Enhanced Oil Recovery Field Development:

Process Flow of EOR Selection for Sandstone Formation

by

Mohamad Faizzudin B Mat Piah

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

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(Dr. Mohammed Abdalla Ayoub Mohammed)

Date: 5 December 2012

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CERTIFICATION OF ORIGINALITY

This is to certify that I, Mohamad Faizzudin B Mat Piah (I/C No: 900704-03-5601), am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

At present, the world-wide production statistics indicate that the average ultimate recovery from light and medium gravity oils by conventional (primary/secondary) methods is around 25-35% of the Oil Initially in Place (OIIP), while from heavy oil deposits on the average, only 10% OIIP is recoverable. Hence, this lead to a substantial percentage of oil in place left unrecoverable by the conventional methods.

The research for tomorrow's oil reserves has directed the efforts of the energy industry to frontiers beyond the conventional exploration and production strategies. Frontier defined not by geography or geology but rather by technology. This frontier is a collection of technologies that involve the use of thermal, gas and chemical means for producing more oil that fall under the broad umbrella called Enhanced Oil Recovery (EOR). The results of successful application of this new technology will have a decisive impact on the energy conservation program of any oil producing country.

Developing technologies for enhanced oil recovery (EOR) from existing oil fields would supply the world’s energy needs for several decades. The application of EOR in many major oil-producing countries remains in its conceptual stage. Every oil reservoir has a unique ionic environment that changes naturally and by human intervention, which makes it difficult to identify recovery mechanism(s) in EOR methods. This study updates the EOR selection criteria and presents new EOR screening tools based on dataset distribution, incremental recovery and deterministic modeling.

This project presents a methodology for the selection of the enhanced oil recovery technologies that better applies to some group of fields using screening criteria. The methodology will be integrated into a process flow in order to make repetitive analysis in an easier way. The methodology incorporates oil and rock properties and the reservoir current conditions, besides the specific knowledge of the reservoir generalities and history

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Oil and gas industry have never been at its peaks as present. Half of the world energy consumption and transportation requirement demand for the petroleum product in order to function (J. P. Brashear 1978). It is shown by the increasing figure of 5% annually for the product even from World War 2 and it peaked in 1973 at 17 million barrel per day (bpd).

Presently, it is acknowledge that the world has sufficient supply to meet increasing future demand. Nevertheless, a changing pattern is being faced in today's oil and gas industry as stockholders face provision challenge to occupy future demand (Gamal Hassan 2012). The ongoing impacts of financial turmoil and economic downturn, the changing structure of world energy markets, and developments in policies and technologies seem to have direct consequences in the industry.

Aging and matured field constitute a major role in today's world oil production and it has raised concern among oil companies, national resource holders and also regulators. When a reservoir has implemented waterflooding method in its production system after primary production, the well is considered mature which its peak production had passed. Therefore, an urgent and unquestionably need for EOR implementation for those reservoir is crucial and vital to increase its economic value and extend the assets' productive life (E. Manrique 2005).

Developing technologies for enhanced oil recovery (EOR) from existing oil fields would supply the world's energy needs for several decades. This alternative represents a valuable option considering the current and future outlook of world energy supplies and reserves. The most significant problems involve the stability of the oil supply, the maturity of alternative sources of energy, the accuracy of oil reserve volumes, the maximum oil production forecasts and increasing energy demands, especially in developing nations.

On the other hand, EOR is not a ready, economical initiative. It is controlled by the crude prices specifically and world economic generally. Not to mention its high dependency on three important contributors which are capital availability, investors willingness to risk their money on considerably EOR “gambles” and also the availability of more attractive investment options (E. Manrique 2005).

According to preliminary studies conducted in Libyan oil reservoir, significant amount of oil reserves which will lead to Libyan’s enhanced recovery scheme and thus tip to the development of the important scheme. Methods such as injectant availability, suitability and requirement and economic feasibility need to be applied with accordance to a strong planning and design of an EOR project (Abdulrazag Y. Zekri 2000).

The sparks to implement EOR have been discussed in many major oil-producing companies since 1959. However, in the early beginning of its implementation, EOR is merely a conceptual design rather than practically implemented in real life. Todays, more than 16 EOR methods have been applied to the field and openly recorded mostly in Society of Petroleum Engineer (SPE) database. Yet, these EOR methods have not been update to incorporate and satisfy current technology or field data. In todays’ hydrocarbon-demand world, these EOR methods must be kept up to date to encourage further EOR development and implementation (Aladasani and Bai 2010).

In this study, EOR selection criteria are updated to include new proposed and improved EOR selection methods based on respective reservoir properties. The EOR projects that have been identified sum up to 600 projects range from years 1998 to 2010 obtained from SPE database. From the study on previously done EOR project, two newly proposed EOR screening tools are present in this report. The first new proposed criteria is based on the dataset distribution of the main EOR methods and the second proposed criteria is based on the recorded enhanced production of the field which implement the selected EOR method. At the end of this project, a process flow for sandstone formation will be developed using a database system where proposed EOR method based on respective oil and reservoir properties given by the user.

1.2 Problem Statement

1.2.1 Problem Identification

Screening criteria has been solely depend on Taber’s et al screening criteria which was designed in the late 90’s. Although the screening criteria still decent, there are some improvement can be made on the selection process. In addition, there are EOR methods which have been recorded in SPE database have not been updated for a long time.

Conventional method to determine type of EOR to be implemented in specific reservoir has raised the concern in the oil and gas industry for the time taken of the screening procedure for each reservoir because of the significantly time-consuming. Thus, computer technologies come out with the solution where improvement in the application of the screening criteria through the use of artificial intelligence techniques has been popular this day.

Nevertheless, the value of these programs depends on the accuracy of the input data. In recent years, there were a number of EOR method that are economically and justifiably suitable for some reservoir, hence old programs which are not accounted for the new techniques become obsolete.

1.2.2 Significance of the Project

The project will improve the selection of EOR method based on the selection criteria that had been developed by Taber et al. In addition, this project also will provide a future reference in helping to determine type of EOR that is going to be implemented in any particular reservoir fast and accurate. The integration of the methodology into a database system will help to make repetitive analysis in an easier way and can be applied to identify the technologies whit higher potential.

1.2.3 Objective and Scope of Study

There are two main objectives that will be acquired upon completing the project which are as follow:

i. To study and improve EOR process flow for sandstone formation reservoir.
ii. To design and introduce an EOR screening criteria database management for sandstone formation.

1.2.4 Relevancy of the Project

The project will be weighted more on research project which will lead to less optimization in mechanical equipment usage. However due to its dependency in collecting and studying reservoir physical characteristic and its economical aspect, it will consume most of the time given in executing the project. Apart from that, less concern will be on the cost and budget allocation for the project as most of the resources (software and lab facilities) is provided by the benefactor (UTP).

CHAPTER 2
LITERATURE REVIEW

2.1 Oil Production

As today demand for hydrocarbon continues to grow rather faster than the supply, the analyst take a step forward and predicting that todays' world oil production has reached its peak and been very critical. Study showed that among 649 billion barrels of oil reservoirs in United State (US), only 22 billion can be produced by the mean of natural depletion and secondary recovery. Then when EOR is taking into consideration and implemented, it can offer the recoverable of the oil up to 200 billion barrels from the existing US reservoir which can be sum up and equivalent to the cumulative oil production to date (DOE 2005).

