epoxy resins* (pp. 37-71): Springer.

Awoleke, O. O., Romero, J. D., Zhu, D., & HIll, D. (2012). Experimental investigation of propped fracture conductivity in tight gas reservoirs using factorial design. *Paper presented at the SPE Hydraulic Fracturing Technology Conference.* 6-8 February, The Woodlands, Texas, USA, 1-15.

Baker, S., & Herrman, T. J. (1995). *Evaluating particle size*: Cooperative Extension Service, Kansas State University. College of Agricultural Sciences.

Balci, S., Dogu, T., & Yucel, H. (1993). Pyrolysis kinetics of lignocellulosic materials. *Industrial & engineering chemistry research, 32*(11), 2573-2579.

Barati, R., & Liang, J. T. (2014). A review of fracturing fluid systems used for hydraulic fracturing of oil and gas wells. *Journal of Applied Polymer Science, 131*(16).

Barmatov, E. B., Lyapunov, K. M., & Golovin, A. V. (2010). Particulate material for proppant flowback control, U.S. Patent 7,718,583.

Barree, R., Cox, S., Barree, V., & Conway, M. (2003). Realistic assessment of proppant pack conductivity for material selection. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 5-8 October, Denver, Colorado, 1-12.

Bazan, L. W., Larkin, S. D., Jacot, R. H., & Meyer, B. R. (2002). Modeling of simultaneous proppant fracture treatments in the Fruitland coal and Pictured Cliffs Formations in the San Juan Basin. *Paper presented at the SPE Eastern Regional Meeting.* 23-26 October, Lexington, Kentucky, 1-12.

Beekman, W. J., Meesters, G. M., Becker, T., Gaertner, A., Gebert, M., & Scarlett, B. (2003). Failure mechanism determination for industrial granules using a repeated compression test. *Powder technology, 130*(1), 367-376.

Bestaoui-Spurr, N. (2014). Materials Science Improves Silica Sand Strength. *SPE International Symposium and Exhibition on Formation Damage Control.* 26-28 February, Lafayette, Louisiana, USA, 1-11.

Bisanda, E., & Ansell, M. P. (1991). The effect of silane treatment on the mechanical and physical properties of sisal-epoxy composites. *Composites Science and Technology, 41*(2), 165-178.

Bjerre, A. B., & Schmidt, A. S. (1997). *Development of chemical and biological processes for production of bioethanol: Optimization of the wet oxidation process and characterization of products*. MS Thesis. Roskilde. Denmark.

Board, M. J., Rorke, T. J., Williams, G. J., & Gay, N. J. (1992). Fluid injection for rockburst control in deep mining. *Paper presented at the The 33th US Symposium on Rock Mechanics (USRMS).* 3-5 June, Santa Fe, New Mexico, 1-10.

Bodirlau, R., & Teaca, C. (2009). Fourier transform infrared spectroscopy and thermal analysis of lignocellulose fillers treated with organic anhydrides. *Rom J Phys, 54*(1-2), 93-104.

Boney, C. L., Miller, M. J., & Lo, S. W. (2004). Conductive proppant and method of hydraulic fracturing using the same. U.S. Patent 6,725,930.

Brannon, H. D., Malone, M. R., Rickards, A. R., Wood, W. D., Edgeman, J. R., & Bryant, J. L. (2004). Maximizing fracture conductivity with proppant partial monolayers: theoretical curiosity or highly productive reality? *Paper presented at the SPE Annual Technical Conference and Exhibition.* 26-29 September, Houston, Texas, 1-23.

Brannon, H. D., & Starks, T. R. (2009). Maximizing Return-On-Fracturing-Investment by Using Ultra-Lightweight Proppants to Optimize Effective Fracture Area: Can Less Be More? *Paper presented at the SPE Hydraulic Fracturing Technology Conference.* 19-21 January, The Woodlands, Texas, 1-13.

Brannon, H. D., Wood, W. D., Edgeman, R., Richards, A. R., Stephenson, C. J., Walser, D., & Malone, M. (2009). Method of Treating Subterranean Formations Using Mixed Density Proppants or Sequential Proppant Stages, U.S. Patent 7,472,751.

Brannon, H. D., Wood, W. D., Rickards, A. R. & Stephenson, C. J. (2010).Method of enhancing hydraulic fracturing using ultra lightweight proppants. U.S. Patent 7,726,399.

Bruins, P. F. (1976). *Unsaturated polyester technology*: Taylor & Francis.

Brydson, J. (1982). Plastic Materials, 4th edn, Chapter 27: Butterworth, London.

Bürer, T., & Günthard, H. H. (1960). Infrarot-Spektren der Cyclane und Cyclanone VI. CH-stretching-und CH2-bending-Schwingungen von Cyclanonen. *Helvetica Chimica Acta, 43*(6), 1487-1494.

Burke, L. H., Nevison, G. W., & Peters, W. E. (2011). Improved Unconventional Gas Recovery With Energized Fracturing Fluids: Montney Example. *Paper presented at the SPE Eastern Regional Meeting.* 17-19 August, Columbus, Ohio, USA, 1-10.

Caffery, H., Lee, L.-J., & Svoboda, C. (2011). Process for coating gravel pack sand with polymeric breaker, U.S. Patent 7,972,997.

Cannan, C. D., & Palamara, T. C. (2006). Low density proppant: U.S. Patent 7,036,591.

Card, R. J., Howard, P. R., Feraud, J. P., & Constien, V. G. (2001). Pumping fibers downhole with proppant to form porous pack that inhibits flow of solid particulates from well: Google Patent.

Carrijo, O, Makishima, N. (2002). Fiber of green coconutshell as agricultural substrate. *Brazilian Horticulture 20.4*, 533–535.

Chapman, M., & Palisch, T. (2014). Fracture conductivity–Design considerations and benefits in unconventional reservoirs. *Journal of Petroleum Science and Engineering*. 124 (1), 407-415.

Chattopadhyay, D., & Raju, K. (2007). Structural engineering of polyurethane coatings for high performance applications. *Progress in Polymer Science, 32*(3), 352-418.

Chen, Z. (2012). The Application of Light and Ultra-Light Weight Proppant in Horizontal Well Sand Control: Unified Model and Case Histories. *SPE Deepwater Drilling and Completions Conference. Society of Petroleum Engineers.* 20-21 June, Galveston, Texas, USA, 1-12.

Chen, T., Wang, Y., Yan, C., Wang, H., Xu, Y., & Ma, R. (2015). Preparation of heat resisting poly (methyl methacrylate)/graphite composite microspheres used as ultra-lightweight proppants. *Journal of Applied Polymer Science*. *132*(18).

Cheung, S. (1988). Effects of acids on Gravels and Proppants. *SPE Production Engineering, 3*(02), 201-204.

Choate, R., Lent, J., & Rightmire, C. (1984). Upper Cretaceous geology, coal, and the potential for methane recovery from coalbeds in San Juan Basin--Colorado and New Mexico.

Chun, K. S., Husseinsyah, S., & Osman, H. (2013). Properties of coconut shell powder-filled polylactic acid ecocomposites: Effect of maleic acid. *Polymer Engineering & Science, 53*(5), 1109-1116.

Cleary, M. (1994). Hydraulic Fracturing in Medium-High Permeability Reservoirs: Methodology and Economic Advantages of Properly-Executed Jobs. *Paper presented at the European Petroleum Conference.* 25-27 October, London, United Kingdom, 1-16.

Cooke. (1975). Hydraulic fracturing method. U.S. Patent 3,888,311.

Cooke Jr, C. (1973). Conductivity of fracture proppants in multiple layers. *Journal of Petroleum Technology, 25*(09), 1,101-101,107.

Coulter, G., & Wells, R. (1972). The Advantages of High Proppant Concentration in Fracture Stimulation. *Journal of Petroleum Technology, 24*(06), 643-650.

Craver, C., & Carraher, C. (2000). *Applied polymer science: 21st century: 21st century*: Elsevier.

Crews, J. B., Huang, T., Gabrysch, A. D., Treadway, J. H., Willingham, J. R., Kelly, P. A., & Wood, W. R. (2010). viscoelastic surfactant (VES) gelled aqueous fluids containing water, a VES, an internal breaker, a VES stabilizer, a fluid loss control agent and a viscosity enhancer are useful as treating fluids, particularly as fracturing fluids for subterranean formations; faster clean-up than polymer-based fluids. Google Patent.

Cutler, R., Enniss, D., Jones, A., & Swanson, S. (1985). Fracture conductivity comparison of ceramic proppants. *Society of Petroleum Engineers Journal, 25*(02), 157-170.

D695-02a, (2002). *Standard Test Method for Compressive Properties of Rigid Plastics*.

Daneshy, A. (2010). Hydraulic Fracturing To Improve Production. *The Way a Head, 6*, 14-17.

Darin, S., & Huitt, J. (1960). Effect of a partial monolayer of propping agent on fracture flow capacity. *Trans., AIME*, 219: 31.

Dasgupta, A. (2001). Improved oil recovery. *Geological Society of India, 57*(3), 283-287.

Dayan, A., Stracener, S. M., & Clark, P. E. (2009). Proppant Transport in Slickwater Fracturing of Shale Gas Formations. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 4-7 October, New Orleans, Louisiana, 1-9.

Dean, B. H., D, G. S., Ray, R. A., & John, S. C. (2004). Method of treating subterranean formations with porous ceramic particulate materials. U.S. Patent 10/824,217.

Decker, K. (2011). Qualifying fluid & proppant performance (pp. 1-11).

Deng, S., Zhou, X., Fan, C., Lin, Q., & Zhou, X. (2012). Release of interfacial thermal stress and accompanying improvement of interfacial adhesion in carbon fiber reinforced epoxy resin composites: Induced by diblock copolymers. *Composites Part A: Applied Science and Manufacturing, 43*(6), 990-996.

Deng, S., Zhou, X., Zhu, M., Fan, C., & Lin, Q. (2013). Interfacial toughening and consequent improvement in fracture toughness of carbon fiber reinforced epoxy resin composites: induced by diblock copolymers. *Express Polymer Letters, 7*(11).

Dewprashad, B. (1995). Method of producing coated proppants compatible with oxidizing gel breakers. U.S. Patent 5,420,174.

Dewprashad, B., Abass, H., Meadows, D., Weaver, J., & Bennett, B. (1993). A method to select resin-coated proppants. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 3-6 October, Houston, Texas, 1-8.

Division, C. O. a. G. C. C. a. N. O. C. (2001). CO Oil and Gas Conservation Commission and NM Oil Conservation Division.

Dos Santos, J. A., Cunha, R. A., de Melo, R. C., Aboud, R. S., Pedrosa, H. A., & Marchi, F. (2009). Inverted-Convection Proppant Transport for Effective Conformance Fracturing. *SPE Production & Operations, 24*(01), 187-193.

Drici, A., Djeteli, G., Tchangbedji, G., Derouiche, H., Jondo, K., Napo, K., Gbagba, M. (2004). Structured ZnO thin films grown by chemical bath deposition for photovoltaic applications. *physica status solidi (a), 201*(7), 1528-1536.

Droppert, D., Fiore, P., Cardarelli, F., & Dessureault, Y. (2002). High strength, heat- and corrosion-resistant ceramic granules for proppants. *Halliburton Energy Services, Houston*.

Duke, J. A. (2000). *Handbook of nuts: herbal reference library* (Vol. 4): CRC press.

Dusterhoft, R. (1994). FracPac completion services-stimulation and sand-control techniques for high-permeability oil and gas wells. *Halliburton Energy Services, Houston*.

Dutta, D. K., Sengupta, P., Saika, K., Sarmah, P. P., & Phukan, A. (2015). Resin coated proppants and process for the preparation thereof, W.O Patent 2015114648.

Eckertova, L. (2012). *Physics of thin films*: Springer Science & Business Media.

Economides, M. (2000). The Color of Oil: The History, the Money and the Politics of the World's Biggest Business. Elsevier.

Economides, M. J. (1992). *A practical companion to reservoir stimulation* (Vol. 34): Elsevier.

Economides, M. J., & Martin, T. (2007). *Modern fracturing: Enhancing natural gas production*: ET Publishing Houston, Texas.

Economides, M. J., & Nolte, K. G. (1989). *Reservoir stimulation*: J. Wiley.

Economides, M. J., Nolte, K. G., Ahmed, U., & Schlumberger, D. (2000). *Reservoir stimulation* (Vol. 18): Wiley Chichester.

Ellis, P. D. & Surles, B. W. (1997).Chemically inert resin coated proppant system for control of proppant flowback in hydraulically fractured wells. U.S.Patents.

Ellis, P. D., & Surles, B. W. (1998). Chemically inert resin coated proppant system for control of proppant flowback in hydraulically fractured wells, U.S. Patent 5,604,184.

Ely, J. W. (1985). *Secondary recovery of oil, oil wells, hydraulic fracturing.*Stimulation Engineering Handbook.

Ely, J. W., Fowler, S. L., Tiner, R. L., Aro, D. J., Sicard Jr, G. R., & Sigman, T. A. (2014). " Slick Water Fracturing and Small Proppant" The future of stimulation or a slippery slope? *Paper presented at the SPE Annual Technical Conference and Exhibition.* 27-29 October, Amsterdam, The Netherlands, 1-12.

England, K. (2004). Hydraulic fracturing method. U.S. Patent 6,776,235.

EPA, U. (2004). Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs Study United States Environmental Protection Agency.

Ercisli, S., Mazhar, K., Ozturk, I., Sayinci, B., & Kalkan, F. (2011). Comparison of some physico-mechanical nut and kernel properties of two walnut (Juglans regia L.) cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 39*(2), 227-231.

Evans, J. A., & Sharp, J. (1988). Process for preparing pre-cured proppant charge, U.S. Patent 4,581,253.

Fan, M., Dai, D. & Huang, B. 2012. Fourier transform infrared spectroscopy for natural fibres. *Fourier transform–materials analysis. InTech*.

Fao. (1989). Coconut-Tree of Life from from http://www.fao.org/docrep.

Fassett, J. E. (2006). The San Juan Basin: A Complex Giant Gas Field, New Mexico and Colorado.

Fast, C., Flickinger, D. H., & Howard, G. C. (1961). Effect of Fracture-formation Flow Capacity Contrast on Well Productivity. *Drilling and Production Practice*. 1 January, New York, New York, 1-7.

Ferrero, J. R. S., & Pershikova, E. M. (2013). Proppant, a method for production thereof and formation hydraulic fracturing method using the produced proppant. U.S. Patent 8,496,057.

Figura, L. O., & Teixeira, A. A. (2007). *Food physics*: Springer.

Fitzgibbon, J. J. (1989). Sintered spherical pellets containing clay as a major component useful for gas and oil well proppants, U.S. Patent No. 4,879,181.

Fleming, J. T., Pauls, R. W., Welton, T. D., McMechan, D. E., Todd, B. L., & Bryant, J. (2011). Clean fluid systems for partial monolayer fracturing: U.S. Patent 8,006,760.

Flex (2015).Proppant Fracturing Sands. From: http://flexfracsand.com.

Flint. (2011). Flint River Green Notebook. from www.FlintRiver.org.

Forum, N. M. E. (2015). Hydraulic fracturing is a means of extracting oil and natural gas from rock formations across the country- including in New Mexico. from http://www.nmenergyforum.com/topics/hydraulic-fracturing.

Fracline. (2010). Critical Proppant Selection Factors. from http://www.hexionfracline.com/critical-proppant-selection-factors.

Frantz Jr, J., Shannon, P., Moody, C., Glaser, T., Sawyer, W., & Williamson, J. (2001). Novel Well Testing Procedures Prove Successful in Dakota Formation Infill Program, San Juan Basin. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 30 September-3 October, New Orleans, Louisiana, 1-8.

Fredd, C., McConnell, S., Boney, C., & England, K. (2000). Experimental study of hydraulic fracture conductivity demonstrates the benefits of using proppants. *Paper presented at the SPE Rocky Mountain Regional/Low-Permeability Reservoirs Symposium and Exhibition.* 12-15 March, Denver, Colorado, 1-14.

Freeman, E. R., Anschutz, D. A., Renkes, J. J., & Milton-Tayler, D. (2006). Qualifying Proppant Performance. *Paper presented at the SPE Annual Technical Conference and Exhibition.*

Gadde, P. B., Liu, Y., Norman, J., Bonnecaze, R., & Sharma, M. M. (2004). Modeling proppant settling in water-fracs. *Paper presented at the SPE annual technical conference and exhibition.* 26-29 September, Houston, Texas: 1-10.

Gallegos, T. J., & Varela, B. (2015). Data regarding hydraulic fracturing distributions and treatment fluids, additives, proppants, and water volumes applied to wells drilled in the United States from 1947 through 2010: US Geological Survey.