Researches on EOR have been remarkable in the early 1980s where during the time, oil prices were rising relentlessly corresponding to the oil demand. Many major oil companies during the time were taking initiative to fund and develop new technologies. As a result, the production of oil reached 20 000 bbl/d in the US alone. However, from 1986 to 2003, oil prices regulate around $20 per barrel. Thus, it is not the best interest of oil operators and producers to invest in either new EOR technologies or new ideas to extract incremental oil from existing reservoir. Nevertheless, todays' oil prices have been firmly at its highest, above $100 per barrel and analyst believe that the competition to invent new technologies among oil companies from all over the world will be commenced to meet current oil ever demanding market.

2.2 Enhanced Oil Recovery

Generally speaking, enhanced oil recovery is any method that can be used to extract liquid hydrocarbon from the reservoir after its production by the means of primary recovery has been significantly depleted. Though, enhanced oil recovery has been professionally defined as *"the process of producing liquid hydrocarbons other than conventional method such as by the mean of the reservoir own energy or the reservoir re-pressurizing schemes either with gas or water"*. It is studied that by using production using primary recovery only constitute 30% of the reservoir production (oil initially in place). Meanwhile, it is estimated that approximately 2000 barrels of conventional oil and 5000 barrels of heavy oil remains in reservoir worldwide after conventional recovery method have been exhausted which constitute to the large and attractive 70% remaining of the reservoir capability. The choice of the method and the expected recovery depends on many considerations, economic as well as technological (S. Thomas 2007).

A large number of variables are associated with a given oil reservoir, for instance, pressure and temperature, crude oil type and viscosity, and the nature of the rock matrix and connate water. Because of these variables, not every type of EOR process can be applied to every reservoir. An initial screening procedure would quickly eliminate some EOR processes from consideration in particular reservoir applications. This screening procedure involves the analysis of both crude oil and reservoir properties. It should be recognized that these screening criteria are only guidelines (Ronald E. Terry 2001).

In EOR screening criteria, a set of reservoir parameters are taken as consideration (temperature, depth, pressures, permeability, oil saturation, viscosity, type of formation, etc.). The parameters data usually are in term of success and failure or by examining the criteria of the EOR method itself. Screening criteria has evolved from simple binary system to an integrated approach based on artificial intelligence data taken from the field (E. Manrique 2005).

The study on large scale geological heterogeneities on the recovery of oil showed the relationship between a sandstone reservoir's architecture and conventional recovery efficiency and EOR strategies, among others. The proposed methodology is a matrix based on the depositional systems characterized in terms of lateral and vertical heterogeneities. Although the location of EOR projects as a function of the depositional system heterogeneities is somewhat subjective due to the geological information, it is still believed that this type of analysis provides guidance for the decision making process associated with EOR projects. With the regard to carbonate reservoirs, this type of reservoir might be analyzed and exploited in the same way by understanding the digenetic changes and depositional environment complexities associated to carbonate formations (E. Manrique 2005).

Using analytical approach, the reservoir was the basic unit of analysis. These reservoirs representing some degree of promise for EOR development were grouped into EOR targets according to the most favorable technique and common development problems. These targets were then separated into four broad categories; (1) those within current technological bounds and unaffected by nonprocess factors, (2) those outside current technology but within the anticipated scope of industry research and development at the current rate of development, (3) those within current or anticipated technology but constrained by nonprocess factors, such as environmental limitations, market imbalances or shortages of critical supplies, and (4) those outside current technology but that could be developed through an accelerated program of research and development (J.P. Brashear 1978).

Analytical approach included the use of a screening module, a process module and a detailed economic module. Screening module applies a series of screening criteria to all known oil reservoirs to determine the enhanced oil recovery and advanced secondary recovery technologies which are applicable to the reservoir. In many cases, the same reservoir is a candidate for several technologies. Process module applies a series designed of production profile functions to the reservoir properties in order to calculate the well-level technical production for each candidate oil project. Economic module forecasts the annual oil and gas production from existing fields, reserve growth and exploration. It perform economic evaluation of the projects and ranks the reserves growth and exploration projects in a way designed to mimic the decision process of the oil and gas industry. Development decisions and project selection depends upon economic viability determined using a full and detailed cash flow assessment and the competition for capital, drilling and other development constraints (Hitesh Mohan 2011).

2.3 EOR Screening Criteria

To summarize this set of screening criteria, it is emphasized that many complexities have surely been over simplified if not disregarded altogether. All this set of criteria should be used for quickly ranking candidate reservoirs for gas EOR potential and should be viewed as a first pass. These proposed screening criteria allow for the ranking of candidate reservoirs for gas EOR as opposed to associating an absolute value of how good a reservoir really is (F. B. Thomas 1996).

One of the most widely cited publications in the field of petroleum engineering is the EOR criteria published by Taber and colleagues in 1996. These criteria consist of 12 EOR methods tabulated against 9 reservoir properties. The reservoir properties are based on minimum, maximum and average values published by The Oil and Gas Journal of EOR surveys from 1974 to 1996.

The EOR criteria published by Taber and colleagues (1996) are updated to include reported EOR projects from 1998 to 2010, as well as new EOR categories, subcategories and project details. Newly-added EOR categories include microbial EOR, miscible WAG, and hot water flooding.

New subcategories also are added under the category of immiscible flooding and include CO2, nitrogen and WAG methods of EOR. The reservoir properties also have been expanded to include porosity, number of EOR projects for each EOR method, permeability and depth ranges for both miscible and immiscible gas EOR methods. The EOR criteria were constructed and updated in the following manner. Oil property and reservoir characteristic fields were queried to determine the range of each reservoir property for each EOR method. An average for each reservoir property was then derived. The EOR selection criteria are not intended to present threshold limits because such limits should be developed scientifically. The consolidation of 652 EOR projects into the screening criteria stands as a testimony to the work of Taber and colleagues (1996).

In analyzing the data stored in the EOR project database, a profile of worldwide EOR projects is constructed. The EOR projects are classified into four main categories, namely, thermal, gas, chemical and microbial methods. The worldwide use of each of these main categories is shown in Figure 1. The main EOR categories are then subcategorized, as shown in Figure 2, to provide a further breakdown of worldwide EOR projects.

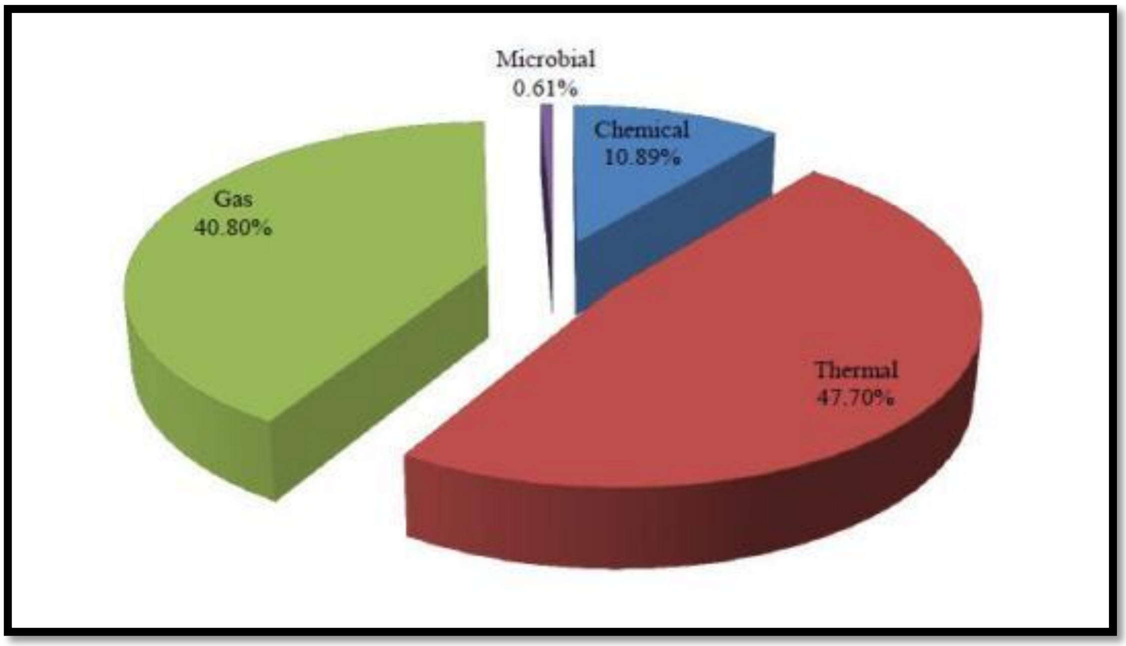

Figure 1: Worldwide EOR Project Categories (1959 - 2010)

Figure 1 indicates that thermal methods are the leading methods used worldwide for EOR projects, followed by gas methods. More specifically, steam flooding is the leading thermal EOR method, followed by miscible gas injection in the gas methods category, as shown in Figure 2. While thermal EOR continues to dominate (Figure 2.1), the adoption of miscible flooding methods has increased gas EOR projects to 41% (Figure 2.2), and since 2006, gas EOR methods in the United States (US) have accounted for the majority of enhanced oil production at 53% (Koottungal, L., 2008).

Most of the prolific oil production and indeed most of the giant oilfields are in sandstones. Sandstones generally exhibit high primary permeabilities as well as secondary permeability characteristics. For example, most of the oil and gas produced in Russia is from clastic reservoir rocks. Much of the production from the USA has also been from clastic reservoir rocks. But there are some notable exceptions. For example, the Permian Basin of the southwestern U.S.A. is a carbonate (limestone) reservoir as is the huge oilfields in the Middle East.

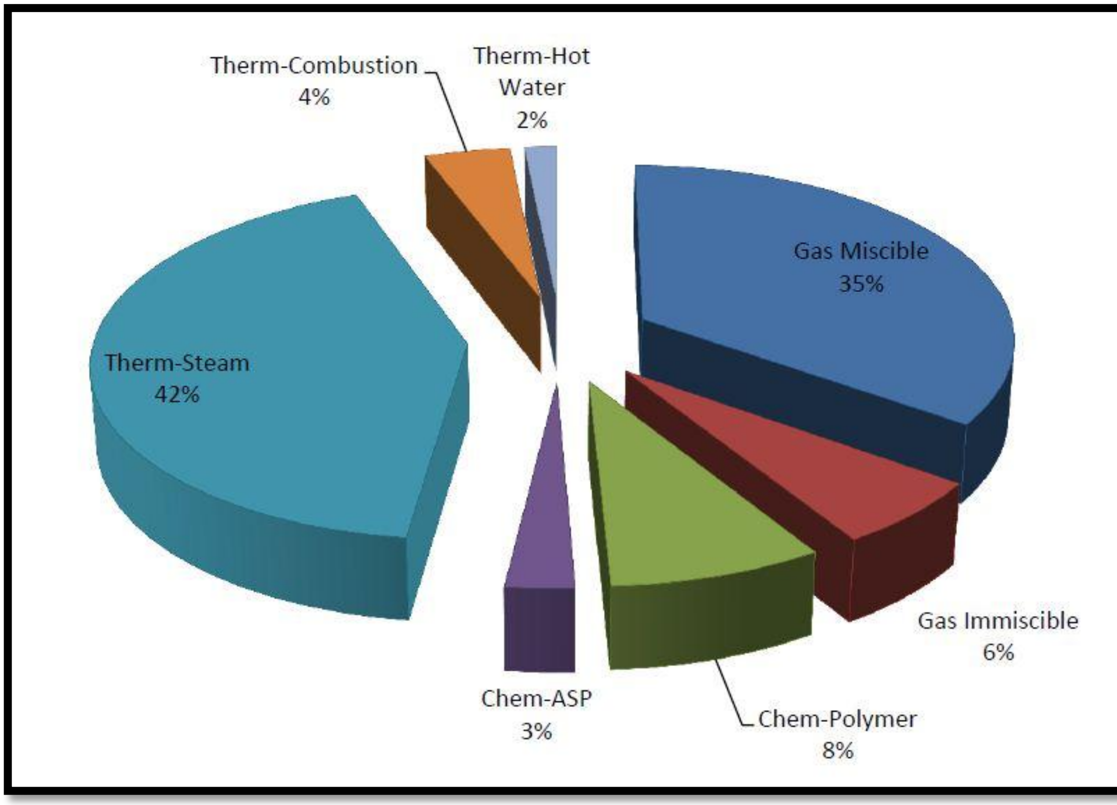

Figure 2: Worldwide EOR Project Subcategories

Limestones (carbonates) are primarily made of the mineral calcite. They are the result of sediment formed by precipitation of minerals from solution in water, either the result of biochemical reactions or by inorganic chemical processes. Inorganic processes mean that calcite is precipitated directly from water; small spheroidal grains, about the size of sand grains, called oolites are found on the floor of oceans. They are composed of calcium carbonate ($CaCO_3$). Oolites found in limestones mean that they were formed in ancient oceans. Cave deposits are also calcite, but they formed in a wet cave on land.

Most geologists think of sandstones and limestones as two distinct rock types, and indeed they are. Compositionally, sandstone is formed through inorganic and clastic processes. Erosion of land surfaces containing all types of existing rocks creates sediments which are transported into a basin where compaction occurs creating sandstone rock. Looking closely at the sediments, one would see that it contains pebbles, sand grains, and other bits and pieces of rocks. All the sediment of this kind is referred to as clastic rocks meaning accumulated particles of broken rock and of skeletal remains. The clastic materials are held together in the rock by cement, generally silica.

Figure 3 indicates that sandstone formation constitute to the highest count of EOR project that has been implemented. More than 60% of total EOR project that have been recorded until 2010 are from sandstone formation reservoir whereas on 1.5% from the total number of projects recorded originate from limestone (carbonate) reservoir.