Gaurav, A. (2010). *Ultra Light Weight Proppants in Shale Gas Fracturing.* (Masters of Science in Engineering), The University of Texas at Austin.

Gaurav, A., Gu, M., & Daneshy, A. (2012). Final Report.

Gaurav, A., Dao, E., & Mohanty, K. (2012). Evaluation of ultra-light-weight proppants for shale fracturing. *Journal of Petroleum Science and Engineering, 92*, 82-88.

Gaurav, A., Dao, E. K., & Mohanty, K. K. (2010). Ultra-Lightweight Proppants for Shale Gas Fracturing. *Paper presented at the Tight Gas Completions Conference*. 2-3 November, San Antonio, Texas, USA, 1-13.

Geertsma, J., & De Klerk, F. (1969). A rapid method of predicting width and extent of hydraulically induced fractures. *Journal of Petroleum Technology, 21*(12), 1,571-571,581.

Gibson, L. J., & Ashby, M. F. (1999). *Cellular solids: structure and properties*: Cambridge university press.

Gidley, J. L. (1989). Recent advances in hydraulic fracturing. Richardson, TX (USA), Society of Petroleum Engineers.

Gkikas, G., Barkoula, N.-M., & Paipetis, A. (2012). Effect of dispersion conditions on the thermo-mechanical and toughness properties of multi walled carbon nanotubes-reinforced epoxy. *Composites Part B: Engineering, 43*(6), 2697-2705.

Glaze, O. H., & Underdown, D. R. (1984). Proppant charge and method, U.S. Patent 4,443,347.

Gnanasaraswathi M, R. J. R., Lakshmipraba S, Aarthi Lakshmipriya V, Kamatchi S. (2014). Evaluation Of Antimicrobial Plant Metabolites Fromachyranthes Aspera Against Multidrug Resistant Chronic Wound Isolates. *Paper presented at the National Conference on Plant Metabolomics,* Phytodrugs.

Goldschmidt, A., & Streitberger, H.-J. (2003). *BASF handbook on basics of coating technology*: William Andrew.

Gómez, A. O. (2014). Experimental Measurement Process of a Volume Displacement of Oil Caught in a Fractured Rock by Gravity and Using Surfactant Foam. *Experimental and Computational Fluid Mechanics* (pp. 227-233): Springer.

Graham, J. W., & Sinclair, A. R. (1985). Novolak-coated particles, high strength, coupling, crosslinking, U.S. Patent 12/808,117.

Grant, K. J., Kohn, S. C., & Brooker, R. A. (2007). The partitioning of water between olivine, orthopyroxene and melt synthesised in the system albite–forsterite–H 2 O. *Earth and Planetary Science Letters, 260*(1), 227-241.

Green, D. W., & Willhite, G. P. (1998). *Enhanced oil recovery*: Richardson, Tex.: Henry L. Doherty Memorial Fund of AIME, Society of Petroleum Engineers.

Halliburton. (2015). San Juan Basin. from http://www.halliburton.com/en-US/ps/solutions/unconventional-resources.

Harper, T., Hagan, J., & Martins, J. (1985). Fracturing Without Proppant. *Paper presented at the SPE/DOE Low Permeability Gas Reservoirs Symposium.* 19-22 March, Denver, Colorado, 1-12.

Harris, P. (1989). Effects of texture on rheology of foam fracturing fluids. *SPE Production Engineering, 4*(03), 249-257.

Harris, P. C. (1987). Dynamic Fluid-Loss Characteristics of CO2-Foam Fracturing Fluids. *SPE Production Engineering, 2*(02), 89-94.

Harris, P. C. (1996). Rheology of crosslinked foams. *SPE Production & Facilities, 11*(02), 113-116.

Harris, P. C., Morgan, R. G., & Heath, S. J. (2005). Measurement of proppant transport of frac fluids. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 9-12 October, Dallas, Texas, 1-12.

Hashemian, S. (2014). A Comparative Study of Cellulose Agricultural Wastes (Almond Shell, Pistachio Shell, Walnut Shell, Tea Waste And Orange Peel) for Adsorption of Violet B Dye from Aqueous Solutions. *Oriental Journal of Chemistry, 30*(4), 2091-2098.

Hayashi, K., Sato, A., & Ito, T. (1997). In situ stress measurements by hydraulic fracturing for a rock mass with many planes of weakness. *International Journal of Rock Mechanics and Mining Sciences, 34*(1), 45-58.

Hayashi, T., Smith, F. T., & Lee, K. H. (1987). Antitumor agents. 89. Psychorubrin, a new cytotoxic naphthoquinone from Psychotria rubra and its structure-activity relationships. *Journal of medicinal chemistry, 30*(11), 2005-2008.

Hexion (2014).Precured Resin Coated Sand. From: http://www.hexion.com.

Hibbitt, Karlsson, & Sorensen. (2001). *ABAQUS/standard user's Manual* (Vol. 1): Hibbitt, Karlsson & Sorensen.

Hibbitt, K. (2005). Sorensen Inc. ABAQUS/standard user's manual, Version 6.5. *Hibbitt, Karlsson, & Sorensen, Inc*.

Holditch. (1989). Staged Field Experiment No. 2: Application of Advanced Geological, Petrophysical and Engineering Technologies to Evaluate and Improve Gas Recovery from Low Permeability Sandstone Reservoirs In GRI-89/0140 (Ed.), (Vol. Volume I): Gas Research Institute.

Holditch. (1990). Staged Field Experiment No. 2: Application of Advanced Geological, Petrophysical and Engineering Technologies to Evaluate and Improve Gas Recovery from Low Permeability Sandstone Reservoirs. In GRI-90/0093 (Ed.), (Vol. Volume II.): Gas Research Institute.

Holditch. (1991). Staged Field Experiment No. 3: Application of Advanced Technologies in Tight Gas Sandstone – Travis Peak and Cotton Valley Formations, Waskom Field, Harrison County, Texas. In GRI-91/0048 (Ed.): Gas Research Institute.

Holditch, S., Ely, J., Semmelbeck, M., Carter, R., Hinkel, J., & Jeffrey Jr, R. (1988). Enhanced recovery of coalbed methane through hydraulic fracturing. *Paper* *presented at the SPE Annual Technical Conference and Exhibition.* 2-5 October, Houston, Texas, 1-9.

Holditch, S. A. (1992). Staged Field Experiment No. 3: Application of Advanced Technologies in Tight Gas Sandstone – Frontier Formation, Chimney Butters Field, Sublette County, Wyoming. In GRI-92/0394 (Ed.): Gas Research Institute.

Hu, G., Campbell, M., & Huang, C. (2014). Dynamic Plastic Deformation of Deepwater Steel Catenary Risers Under Extreme Cyclic Compressive Loading. *Oil and Gas Facilities, 4*(01), 73-79.

Huang, C.-L., Lindström, H., Nakada, R., & Ralston, J. (2003). Cell wall structure and wood properties determined by acoustics—a selective review. *Holz als Roh-und werkstoff, 61*(5), 321-335.

Huang, T., & Crews, J. B. (2008). Nanotechnology applications in viscoelastic surfactant stimulation fluids. *SPE Production & Operations, 23*(04), 512-517.

Huang, Z., Li, Y., Lin, S., & Wu, W. (2010). Composition and method for producing an ultra-lightweight ceramic proppant, U.S. Patent 14/247,578.

Huda, M. S., Drzal, L. T., Mohanty, A. K., & Misra, M. (2008). Effect of fiber surface-treatments on the properties of laminated biocomposites from poly (lactic acid)(PLA) and kenaf fibers. *Composites Science and Technology, 68*(2), 424-432.

Huffman, A. C. (2002). San Juan Basin Province (22).

Huitt, B., & McGlothlin, B. (1966). Fracturing process and impregnated propping agent for use therein. U.S. Patent 3,254,717.

Hussain, H., McDaniel, R. R., & Callanan, M. J. (2003). Proppants with fiber reinforced resin coatings. U.S. Patent 6,528,157.

Husseinsyah, S., & Mostapha, M. (2011). The effect of filler content on properties of coconut shell filled polyester composites. *Malaysian polymer journal, 6*(1), 87-97.

Institute, G. T. (2002). Drilling and Production Statistics for Major US Coalbed Methane and Gas Shale Reservoirs. from http://www.gastechnology.org.

IPPC. (2007). Ceramic Manufacturing Industry. Europe Union: IPPC.

ISO, I. S. O. (2006). Procedures for measuring the long-term conductivity of proppants (pp. 25).