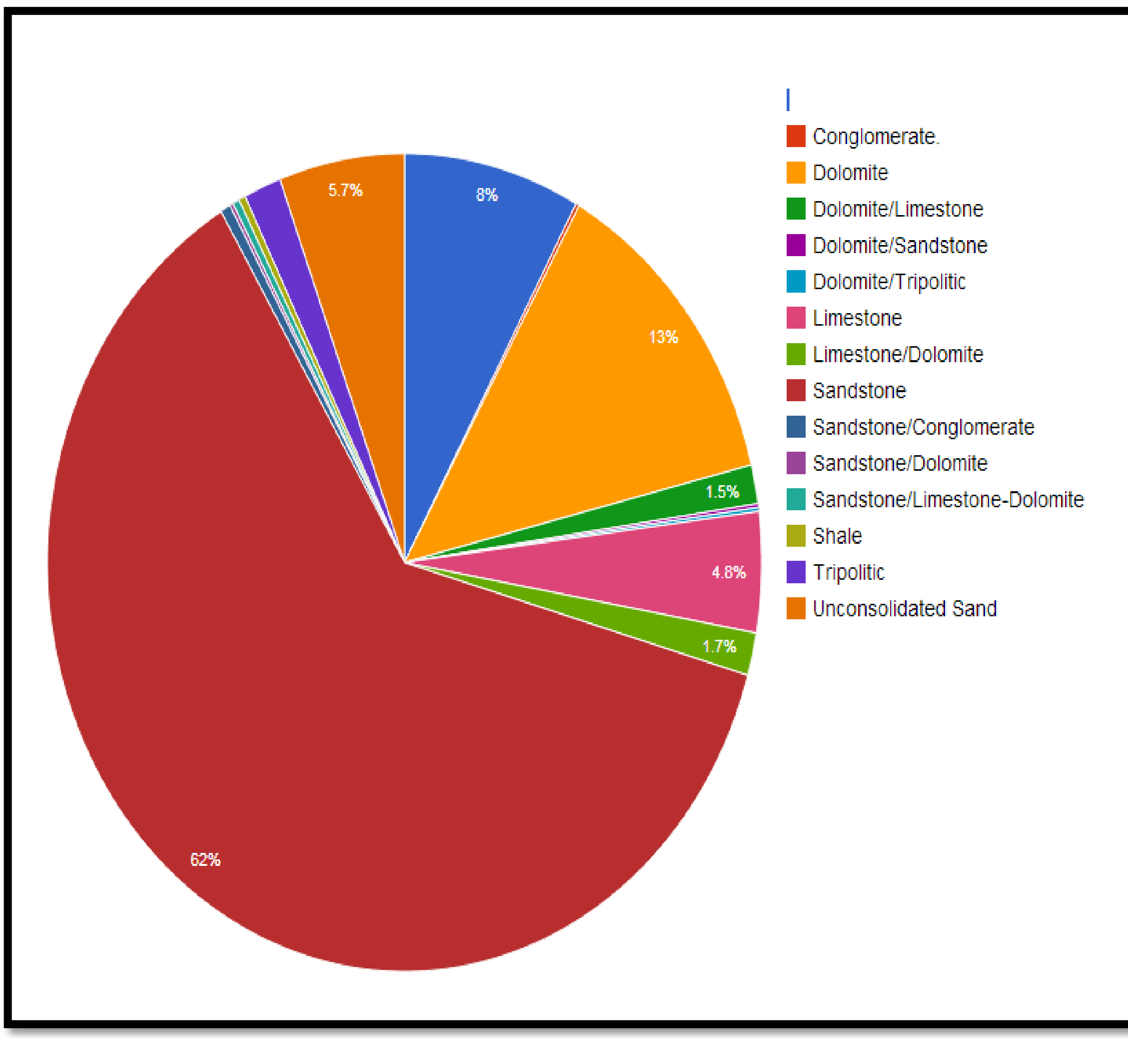

Figure 3: Count of Total Project by Formation Type

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

This methodology includes 4 main aspects.

3.1.1 Binary Technical Screening

Binary technical screening is generally an assessment of proposed reservoir fluids properties from diverse author continuously. It aims is to determine the best enhanced oil recovery method which is feasible technically to the field (M. Trujilo 2010). Properties such as porosity, permeability, viscosity, API, S_o, thickness, depth, reservoir temperature, pressure and lithology are analyzed. The method is a universal which can be applied to different type of reservoir such as light, medium, heavy oil, deep and also shallow reservoir.

The screening criteria are the most common, fast and easy tool to use to determine if a field/reservoir becomes a good candidate for implementing an enhanced oil recovery process. In the specialized technical literature are published a series of screening criteria for different recovery methods, which have been obtained from the experience gained from many worldwide projects.

The screening criteria are proposed by different authors and at different stages of maturity of a recovery process, therefore, special care must be taken with this aspect when the applicability of a method cannot be ruled out if some of the screening criteria proposed by different experts or incorporated into commercial tool are not met in this aspect, the analogies and the benchmarking methodology play an important role. Additionally, the knowledge and criterion of the engineer are the most important aspects.

The properties compared with the screening criteria are shown in Table 1. Additional properties are compared, depending on the recovery method being evaluated. Table 1 shows that the binary screening requires few data, which turns the methodology into a tool easy to apply, because in many occasions the fields do not have sufficient information to realize more detailed studies.

After selecting the method or methods of recovery that technically apply to the field/reservoir by means of binary technical screening complemented with analogies and benchmarking methodology, the operator would initiate the acquisition of the information necessary to carry out a more exhaustive study that can include experimental evaluations, geological models, numerical simulation, economic analysis, etc.. This study would finally determine the feasibility of application of a particular method. Because pressure and fluid saturations change during the productive life of the field, it is important to evaluate these properties to the current conditions of the field/reservoir, to avoid mistaken selection of the methods that will be applied to the field under study.

Table 1: Fluid and reservoir properties used to perform binary technical screening

Reservoir Properties	**Fluid Properties**
Current oil saturation, fraction	Viscosity, cp
Thickness, ft	API gravity, ^{o}API
Permeability, mD	
Porosity, fraction	
Depth, ft	
Reservoir temperature, ^{o}F	
Pressure, psia	
Lithology	

3.1.2 Analogies

The analogies are based on analog model which allow up to 1000 projects to be identified for its specific enhanced oil recovery technology. Once the analogs fields have been selected, the best practices can be identified when they matched the optimum theoretical data. This can be achieved by associating the application of the recovery method and the lesson learned.

3.1.3 Benchmarking

A methodology developed by Perez et al for benchmarking a successful steamflood project characteristic has been used to rank potential reservoir. A predicted score near to one hundred indicates a high probability of success of the steam injection in the field under study.

3.1.4 Analytical Prediction

3.1.4.1 Dataset Distribution

This stage of analysis requires representing the distribution of EOR projects against the reservoir properties to determine where EOR projects are concentrated for each reservoir range. As an example, Figure 4 represents API gravity. Extreme minimum and maximum values could adversely impact the EOR criterion, even when averages are established; therefore, box charts are used to illustrate reservoir property distributions for the main EOR methods.

Figures 4 represent the range within which the majority of EOR projects are located, plotted against selected reservoir properties. As an example, the minimum and maximum API gravity values were identified for each of the five EOR methods outlined in Figure 5 (with a red box and a purple cross indicating the minimum and maximum values, respectively). The average API value then was determined for each of the EOR methods and highlighted as a green triangle. (This was the basis for J.J. Taber's establishment of the EOR selection criteria in 1995) The next step was to identify the number of projects for each API value from the minimum to the maximum API value. Finally, the API range with the most datasets or projects was identified from r1 (blue diamond) to r2 (sky-blue asterisk); therefore, r1 - r2 represents an API range within which the majority of miscible flooding projects have been implemented.

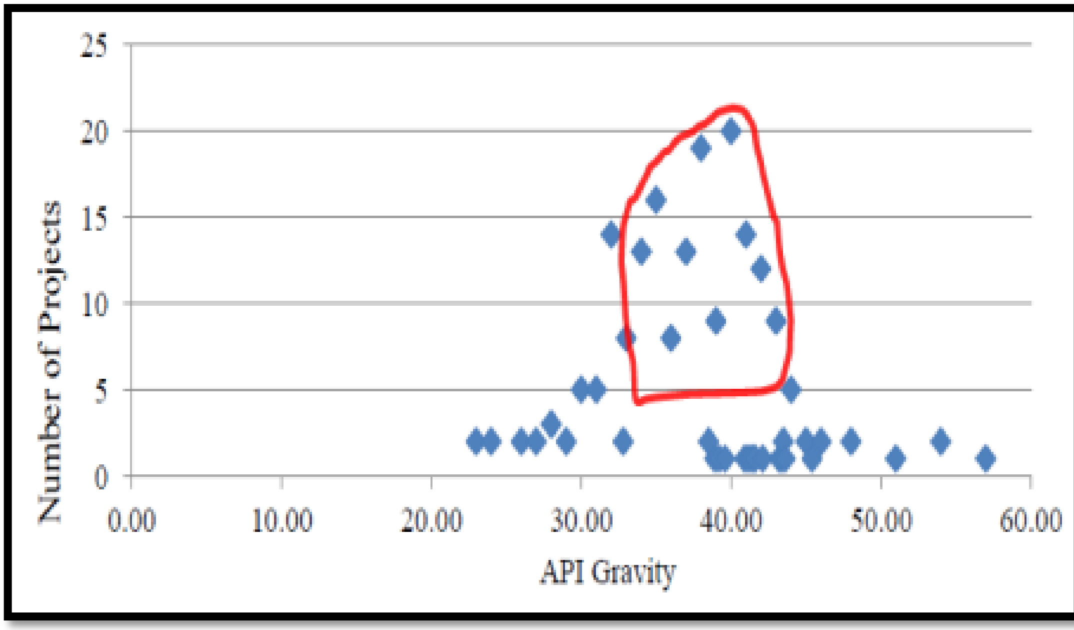

Figure 4: API gravity distribution in miscible EOR projects

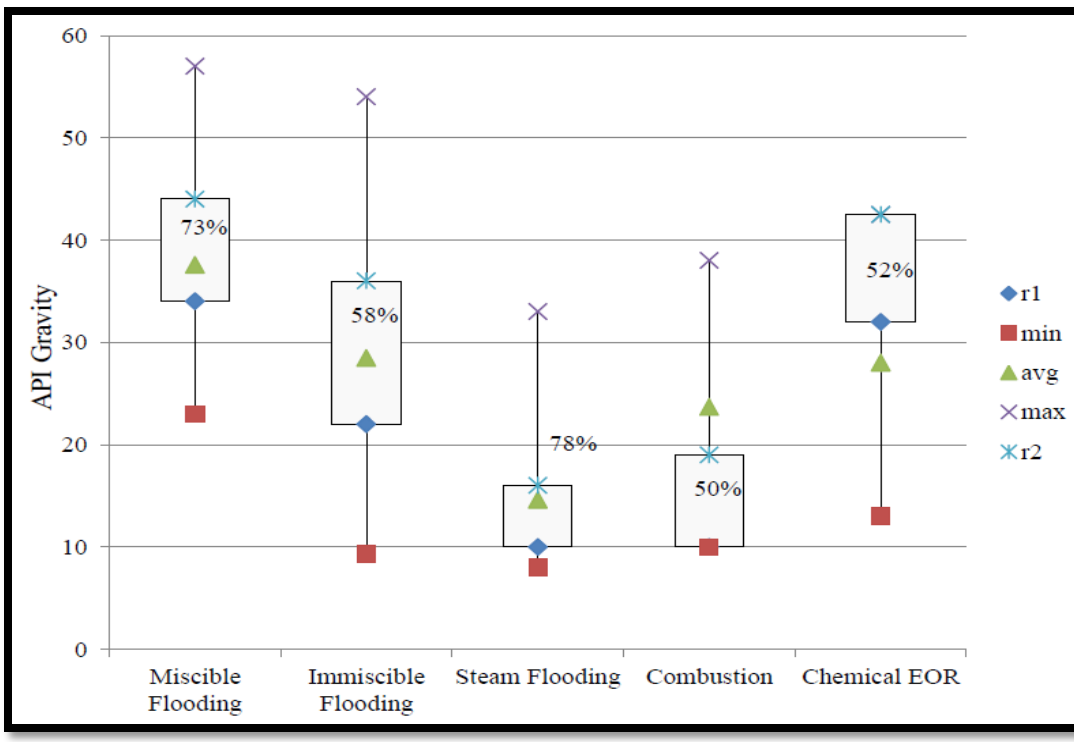

Figure 5: Gravity distribution versus selected EOR methods

3.2 Project Activities

Initially, research study commenced on the basic knowledge of EOR screening and selection criteria. The study will also include the concept how it will function from input to process and from process to output. The understanding of basics mostly focused on interpreting and investigating on the Taber famous EOR screening criteria.

From indulgencing the basic knowledge on how the EOR screening criteria works, selection of fluid and reservoir parameters (API gravity, viscosity, depth, thickness, temperature, pressure, etc.) are made into consideration.

As the data have been collected, the next step will be on analyzing and interpreting the data. From the analysis, improved and modification on the current EOR screening criteria are proposed and matched corresponding to the existing EOR screening criteria.

At the last part of the project, a database system for selecting best optimum EOR to be implemented in sandstone reservoir formation is developed. The database are developed based on all EOR methods that resulted from existing and newly improved EOR method.