Jacobs, T. (2015). Shale Revolution Revisits the Energized Fracture. from http://www.spe.org/jpt/article/6439-shale-revolution-revisits-the-energized-fracture.

Jennings, J., & Macmillan, N. (1986). A tough nut to crack. *Journal of materials science, 21*(5), 1517-1524.

John, M. J., & Anandjiwala, R. D. (2009). Chemical modification of flax reinforced polypropylene composites. *Composites Part A: Applied Science and Manufacturing, 40*(4), 442-448.

Johnson Alengaram, U., Jumaat, M. Z., Mahmud, H., & Fayyadh, M. M. (2011). Shear behaviour of reinforced palm kernel shell concrete beams. *Construction and Building Materials, 25*(6), 2918-2927.

Jones, A. H., & Cutler, R. A. (1985). Hollow proppants and a process for their manufacture, U.S. Patent 4,547,468.

Jonoobi, M., Niska, K. O., Harun, J., & Misra, M. (2009). Chemical composition, crystallinity, and thermal degradation of bleached and unbleached kenaf bast (Hibiscus cannabinus) pulp and nanofibers. *BioResources, 4*(2), 626-639.

Jung, G.-B., Lee, H.-J., Kim, J.-H., Lim, J. I., Choi, S., Jin, K.-H., & Park, H.-K. (2011). Effect of cross-linking with riboflavin and ultraviolet A on the chemical bonds and ultrastructure of human sclera. *Journal of biomedical optics, 16*(12), 125004-1250046.

Kalia, S., Dufresne, A., Cherian, B. M., Kaith, B., Avérous, L., Njuguna, J. & Nassiopoulos, E. (2011). Cellulose-based bio-and nanocomposites: a review. International Journal of Polymer Science 2011.

Karthikeyan, J. (2004). Cold spray technology: International status and USA efforts. *Report from "ASB Industries Inc, 1031*, 1-14.

Kathalingam, A., Ambika, N., Kim, M., Elanchezhiyan, J., Chae, Y., & Rhee, J. (2010). Chemical bath deposition and characterization of nanocrystalline ZnO thin films. *Materials Science (0137-1339), 28*(2).

Kazayawoko, M., Balatinecz, J., & Matuana, L. (1999). Surface modification and adhesion mechanisms in woodfiber-polypropylene composites. *Journal of materials science, 34*(24), 6189-6199.

Kelly, A. (2012). *Concise encyclopedia of composite materials*: Elsevier.

Kendrick, D. E., Puskar, M. P., & Schlotterbeck, S. T. (2005). *Ultralightweight proppants: a field study in the big sandy field of eastern Kentucky.* Paper presented at the SPE Eastern Regional Meeting.

Khandal, D. R. K. (2006). *Organic Chemistry Synthetic Polymers and Dyes*: ShriRam Institute for Industrial Research 19, University Road Delhi.

Khanna, A., Kotousov, A., Sobey, J., & Weller, P. (2012). Conductivity of narrow fractures filled with a proppant monolayer. *Journal of Petroleum Science and Engineering, 100*, 9-13.

Khristianovic, S., & Zheltov, Y. (1955). *Formation of vertical fractures by means of highly viscous fluids.* Paper presented at the Proc. 4th world petroleum congress, Rome.

Kim, Y. H. (2013). *Modeling and analysis of fluid driven fracture propagation under the plane strain condition.* (PhD.), University of California, Ann Arbor, USA.

Kincaid, K. P., Snider, P. M., Herring, M., Mahoney, R. P., & Soane, D. (2013). Self-Suspending Proppant. *Paper presented at the SPE Hydraulic Fracturing Technology Conference.* 4-6 February, The Woodlands, Texas, USA, 1-12.

Kogut, L., & Etsion, I. (2002). Elastic-plastic contact analysis of a sphere and a rigid flat. *Journal of Applied Mechanics, 69*(5), 657-662.

Koslowski, H. J. (2000). Dictionary of man-made fibers. *Special edition*.

Kramer. (2015). Walnut Shell Abrasive Media. 2015, from http://www.kramerindustriesonline.com.

Krumbein, W., & Sloss, L. (1963). Stratigraphy and sedimentation. *Department of Geology, Northwestern University*.

Kulkarni, M., & Ochoa, O. (2012). Light weight composite proppants: computational and experimental study. *Mechanics of Advanced Materials and Structures, 19*(1-3), 109-118.

Kulkarni, M. C. (2008). *Characterization of light weight composite proppants.* M.S Thesis. Texas A&M University.

Kurz, B. A., Schmidt, D. D., & Cortese, P. E. (2013). Investigation of Improved Conductivity and Proppant Applications in the Bakken Formation. *Paper presented at the SPE Hydraulic Fracturing Technology Conference.* 4-6 February, The Woodlands, Texas, USA, 1-13.

Kuwata, M., & Hogg, P. (2011). Interlaminar toughness of interleaved CFRP using non-woven veils: Part 1. Mode-I testing. *Composites Part A: Applied Science and Manufacturing, 42*(10), 1551-1559.

Lamond, J. F., & Pielert, J. H. (2006). *Significance of tests and properties of concrete and concrete-making materials* (Vol. 169): ASTM International.

Langenkamp, R. D. (1980). Illustrated petroleum reference dictionary.

Lesko, T., Brown, J. E., Willberg, D. M., Kosarev, I., & Medvedev, A. (2008). Heterogeneous Proppant Placement in a Fracture with Removable Channelant Fill, U.S. Patent 7,581,590.

Lewin, M. (2006). *Handbook of fiber chemistry*: Crc Press.

Li, B., Li, L., Huang, Y., & Zhang, A.-M. (2009). Preparation of Resinified Granulated Walnut Shell as Fracturing Proppant of Ultralow Density [J]. *Oilfield Chemistry, 3*, 006.

Li, L., Liu, S., & Liu, J. (2011). Surface modification of coconut shell based activated carbon for the improvement of hydrophobic VOC removal. *Journal of hazardous materials, 192*(2), 683-690.

Li, X., Tabil, L. G., & Panigrahi, S. (2007). Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review. *Journal of Polymers and the Environment, 15*(1), 25-33.

Li, Y., Huang, Z., Lin, S., & Wu, W. (2013). Composition and method for producing an ultra-lightweight ceramic proppant. U.S. Patent 8,727,003.

Li, Y., Lin, S., & Wu, W. (2014). Composition and method for producing an ultra-lightweight ceramic proppant, U.S. Patent 14/247,578.

Liang, F., Sayed, M., Al-Muntasheri, G. A., Chang, F. F., & Li, L. (2015). A Comprehensive Review on Proppant Technologies. *Petroleum, 2*(1), 26-39.

Lilholt, H., & Lawther, J. (2000). Natural organic fibers. *Comprehensive composite materials, 1*, 303-325.

Lin, O. H., Kumar, R. N., Rozman, H., & Noor, M. A. M. (2005). Grafting of sodium carboxymethylcellulose (CMC) with glycidyl methacrylate and development of UV curable coatings from CMC-g-GMA induced by cationic photoinitiators. *Carbohydrate Polymers, 59*(1), 57-69.

Luo, H., Santra, A., Norman, L. R., Parker, M., Powell, R. J., & Saini, R. K. (2011). Sintered proppant made with a raw material containing alkaline earth equivalent. U.S. Patent 8,012,582.

Lyle, D. (2011). Proppant Open Production Pathways. *Schlumberger Ind. Artic.* 1-6.

Mader, D. (1989). *Hydraulic proppant fracturing and gravel packing*: Elsevier.

Mahoney, R. P., Soane, D. S., Herring, M. K., & Kincaid, K. P. (2012). Self-suspending proppants for hydraulic fracturing. U.S. Patent 13/923,158.

Maide. (2015). Physical & Chemical Properties of ceramic proppants, Retrieved from http://www.maideceramics.com/curable-resin-coated-proppant.

Malhotra, S., & Sharma, M. M. (2014). Experimental Measurement of Settling Velocity of Spherical Particles in Unconfined and Confined Surfactant-based Shear Thinning Viscoelastic Fluids. *JoVE (Journal of Visualized Experiments)*(83), 50749-50749.

Malone, P. (2012). Resin-Coated Sands. 2015, from http://www.upstreampumping.com.

Martone, P. T., Boller, M., Burgert, I., Dumais, J., Edwards, J., Mach, K., Speck, T. (2010). Mechanics without muscle: biomechanical inspiration from the plant world. *Integrative and comparative biology, 50*(5), 888-907.

Mauseth, J. D. (2014). *Botany: an introduction to plant biology*: Jones & Bartlett Publishers.