3.3 Gantt Chart

Table 2: Gantt chart – FYP I

Activities	**Week**														
	1	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
FYP briefing								**S**							
Selection of project topic								**E**							
Preliminary research work								**M**							
Submission of extended proposal								**B**							
Proposal defense								**R**							
Project work continue								**E**							
Submission of interim draft								**A**							
Submission of interim final draft								**K**							

Table 3: Gantt chart – FYP II

Activities	**Week**														
	1	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project work continues								**S**							
Submission of progress report								**E**							
Project work continues								**M**							
Pre - SEDEX								**B**							
Submission of technical paper								**R**							
Submission of dissertation								**E**							
Final / Oral presentation								**A**							
Submission of project dissertation (hard bound)								**K**							

3.4 Key Milestones

Table 4: Key milestones of FYP II

Milestones	Final Year Project II (FYP-2)														
	1	2	3	4	5	6	7	S	8	9	10	11	12	13	14
Analyzing and interpreting existing EOR screening criteria								E							
Add on exiting number of EOR methods								M							
Suggest new EOR screening criteria								B							
Develop EOR process flow selection database system for sandstone formation								R E							
Presentation and final report compilation/ submission								A K							

CHAPTER 4

RESULT AND DISCUSSION

4.1 EOR Guidelines

Enhanced oil recovery (EOR) technologies can augment the production of hydrocarbons and therefore are keys in achieving the ultimate goal of increasing recovery volumes, which, is critical given the world's predicted energy needs and current supply. A review of the existing EOR criteria is analyzed and the need for updated criteria is revealed because of their datedness and their emphasis on minimum and maximum average values that do not represent a sound basis for the selection of candidate reservoirs for EOR. Updated criteria that provide a more representative understanding of selection values are necessary if EOR technologies are to be implemented to their full potential. These criteria also consider new EOR methods and the addition of reservoir properties.

The creation of the first new EOR criterion was motivated by the inherent risks of using average values of reservoir properties for each EOR method. Alternatively, a data distribution, as presented here, delineates ranges within which the majority of projects fall, thus providing a much clearer picture of the reservoir properties for each EOR method (Aladasani and Bai, 2010). The second proposed EOR criterion is based on incremental recovery (Aladasani and Bai, 2011). The reservoir properties that achieve the highest production gains are highlighted.

4.2 EOR Selection Criteria

The EOR criteria published by Taber and colleagues (1996) was updated to include EOR survey reports submitted from 1998 through 2010. The updates to the EOR criteria include the addition of the entire range of oil and reservoir properties for all EOR methods, a reservoir fluid property, namely, porosity, and permeability and depth ranges for miscible and immiscible gas EOR methods because of their importance.

New categories and subcategories of EOR methods also were added to the EOR criteria, including the categories of microbial EOR, miscible WAG, and hot water flooding, as well as the immiscible gas flooding subcategories of CO_2, nitrogen and WAG. Furthermore, the new criteria include the number of EOR projects (the number of datasets) to provide an impression of the confidence level used for each EOR method to derive the EOR selection criteria.

As a result, the majority of the reservoir properties were updated, and the number of EOR methods has been expanded from 12 to 16. To illustrate the contributions in updating the EOR criteria, box figures represent values adopted from Taber and colleagues (1996).

The first step in analyzing the data stored in the EOR project database is to construct a profile of worldwide EOR projects. The EOR projects are classified into four main categories, namely, thermal, gas, chemical and microbial methods.

One of the most widely cited publications in the field of petroleum engineering is the EOR criteria published by Taber and colleagues in 1996. These criteria consist of 12 EOR methods tabulated against 9 reservoir properties. The reservoir properties are based on minimum, maximum and average values published by The Oil and Gas Journal of EOR surveys from 1974 to 1996.

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4.3 Taber's Improved EOR Selection Criteria

Table 5 below is the improved selection criteria which are developed from Taber's EOR selection criteria. From Taber's EOR selection criteria, it contains 12 EOR methods that widely applied in the oil and gas industry. In addition to the Taber's, another 4 methods have been added into the list of possible EOR methods to be implemented so that the new selection criteria will meet the need to incorporate and satisfy current technology or field data.

Table 5: Updated Taber's EOR selection criteria

Oil Properties					**Reservoir Characteristic**						
SN	EOR Method	Number of Projects	Gravity (°API)	Viscosity (cp)	Porosity (%)	Oil Saturation (%)	Formation Type	Permeability (mD)	Net Thickness	Depth (ft)	Temperature (°F)
Miscible Gas Injection											
1	CO_2	153	22-45 Avg. 37	35-0 Avg. 2.08	Avg. 15.15	15-89 Avg. 46	Sandstone or Carbonate	1.5 – 4500 Avg. 209.73	Wide Range	1500-13365 Avg. 6230.17	82-257 Avg. 138.10
2	HC	67	23-57 Avg. 38.3	18000-0.04 Avg. 286.1	4.25-45 Avg. 14.5	30-98 Avg. 71	Sandstone or Carbonate	0.1-5000 Avg. 726.2	Thin unless dipping	4040-15900 Avg. 8343.6	85-329 Avg. 202.2

3	WAG	3	33-39 Avg. 35.6	0.3-0.9 Avg. 0.6	Avg. 18.3	NC	Sandstone	130-1000 Avg. 1043.3	NC	7545-8887 Avg. 8216.8	194-253 Avg. 229.4
4	N_2	3	38-54 Avg. 47.6	0.2-0 Avg. 0.07	7.5-14 Avg. 11.2	0.76-0.8 Avg. 0.78	Sandstone or Carbonate	0.2-35 Avg. 15.0	Thin unless Dipping	10000 – 18500 Avg. 14633.3	190-325 Avg. 266.6
Immiscible Gas Injection											
5	N_2	8	16-54 Avg. 47.6	18000-0 Avg 2256.8	Avg 19.46	47-98.5 Avg 71	Sandstone	Avg 1041.7	NC	1700-18500 Avg. 7914.2	82-325 Avg 173.1
6	CO_2	16	Avg 22.6	592-0.6 Avg 65.5	17-32 Avg 56	42-78 Avg 56	Sandstone or carbonate	30-1000 Avg 217	NC	1150-8500 Avg 3385	82-198 Avg 124
7	HC	2	22-48 Avg 35	4-0.25 Avg 2.1	Avg 13.5	75-83 Avg 79	Sandstone	40-1000 Avg 520	NC	6000-7000 Avg 6500	170-180 Avg 175
8	HC + WAG	14	9.3-41 Avg	16000-0.17 Avg	18-31.9 Avg 25.09	Avg 88	Sandstone or carbonate	100-6600 Avg 2392	NC	2650-9199 Avg 7218.71	131-267 Avg 198.7

			31	3948.2							
Chemical Methods											
9	Poly-mer	53	13-42.5 Avg 26.5	4000-0.4 Avg 123.2	10.4-33 Avg 22.5	34-82 Avg 64	sandstone	1.8-5500 Avg 834.1	NC	9460-700 Avg 4221.9	237.2-74 Avg 167
10	ASP	13	23-34 Avg 32.6	6500-11 Avg 875.8	26-32 Avg 26.6	68-74.8 Avg 73.7	sandstone	596-1520	NC	3900-2732 Avg 2984.5	158-118 Avg 121.6
11	Surfa-ctant + P/A	4	22-39 Avg 31.75	15.6-2.63 Avg 7.08	14-16.8 Avg 15.6	43.5-53 Avg 49	sandstone	50-60 Avg 56.67	NC	5300-625 Avg 3406.25	155-122 Avg 126.33
Thermal / Mechanical Method											
12	Com-bustio n	27	Avg 23.6	2770-1.44 Avg	14-35 Avg	50-94 Avg 67	Sandstone or carbonate	10-15000 Avg 1981.5	>10	400-11300 Avg 5569.6	64.4-230 Avg 175.5

				504.8	23.3		(preferra-ble)				
13	Steam	274	Avg 14.61	Avg 32594.96	Avg 32.2	35-90 Avg 66	sandstone	1-15001 Avg 2669.70	>20	200-9000 Avg 1647.42	10-350 Avg 105.91
14	Hot Water	10	Avg 18.6	8000-170 Avg 2002	25-37 Avg 31.2	15-85 Avg 58.5	sandstone	900-6000 Avg 3346	NC	500-2950 Avg 1942	75-135 Avg 98.5
15	Surface Mining	-	7-11	Zero cold flow	NC	>8 wt% of sand	Mineable tar sand	NC	>10	>3:1 overbur-den to sand ratio	NC
Microbial											
16	Micro-bial	4	Avg 26.6	8900-1.7 Avg 2977.5	Avg 19	55-65 Avg 60	sandstone	180-200 Avg 190	NC	1572-3463 Avg 2445.3	86-90 Avg 88

4.4 New Enhanced Recovery Selection Criteria

EOR projects are better represented through dataset distribution. The number of EOR projects (datasets) should be evaluated to indicate where EOR projects are concentrated for each reservoir range. Extreme minimum and maximum values could adversely impact on the EOR criteria, even when averages are established; therefore, box charts are used to illustrate the reservoir property distributions for the main EOR methods. The generated figures represent the range in which the majority of EOR projects are located and plotted against selected reservoir properties. The minimum and maximum values for each reservoir property are identified. Five EOR methods were selected to ensure an adequate number of data-sets. Legends include the minimum and maximum range and the average value; more significantly, the number of projects for each value was determined from the minimum to maximum API range. Subsequently, the highest percentage concentration of project clusters within the reservoir property range was established. The project clusters and the reservoir property dataset distributions are more indicative of EOR selection criteria than the minimum, maximum and average values, similar to the data-set distribution of reservoir properties reported in EOR projects.

Enhanced production, rather than project count, is used as an EOR selection criterion to establish key reservoir properties and their corresponding ranges. Two new approaches are proposed to identify candidate reservoirs for EOR methods. The first criterion correlates reservoir properties with enhanced production, and the second criterion correlates the number of data-set distributions.

Table 6: New EOR criteria – based on project distributions of reservoir properties

EOR Method	Number of projects	**Reservoir Properties**						
		API	Viscosity (cp)	Start oil saturation	Permeability (mD)	Porosity (%)	Depth (ft)	Temperature (°F)
Miscible Flooding	226	34-44 73 %	0-1 64 %	0.33-0.55 62 %	0.1-100 64 %	62 %	4200-6700 55 %	95-160 52%
Immiscible flooding	40	19-36 66 %	0-10.5 58 %	0.42-0.62 67 %	30-300 53 %	22-32 69 %	1970-5708 51 %	120-194 68 %
Steam Flooding	274	78 %	51 %	0.50-0.70 64 %	1000-3000 56 %	30-38.8 76 %	800-1800 64 %	80-130 77 %
Combustion	27	19-27 50 %	1.44-2 67 %	0.50-0.70 70 %	52 %	17-25 55 %	1575-5000 48 %	185-230 64 %
Chemical (mainly Polymer)	70	32-42.5 52 %	69 %	0.65-0.82 65 %	173-875 60 %	21-33 67 %	2723-3921 48 %	108-158 65 %

Table 7: New EOR criteria – based on enhanced production

Reservoir Properties	**Reservoir Properties**		
	Miscible CO_2	Miscible HC	Thermal (steam)
API	30-36 (137 413) 36-42 (112 117)	24-30 (116 500) 36-42 (144 088)	6-12 (327 182) 12-18 (846 065) 18-24 (264 804)
Viscosity (cp)	0-10 (264 304)	0-10 (375 174)	242-484 (202 692) 3872-4114 (197 083)
Start oil saturation	0.3-0.4 (66 352) 0.4-0.5 (88 415)	0.8-0.9 (204 483)	0.5-0.6 (477 540) 0.6-0.7 (602 737) 0.7-0.8 (147 848) 0.8-0.9 (197 083)
Permeability (mD)	0-20 (180 979)	1000-1020 (128 400)	1500-2000 (445 451) 2000-2500 (226 337) 3000-3500 (117 184) 4000-4500 (264 406)
Porosity (%)	10-15 (141 771)	20-25 (239 676)	25-30 (123 203) 30-35 (915 595) 35-40 (368 345)
Depth (ft)	4000-6000 (169 770)	8000-10000 (113 593) 10000> (187 623)	0-2000 (1 137 316) 2000-4000 (258 601)

4.5 EOR Process Flow for Sandstone Formation

In order to come out with the easiest way of finding the most compatible EOR method to be implemented in sandstone formation, a database system is developed. In the database, a tool (Microsoft Excel) is being used to aid in developing the system.

First of all, all of the data ranges for each of the EOR methods parameters are created into a database management accordingly. Then the data value key-in by the user will go through one by one of these seven oil properties and reservoir characteristics parameters.

To come out with the best recommended EOR method, the value that being key-in by the user have to satisfy all the data that are recorded originally. However, if the data will not satisfy all of the parameters, the user will be shown EOR method that are suggested, either probable methods or non-recommended methods.

It should be point out that there are seven parameters that are taken into consideration of the database system which are API gravity and viscosity for oil properties; porosity, oil saturation, permeability, depth and also temperature for reservoir characteristic. Noted that the parameters will be weighed equally in the database where EOR methods that are shown are based on the number of parameters that have been satisfied by the input data.

In addition, if the data given by users satisfy all the parameters, suggested EOR method/methods will show in the Graphic User Interface (GUI) and will be highlighted in green colors. Plus, if the value satisfy five (5) or six (6) of the parameters, suggested EOR method/methods will be shown in the GUI and highlighted in yellow which means that the EOR method/methods shown are only probable method/methods. Yet if the data only satisfy four (4) and below of the seven parameters, the EOR method/methods that come out at the GUI will be highlighted in red colors where it indicates that the EOR method/methods is/are not recommended. The GUI of the database system is shown in Figure 6 and the parameters are shown in attached at the appendices.