Maxey, J., Crews, J., & Huang, T. (2008). Nanoparticle Associated Surfactant Micellar Fluids. *Paper presented at the The Xv International Congress On Rheology: The Society of Rheology 80th Annual Meeting.* 12-14 June, Noordwijk, Netherlands, 1-11.

Mayavan.T, K. L. (2013). Experimental and Finite Element Studies on Formability of Low Carbon Steel Sheets using Deep Drawing. *International Journal of Engineering and Technology (IJET), Vol 5 No 1.*

McDaniel, G. A., Abbott, J., Mueller, F. A., Anwar, A. M., Pavlova, S., Nevvonen, O., Alary, J. (2010). Changing the shape of fracturing: new proppant improves fracture conductivity. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 19-22 September, Florence, Italy, 1-21.

McDaniel, R. R., & McCrary, A. L. (2015). Coated and cured proppants, U.S. Patent 14/673,340.

McDaniel, R. R., McCrary, A. L., Green, J. W., & Xu, L. (2012). Particles for use as proppants or in gravel packs, methods for making and using the same, U.S. Patent 8,227,026.

McDaniel, R. R., & Willingham, J. R. (1978). The effect of various proppants and proppant mixtures on fracture permeability. *Paper presented at the SPE Annual Fall Technical Conference and Exhibition.* 1-3 October, Houston, Texas, 1-12.

Mcdaniel, R., Mccrary, A., Monastiriotis, S. & Barthel, R. (2014).Coated and cured proppants. U.S. Patent 673,340.

McEwen, M. (2015). Hydraulic fracturing drives proppant use to 135 billion pounds in 2014. from http://www.mrt.com/business/oil/article.

Meyer, B. (1986). Design formulae for 2-D and 3-D vertical hydraulic fractures: model comparison and parametric studies. *Paper presented at the SPE Unconventional Gas Technology Symposium.* 18-21 May, Louisville, Kentucky, 1-18.

Mihoc, G., Ianoş, R., Păcurariu, C., & Lazău, I. (2013). Combustion synthesis of some iron oxides used as adsorbents for phenol and p-chlorophenol removal from wastewater. *Journal of thermal analysis and calorimetry, 112*(1), 391-397.

Milczarek, J. M., Dziadosz, M., & Ziêba-Palus, J. (2009). Way to distinguish car paint traces based on epoxy primer layers analysis by pyrolysis-gas chromatography-mass spectrometry. *Chemia Analityczna, 54*(2), 173.

Moeller, T., Sherwood, W., Land, M., Ely, J., Dyk, T., & Hopkins, A. (2015). Methods of hydraulically fracturing and recovering hydrocarbons. U.S. Patent 14/324,056.

Mohanty, A., Misra, M., & Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: an overview. *Macromolecular Materials and Engineering, 276*(1), 1-24.

Mohd Saaid, I., Kamat, D., & Muhammad, S. (2011). Characterization of Malaysia Sand for Possible Use as Proppant. *American International Journal of Contemporary Research, 1*(1), 37-44.

Monteiro, S., Terrones, L., & D’almeida, J. (2008). Mechanical performance of coir fiber/polyester composites. *Polymer testing, 27*(5), 591-595.

Montgomery, C. (2013). Fracturing Fluids. *Paper presented at the ISRM International Conference for Effective and Sustainable Hydraulic Fracturing.* 20-22 May, Brisbane, Australia, 1-23.

Montgomery, C., & Steanson, R. (1985). Proppant selection: the key to successful fracture stimulation. *Journal of Petroleum Technology, 37*(12), 2,163-162,172.

Murdoch, L. C., & Slack, W. W. (2002). Forms of hydraulic fractures in shallow fine-grained formations. *Journal of Geotechnical and Geoenvironmental Engineering, 128*(6), 479-487.

Murphey, J. R., & Totty, K. D. (1989). Method for providing coated particulate materials suspended in aqueous gels. U.S. Patent 5,128,390.

Mwaikambo, L., & Ansell, M. (2003). Hemp fibre reinforced cashew nut shell liquid composites. *Composites Science and Technology, 63*(9), 1297-1305.

Mwaikambo, L. Y., & Ansell, M. P. (2002). Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization. *Journal of Applied Polymer Science, 84*(12), 2222-2234.

Myers, R., Potratz, J., & Moody, M. (2004). Field application of new lightweight proppant in Appalachian tight gas sandstones. P*aper presented at the SPE Eastern Regional Meeting.* 15-17 September, Charleston, West Virginia: 1-9.

Nagpal, S., Jain, N., & Sanyal, S. (2011). Stress concentration and its mitigation techniques in flat plate with singularities-A critical review. *Engineering Journal, 16*(1), 1-16.

Neto, J., Abrahao, T., Prata, F. G. M., Gomez, J., Pedroso, C. A., Martins, M., & Silva, D. N. (2012). Ultralightweight Proppants: An Effective Approach To Address Problems in Long Horizontal Gravel Packs Offshore Brazil. *SPE Drilling & Completion, 27*(04), 613-624.

Ngaruiya, J. M. (2004). *Fundamental Processes in Growth of Reactive DC Magnetron Sputtered Thin Films.* Universitätsbibliothek.

Ngo, A. D. (2010). *Design, Manufacturing and Applications of Composites: Proceedings of the Eighth Joint Canada-Japan Workshop on Composites: École de Technologie Supérieure, Montréal, Québec, Canada; Industrial Materials Institute, Boucherville, Québec, Canada: July 26-29*: DEStech Publications, Inc.

Nguyen, P., Weaver, J., Parker, M., McCabe, M., Hoogteijling, M., & van der Horst, M. (2002). A novel approach for enhancing proppant consolidation: laboratory testing and field applications. *Paper presented at the SPE Annual*

Technical Conference and Exhibition. 29 September-2 October, San Antonio, Texas, 1-12.

Nikiforuk, A. (2015a). *Slick water : fracking and one insider's stand against the world's most powerful industry* (eBook : Document : Biography : English ed.): Vancouver ; Berkeley : Greystone Books.

Nikiforuk, A. (2015b). Slick Water: Fracking and One Insider's Stand against the World's Most Powerful Industry. Greystone Books Ltd.

Nikiforuk, A. (2015c). *Slick Water: Fracking and One Insider's Stand against the World's Most Powerful Industry*.

Nolte, K. (1988). Principles for fracture design based on pressure analysis. *SPE Production Engineering, 3*(01), 22-30.

Nordgren, R. (1972). Propagation of a vertical hydraulic fracture. *Society of Petroleum Engineers Journal, 12*(04), 306-314.

Novotny, E. (1977). Proppant transport. *Paper presented at the SPE Annual Fall Technical Conference and Exhibition*. 9-12 October, Denver, Colorado, 1-12.

O'Brien, F., & Haller, C. (2014). Ceramic proppants: Google Patent.

Öchsner, A., & Altenbach, H. (2014). *Design and Computation of Modern Engineering Materials* (Vol. 54): Springer.

Olanipekun, E., Olusola, K., & Ata, O. (2006). A comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates. *Building and environment, 41*(3), 297-301.

Ozkan, G., & Koyuncu, M. A. (2005). Physical and chemical composition of some walnut (Juglans regia L) genotypes grown in Turkey. *Grasas y Aceites, 56*(2), 141-146.

Palisch, T., Vincent, M., & Handren, P. (2010). Slickwater Fracturing: Food for Thought. SPE Prod & Oper 25 (3): 327–344: SPE-115766-PA. http://dx. doi. org/10.2118/115766-PA.

Palisch, T. T., Chapman, M. A., & Godwin, J. W. (2012). Hydraulic Fracture Design Optimization in Unconventional Reservoirs-A Case History. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 8-10 October, San Antonio, Texas, USA, 1-14.

Palisch, T. T., Duenckel, R. J., Bazan, L. W., Heidt, J. H., & Turk, G. A. (2007). Determining Realistic Fracture Conductivity and Understanding its Impact on

Well Performance-Theory and Field Examples. *Paper presented at the SPE Hydraulic Fracturing Technology Conference.* 29-31 January, College Station, Texas, U.S.A, 1-13.

Palisch, T. T., Duenckel, R. J., Chapman, M. A., Woolfolk, S., & Vincent, M. C. (2009). How to Use and Misuse Proppant Crush Tests--Exposing the Top 10 Myths. *Paper presented at the SPE Hydraulic Fracturing Technology Conference.* 19-21 January, The Woodlands, Texas, 1-15.

Palisch, T. T., Vincent, M. C., & Handren, P. J. (2008). *Slickwater fracturing: food for thought.* Paper presented at the SPE Annual Technical Conference and Exhibition. 21-24 September, Denver, Colorado, USA, 1-20.

Palmer, I., & Kutas, G. (1991). Hydraulic Fracture Height Growth in San Juan Basin Coalbeds. *Paper presented at the Low Permeability Reservoirs Symposium.* 15-17 April, Denver, Colorado, 1-18.

Parse, J. B., & Jette, B. D. (2011). Multiple component neutrally buoyant proppant: U.S. Patent 9,051,511.

Peng, F., Ren, J.-L., Xu, F., Bian, J., Peng, P., & Sun, R.-C. (2009). Fractional study of alkali-soluble hemicelluloses obtained by graded ethanol precipitation from sugar cane bagasse. *Journal of agricultural and food chemistry, 58*(3), 1768-1776.

Perinović, S., Andričić, B., & Erceg, M. (2010). Thermal properties of poly olive stone flour composites. *Thermochimica acta*, *510*(1), 97-102.

Perkins, T., & Kern, L. (1961). Widths of hydraulic fractures. *Journal of Petroleum Technology*, *13*(09), 937-949.

Pershikova, E. (2007). Proppant and method of forming proppant, U.S. Patent 11/768,494.

Pershing, L. W., & Goldslager, B. A. (2014). Coating compositions and related products and methods, U.S. Patent 8,790,768.

Pongthunya, P. (2007). *Development, setup and testing of a dynamic hydraulic fracture conductivity apparatus.* M.S Thesis. Texas A&M University.

Portier, S., André, L., & Vuataz, F.-D. (2007). Review on chemical stimulation techniques in oil industry and applications to geothermal systems. *Engine, work package, 4*, 32.

Posey, D. (2007). Light proppant gets heavy results. *Hart's E & P*, *80*(10), 90-91.

Powell, R., McCabe, M., Slabaugh, B., Terracina, J., Yaritz, J., & Ferrer, D. (1997). Applications of a New Efficient Hydraulic Fracturing Fluid System. *Paper presented at the Latin American and Caribbean Petroleum Engineering Conference.* 30 August-3 September, Rio de Janeiro, Brazil, 1-7.

Prasanna, G. V., & Subbaiah, K. V. (2013). Modification, flexural, impact, compressive properties & chemical resistance of natural fibres reinforced blend composites. *Malays Polym J, 8*(1), 38-44.

Raaen, A., Skomedal, E., Kjørholt, H., Markestad, P., & Økland, D. (2001). Stress determination from hydraulic fracturing tests: the system stiffness approach. *International Journal of Rock Mechanics and Mining Sciences, 38*(4), 529-541.

Rahim, Z., Alanazi, H., & AlKanaan, A. (2013). Selecting Optimal Fracture Fluids, Breaker System and Proppant Type for Successful Hydraulic Fracturing and Enhanced Gas Production Case Studies. *Saudi Aramco J. Technol, 22*.

Raj, R., Kokta, B., Dembele, F., & Sanschagrain, B. (1989). Compounding of cellulose fibers with polypropylene: Effect of fiber treatment on dispersion in the polymer matirx. *Journal of Applied Polymer Science, 38*(11), 1987-1996.

Ramurthy, M., Magill, D. P., Sanchez, P. W. & Parker, M. A. (2013). Case history: production results from partial monolayer proppant fracture treatments in the pictured cliffs formation horizontal wells of San Juan basin. *SPE Hydraulic Fracturing Technology Conference. Society of Petroleum Engineers.* 4-6 February, The Woodlands, Texas, USA, 1-12.

Reddy, B. D., Jyothy, S. A. & Shaik, F (2014). Experimental analysis of the use of coconut shell as coarse aggregate. *IOSR J Mech Civil Eng,* 10**,** 06-13.

Rediger, R. A. (2011). Proppants for use in hydraulic fracturing of subterranean formations, U.S. Patent 9,045,678.

Reidenbach, V., Harris, P., Lee, Y., & Lord, D. (1986). Rheological study of foam fracturing fluids using nitrogen and carbon dioxide. *SPE Production Engineering, 1*(01), 31-41.

Reinicke, A. (2011). *Mechanical and hydraulic aspects of rock-proppant systems: laboratory experiments and modelling approaches.* Potsdam, Univ., Diss.

Reinicke, A., Rybacki, E., Stanchits, S., Huenges, E., & Dresen, G. (2010). Hydraulic fracturing stimulation techniques and formation damage mechanisms—Implications from laboratory testing of tight sandstone–proppant systems. *Chemie Der Erde-Geochemistry, 70*, 107-117.

Ribeiro, L. H., & Sharma, M. M. (2012). Multiphase fluid-loss properties and return permeability of energized fracturing fluids. *SPE Production & Operations, 27*(03), 265-277.

Rickards, A. R., Brannon, H. D., & Wood, W. D. (2006). High strength, ultralightweight proppant lends new dimensions to hydraulic fracturing applications. *SPE Production & Operations, 21*(02), 212-221.

Rickards, A. R., Brannon, H. D., Wood, W. D., & Stephenson, C. J. (2003a). High Strength Ultra-Lightweight Proppant Lends New Dimensions to Hydraulic Fracturing Applications. *Paper presented at the SPE annual technical conference and exhibition.* 5-8 October, Denver, Colorado, 1-14.

Rickards, A. R., Brannon, H. D., Wood, W. D., & Stephenson, C. J. (2003b). High strength, ultra-lightweight proppant lends new dimensions to hydraulic fracturing applications. *Paper presented at the SPE annual technical conference and exhibition.* 5-8 October, Denver, Colorado, 1-14.

Riew, C. K. (1989). *Rubber-toughened plastics*: American chemical society.

Robertson, J., Chilingarian, G., & Kumar, S. (1989). *Surface Operations in Petroleum Production, II* (Vol. 19): Elsevier.

Robillard, M., & Lebrun, G. (2010). Processing And Mechanical Properties Of Unidirectional Hemp-Paper/Epoxy Composites. *Paper presented at the The 10 th International Conference on Flow processes in Composite Materials (FPCM 10).* Monte Verita, Ascona, CH-July, 10-15.

Rohring, S. (2013). Porous proppants, W.O. Patent 2013059793.

Rong, M. Z., Zhang, M. Q., Liu, Y., Yang, G. C., & Zeng, H. M. (2001). The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites. *Composites Science and Technology, 61*(10), 1437-1447.

Roodhart, L. (1985). Proppant settling in non-Newtonian fracturing fluids. *Paper presented at the SPE/DOE Low Permeability Gas Reservoirs Symposium.* 19-22 March, Denver, Colorado, 1-10.

Rout, T. K. (2013). *Pyrolysis of coconut shell.* Master of Technology. NIT. Rourkela.

Rumpf, D. S., & Lemieux, P. R. (1990). Method for making lightweight proppant for oil and gas wells, U.S. Patent 4,977,116.

Russell, A., Müller, P., Shi, H., & Tomas, J. (2014). Influences of loading rate and preloading on the mechanical properties of dry elasto-plastic granules under compression. *AIChE Journal*, *60*(12), 4037-4050.

Russell, A., & Street, K. (1985). Delamination and debonding of materials. *ASTM STP, 876*, 349.

Saha, P., Manna, S., Chowdhury, S. R., Sen, R., Roy, D., & Adhikari, B. (2010). Enhancement of tensile strength of lignocellulosic jute fibers by alkali-steam treatment. *Bioresource technology, 101*(9), 3182-3187.

Salmah, H., Marliza, M., & Teh, P. (2013). Treated Coconut Shell Reinforced Unsaturated Polyester Composites. *International journal of Engineering and Technology IJET-IJEN, 13*(02), 94-103.

Samanta, B. & Maity, T. (2012). Effectiveness of amine functional aniline furfuraldehyde condensate as toughening agent for epoxy resin. Pigment & Resin Technology 41(6): 344-350.

Sankapal, B., Sartale, S., Lokhande, C., & Ennaoui, A. (2004). Chemical synthesis of Cd-free wide band gap materials for solar cells. *Solar energy materials and solar cells, 83*(4), 447-458.

Santrol, F. (2015). Choose the Right Proppant, Google Patent.

Sapieha, S., Allard, P., & Zang, Y. (1990). Dicumyl peroxide-modified cellulose/LLDPE composites. *Journal of Applied Polymer Science, 41*(9-10), 2039-2048.

Sapuan, S., Harimiand, M., & Maleque, M. (2003). Mechanical properties of epoxy/coconut shell filler particle composites. *Arabian Journal for Science and Engineering, 28*(2), 171-182.

Schein, G. (2005). The Application and technology of slickwater fracturing. *SPE-108807-DL.*

Schein, G. W., Carr, P. D., Canan, P. A., & Richey, R. (2004). Ultra lightweight proppants: their use and application in the Barnett Shale. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 26-29 September, Houston, Texas, 1-10.

Schüler, P., Speck, T., Bührig-Polaczek, A., & Fleck, C. (2014). Structure-Function Relationships in Macadamia integrifolia Seed Coats–Fundamentals of the Hierarchical Microstructure. *PloS one, 9*(8), 102913.

Senturk, U., Lanci, M. P., Jackson, R., & Lau, J. W. (2006). for use in pavement markings having high resistance to degradation from environmental exposure; reflective devices or coatings, U.S. Patent 7,045,475.

Şengül, A., & Arslan, H. (2008). Synthesis and Characterization of Novel Polyamide and Polyhydrazides Based on the 6, 6´-disubstituted-2, 2´-bipyridine. Turkish Journal of Chemistry, 32(3), 355-364.

Sharma, R., Patil, S., Bhavsar, S., Patil, A., & Dori, L. (1999). Compositional effect on optical characteristic of solution grown Cd~ 1~ x Mn~ xSe thin films. *Indian Journal Of Pure And Applied Physics, 37*(12), 876-880.

Shen, X., Bai, M., & Standifird, W. (2011). *Drilling and Completion in Petroleum Engineering: Theory and Numerical Applications*: CRC Press.

Shmotev, S., & Pliner, S. (2009). Ceramic proppant with low specific weight, U.S. Patent 7,521,389.

Shojamoradi, A., Abolghasemi, H., Esmaili, M., Foroughi-dahr, M., & Fatoorehchi, H. (2013). Experimental Studies On Congo Red Adsorption By Tea Waste In The Presence Of Silica And Fe2o3 Nanoparticles. *Journal of Petroleum Science and Technology, 3*(2), 25-34.

Sierra, L. (2009). First Regional Selective Packerless Acid Fracture Stimulation With Coiled Tubing: A Documented Case History From Saudi Arabia. *Paper presented at the 8th European Formation Damage Conference.* 27-29 May, Scheveningen, The Netherlands, 1-14.

Sinclair, A. R., Akbar, S., & Okell, P. R. (2007). Soluble fibers for use in resin coated proppant. U.S. Patent 7,244,492.

Sinclair, A. R., & Richard, L. J. I. I. (1997). Composite and reinforced coatings on proppants and particles, U.S. Patent 5,597,784.

Singh, B., Gupta, M., & Verma, A. (1996). Influence of fiber surface treatment on the properties of sisal-polyester composites. *Polymer composites, 17*(6), 910-918.

Singh, H., Sidhu, T., & Kalsi, S. (2012). Cold spray technology: future of coating deposition processes. *Frattura e Integrita Strutturale* (22).

Singh, K., Risse, M., Das, K., & Worley, J. (2009). Determination of composition of cellulose and lignin mixtures using thermogravimetric analysis. *Journal of Energy Resources Technology, 131*(2), 022201.

Singh, P., Quraishi, M., & Ebenso, E. E. (2013). Microwave Assisted Green Synthesis of Bis-Phenol Polymer Containing Piperazine as a Corrosion Inhibitor for Mild Steel in 1M HCl. *Int. J. Electrochem. Sci, 8*(8), 10890-108902.

Singhapura, S., Perera, M., Chathushka, P., & De Silva, G. (2013). Investigation on compressive strength of masonry blocks manufactured using crushed coconut shells. University of Moratuwa, Sri Lanka.

Smith, R. J., Loscutova, J. R., Coker, C. E., Barron, A. R., Skala, R. D., Whitsitt, E. A., Bordia, R. (2011). Composition and method for making a proppant, U.S. Patent 7,867,613.

Soane, D., Mahoney, R. P., & Portilla, R. C. (2010). Proppants for hydraulic fracturing technologies, U.S. Patent 12/908,411.

Soucek, M. D., Templeman, C. G., Alyamac, E., Gu, H., & Ishii, M. (2012). Modified epoxide primers, U.S. Patent 13/020,642.

Sousa, F. W., Sousa, M. J., Oliveira, I., Oliveira, A. G., Cavalcante, R. M., Fechine, P., Nascimento, R. F. (2009). Evaluation of a low-cost adsorbent for removal of toxic metal ions from wastewater of an electroplating factory. *Journal of Environmental Management, 90*(11), 3340-3344.

Spray,C.(2015).Cold spray-how does this process work?, from http://www.impact-innovations.com/en/coldgas/process_en.html.

Stevens, S. H., Kuuskraa, J., & Schraufnagel, R. (1996). Technology spurs growth of US coalbed methane. *Oil and Gas Journal, 94*(1).

Stosur, G. J., Hite, J. R., Carnahan, N. F., & Miller, K. (2003). The Alphabet Soup of IOR EOR and AOR: Effective Communication Requires a Definition of Terms. *Paper presented at the SPE International Improved Oil Recovery Conference in Asia Pacific.* 20-21 October, Kuala Lumpur, Malaysia, 1-3.

Surguchev, L., Manrique, E., & Alvarado, V. (2005). Improved oil recovery: status and opportunities. *Paper presented at the 18th World Petroleum Congress.* 25-29 September, Johannesburg, South Africa, 1-17.

Sosun (2016).Ceramic proppant. From: http://www.osunsteel.com.

Svoboda, C., Caffery, H. & Lee, L. J. 2011. Process for coating gravel pack sand with polymeric breaker, U.S. Patent 7,972,997.

Syed, A., (2002). Proppant composition for gas and oil-well fracturing, U.S. Patent 6,372,678.

Tahir, H., & Alam, U. (2014). Lignocellulosic: Non-Conventional Low Cost Biosorbent for the Elution of Coomassie Brilliant Blue (R-250). *International Journal of Chemistry, 6*(2), p56.

Tanguay, C., & Kumar, R. (2014). Resin-Coated Proppant And Methods Of Use. U.S. Patent. 14/115,395.

Tarek, T. A. (2014). Petrophysical Characterization of the Effect of Xanthan. M.E Thesis. Dalhousie University. Halifax, Nova Scotia.

Tavares, L., & King, R. (1998). Single-particle fracture under impact loading. *International Journal of Mineral Processing, 54*(1), 1-28.

Terracina, J. M., Turner, J. M., Collins, D. H., & Spillars, S. (2010). Proppant selection and its effect on the results of fracturing treatments performed in shale formations. P*aper presented at the SPE Annual Technical Conference and Exhibition.* 19-22 September, Florence, Italy, 1-17.

Terzaghi, K. v. (1923). Die berechnung der durchlassigkeitsziffer des tones aus dem verlauf der hydrodynamischen spannungserscheinungen. *Sitz. Akad. Wiss. Wien, Abt. IIa, 132*, 125-138.

Texasfracsand. (2015). Brady, TX Area Frac Sand - Product Specifications. from http://texasfracsands.com.

Thaker, N., Srinivasulu, B., & Shit, S. C. (2013). A Study on Characterization and Comparison of Alkali Treated and Untreated Coconut shell Powder Reinforced Polyester Composites. *International Journal of Scientific Engineering and Technology, 2*, 469-473.

Thomas, S., Visakh, P., & Mathew, A. P. (2013). Advances in natural polymers. *Advanced Structured Materials*, 255-312.

Tinashe, S. E. (2010). *Conceptual design of a low pressure cold gas dynamic spray (LPCGDS) system.* Faculty of Engineering and the Built Environment, University of the Witwatersrand.

Toledo, R. T. (2007). *Fundamentals of food process engineering*: Springer Science & Business Media.

Tserki, V., Matzinos, P., & Panayiotou, C. (2006). Novel biodegradable composites based on treated lignocellulosic waste flour as filler. Part II. Development of biodegradable composites using treated and compatibilized waste flour. *Composites Part A: Applied Science and Manufacturing, 37*(9), 1231-1238.

Tunio, S. Q., Tunio, A. H., Ghirano, N. A., & El Adawy, Z. M. (2011). Comparison of different enhanced oil recovery techniques for better oil productivity. *Int. J. Appl., Sci. Technol, 1*(5).

Tyler, A., & Fields, W. (2014). Three wire press solids dewatering method and apparatus for oil and gas field applications, U.S. Patent 14/134,796.

Ueno, K., Kunisada, K., Yamada, K. (2014). Well proppant and method for recovering hydrocarbon from hydrocarbon-bearing formation, W.O Patent 2014045815.

Underdown, D. R., & Glaze, O. H. (1986). Proppant charge and method, U.S. Patent 4,564,459.

Unnikrishnan, K., & Thachil, E. T. (2006). Toughening of epoxy resins. *Designed monomers and polymers, 9*(2), 129-152.

Valadez-Gonzalez, A., Cervantes-Uc, J., Olayo, R., & Herrera-Franco, P. (1999). Effect of fiber surface treatment on the fiber–matrix bond strength of natural fiber reinforced composites. *Composites Part B: Engineering, 30*(3), 309-320.

Vermylen, J. P. (2011). *Geomechanical studies of the Barnett shale, Texas, USA*: Stanford University.

Villafuerte, J. (2010). Recent trends in cold spray technology: looking at the future. *Surface Engineering, 26*(6), 393-394.

Vincent, M. (2004). Field Trial Results: Investigating the Benefits of Increased Fracture Conductivity in the Low-Permeability Sandstones of the Pinedale Anticline Western Wyoming. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 26-29 September, Houston, Texas, 1-16.

Vincent, M. C. (2009). Examining Our Assumptions-Have Oversimplifications Jeopardized Our Ability to Design Optimal Fracture Treatments? *Paper presented at the SPE Hydraulic Fracturing Technology Conference.* 19-21 January, The Woodlands, Texas, 1-51.

Vu-Quoc, L., Zhang, X., & Lesburg, L. (2000). A normal force-displacement model for contacting spheres accounting for plastic deformation: force-driven formulation. *Journal of Applied Mechanics, 67*(2), 363-371.

Wada, M., Ike, M., & Tokuyasu, K. (2010). Enzymatic hydrolysis of cellulose I is greatly accelerated via its conversion to the cellulose II hydrate form. *Polymer Degradation and Stability, 95*(4), 543-548.

Walker, J. C. (2006). *Primary wood processing: principles and practice*: Springer.

Wang, W., & Huang, G. (2009). Characterisation and utilization of natural coconut fibres composites. *Materials & Design, 30*(7), 2741-2744.

Wang, X., Perzon, E., Delgado, J. L., de la Cruz, P., Zhang, F., Langa, F., Inganäs, O. (2004). Infrared photocurrent spectral response from plastic solar cell with low-band-gap polyfluorene and fullerene derivative. *Applied physics letters, 85*(21), 5081-5083.

Wang, Z. (2013). *Modeling acid fracture conductivity to stimulate tight carbonates.* M.s Thesis. The Petroleum Institute (United Arab Emirates).

Weaver, J. D., Nguyen, P. D., Parker, M. A., & van Batenburg, D. W. (2005). Sustaining fracture conductivity. *Paper presented at the SPE European Formation Damage Conference.* 25-27 May, Sheveningen, Netherlands,1-10.

Wechsler, A., Zaharia, M., Crosky, A., Jones, H., Ramírez, M., Ballerini, A, Sahajwalla, V. (2013). Macadamia (Macadamia integrifolia) shell and castor (Rícinos communis) oil based sustainable particleboard: A comparison of its properties with conventional wood based particleboard. *Materials & Design, 50*, 117-123.

Wei, Q., Ma, X., Zhao, Z., Zhang, S., & Liu, S. (2010). Antioxidant activities and chemical profiles of pyroligneous acids from walnut shell. *Journal of Analytical and Applied Pyrolysis, 88*(2), 149-154.

Welker, C. M., Balasubramanian, V. K., Petti, C., Rai, K. M., DeBolt, S., & Mendu, V. (2015). Engineering Plant Biomass Lignin Content and Composition for Biofuels and Bioproducts. *Energies, 8*(8), 7654-7676.

Westwood, W. D. (2003). *Sputter deposition*. AVS Education Committee.

Wheeler, R. S., Newhall, C., Myers, R. R., Ward, B., Beall, B. B., & Brannon, H. (2013). Method of fracturing using ultra lightweight proppant suspensions and gaseous streams, Google Patent.

Wheeler, R. S., Newhall, C. C., Myers, R. R., Ward, B., Beall, B. B., & Brannon, H. D. (2012). Method of fracturing using ultra lightweight proppant suspensions and gaseous streams, U.S. Patent 8,109,336.

Wilhelm, U. T. (2006). Lightweight proppant and method of making same, U.S. Patent 11/042,104.

Windebank, M., Parias, T., & Hart, J. (2013). Proppants and anti-flowback additives comprising flash calcined clay, methods of manufacture, amd methods of use, U.S. Patent 14/405,493.

Wong, D. W., Lin, L., McGrail, P. T., Peijs, T., & Hogg, P. J. (2010). Improved fracture toughness of carbon fibre/epoxy composite laminates using dissolvable thermoplastic fibres. *Composites Part A: Applied Science and Manufacturing, 41*(6), 759-767.

Wood, W. D., Brannon, H. D., Rickards, A. R., & Stephenson, C. (2003). Ultra-lightweight proppant development yields exciting new opportunities in hydraulic fracturing design. *Paper presented at the SPE Annual Technical Conference and Exhibition.* 5-8 October, Denver, Colorado, 1-19.

World, G. (2015). Aappg Bulletin,

http://aapgbull.geoscienceworld.org/content/90/10/1519/F1.expansion.html.

Wu, T., Wu, B., & Zhao, S. (2013). Acid resistance of silicon-free ceramic proppant. *Materials Letters, 92*, 210-212.

Xiao, B., Sun, X. & Sun, R. (2001). Chemical, structural, and thermal characterizations of alkali-soluble lignins and hemicelluloses, and cellulose from maize stems, rye straw, and rice straw. Polymer Degradation and Stability 74(2): 307-319.

Xie, Y., Hill, C. A., Xiao, Z., Militz, H., & Mai, C. (2010). Silane coupling agents used for natural fiber/polymer composites: A review. *Composites Part A: Applied Science and Manufacturing, 41*(7), 806-819.

Xiong, X. Y., Cao, D. Y., Jiang, Y. T., Bian, L. H., Wang, W., Wang, L., & Liu, Q. (2014). Application of Well Temperature Logging in Coalbed Methane Well Fracture Effectiveness Evaluation. *Applied Mechanics and Materials, 522*, 1522-1527.

Xu, L., McCrary, A. L., & Green, J. W. (2012). Methods for making and using UV/EB cured precured particles for use as proppants, U.S. Patent 8,240,383.

Xu, X., Huang, R., Li, H., & Huang, Q. (2014). Determination of Poisson’s Ratio of Rock Material by Changing Axial Stress and Unloading Lateral Stress Test. *Rock Mechanics and Rock Engineering,* 1-5.

Ying-ting, T. Y.-z. G. (2003). Study of Chemical Composition of Lignin and Its Application [J]. Journal of Cellulose Science and Technology 1.

Yee, A. F., & Pearson, R. A. (1986). Toughening mechanisms in elastomer-modified epoxies. *Journal of materials science, 21*(7), 2462-2474.

Yew, C. H. (1997). *Mechanics of hydraulic fracturing*: Gulf Professional Publishing.

Ying-ting, T. Y.-z. G. (2003). Study of Chemical Composition of Lignin and Its Application [J]. *Journal of Cellulose Science and Technology, 11*(1), 42-55.

Yokota, K., & Konno, M. (1980). *Dynamic Poisson's ratio of soil.* Paper presented at the Proc. 7th World Conf. Earthquake Eng., Istanbul, 475-478.

Yoshida, S. (2014). Quantitative evaluation of an epoxy resin dispersion by infrared spectroscopy. *Polymer journal, 46*(7), 430-434.

Zeng, X., & Ruckenstein, E. (1996). Control of pore sizes in macroporous chitosan and chitin membranes. *Industrial & engineering chemistry research, 35*(11), 4169-4175.

Zhang, M. Q., Rong, M. Z. & Luo, Y. (2008). Sliding wear performance of epoxy-based nanocomposites. *Tribology and Interface Engineering Series,* 55**,** 108-129.

Zhang, S. (2010). *Nanostructured Thin Films and Coatings: Mechanical Properties*: CRC Press.

Zohary, D., Hopf, M., & Weiss, E. (2012). *Domestication of Plants in the Old World: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin*: Oxford University Press.

Zotskine, Y. (2014). Simultaneous injection of an acidic well treatment fluid and a proppant into a subterranean formation, C. A Patent 2798861.