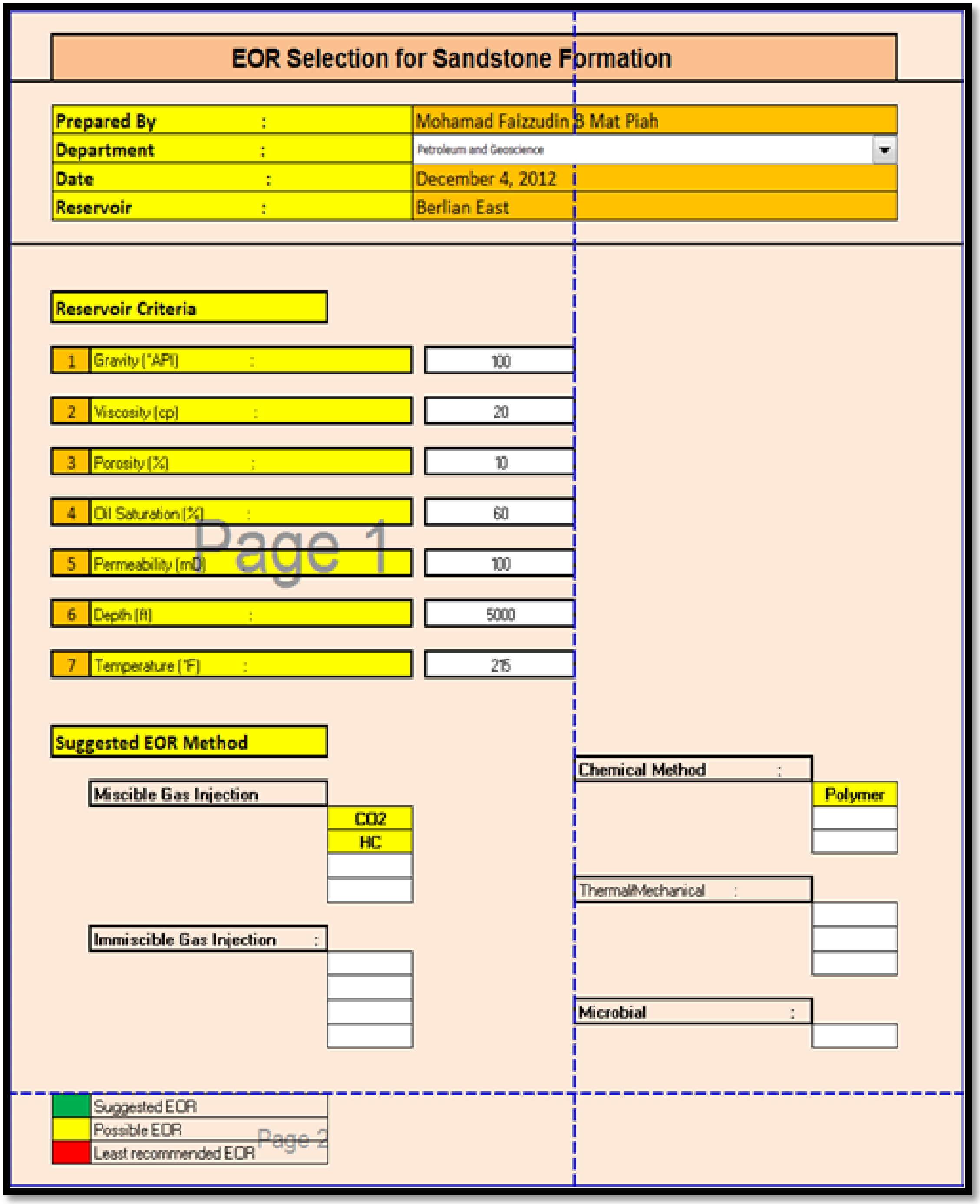

Figure 6: EOR selection database system GUI

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of this project is to identify the EOR method that can be used on a sandstone reservoir using the technical screening method with the aid of screening software. This research focused mainly on the technical part of the screening that determined which EOR method is the best to be implemented. Economic feasibility is reviewed generally. In order to achieve the objectives, all the experimental framework was carefully prepared, which was completed within the time frame of the research, while taking into consideration of the availability of the equipment and, materials. After doing all the technical screening, it is proven that EOR method cannot be implemented without a thorough analysis and screening. This study proves that EOR screening can provide an insight to a well for EOR implementation. It is also proven that by using an assisting software, the screening process can be completed and analyze in much faster time than just using manual screening that is time consuming.

Through synchronizing the initial objective and the outcome at the end of the project, it can be concluded that:

i. Sandstone formation play a vital role in today's world oil production, hence its EOR method is in need of frequent update and improvement.
ii. An EOR database system can significantly impact on reducing time needed to choose a suitable EOR method base on its criteria.
iii. This criterion is valid for the number of projects collected from the literature in the period of 1986-2012. Hence care must be taken when applying this criteria for period beyond the stated one.

5.2 Recommendation

From this whole planning work done by the author, there are rooms for improvement for this research. After doing this project for two semesters, the author has gained the awareness and the importance of EOR screening. The main objective of this project is to determine the best and most suitable EOR method for a sandstone reservoir. The improvements that can be made onto this project are as follow:

i. EOR screening criteria must be frequently updated so that the EOR that being taken into consideration can optimize the reservoir production and keep up to date with latest technologies.

ii. In developing a sophisticated software for choosing the EOR method to be implemented, expert in the programming language should be include in executing the project.

CHAPTER 6

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CHAPTER 7
APPENDICES

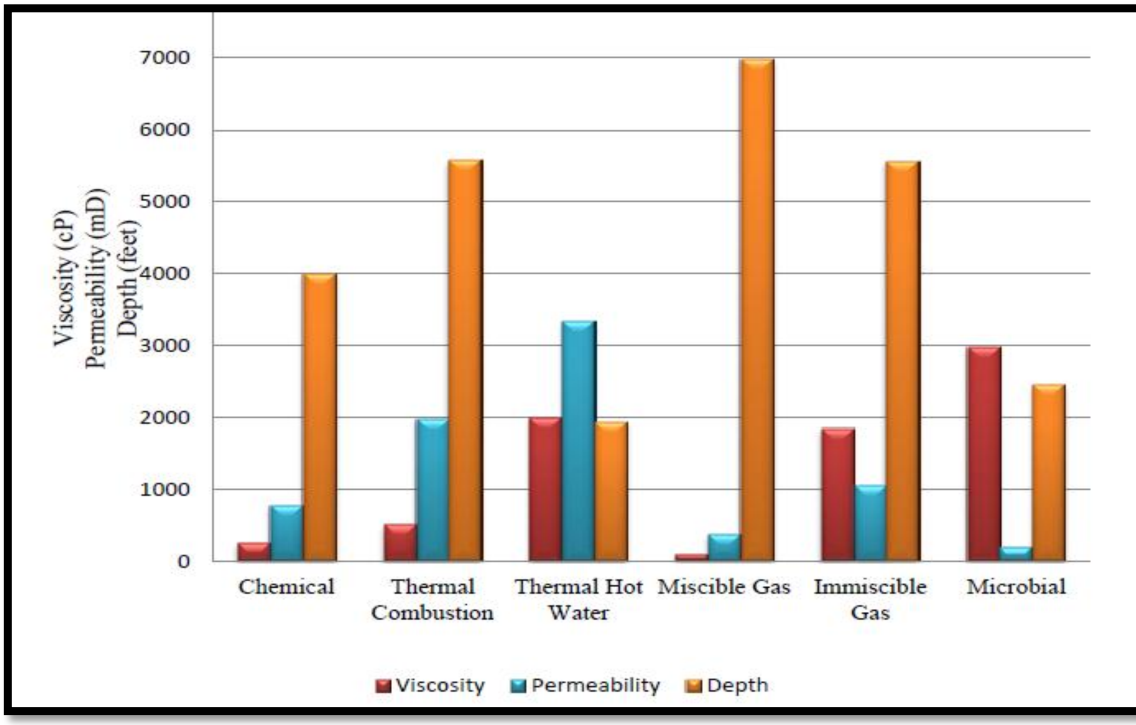

Figure 7: EOR Methods – selected average fluid and reservoir properties

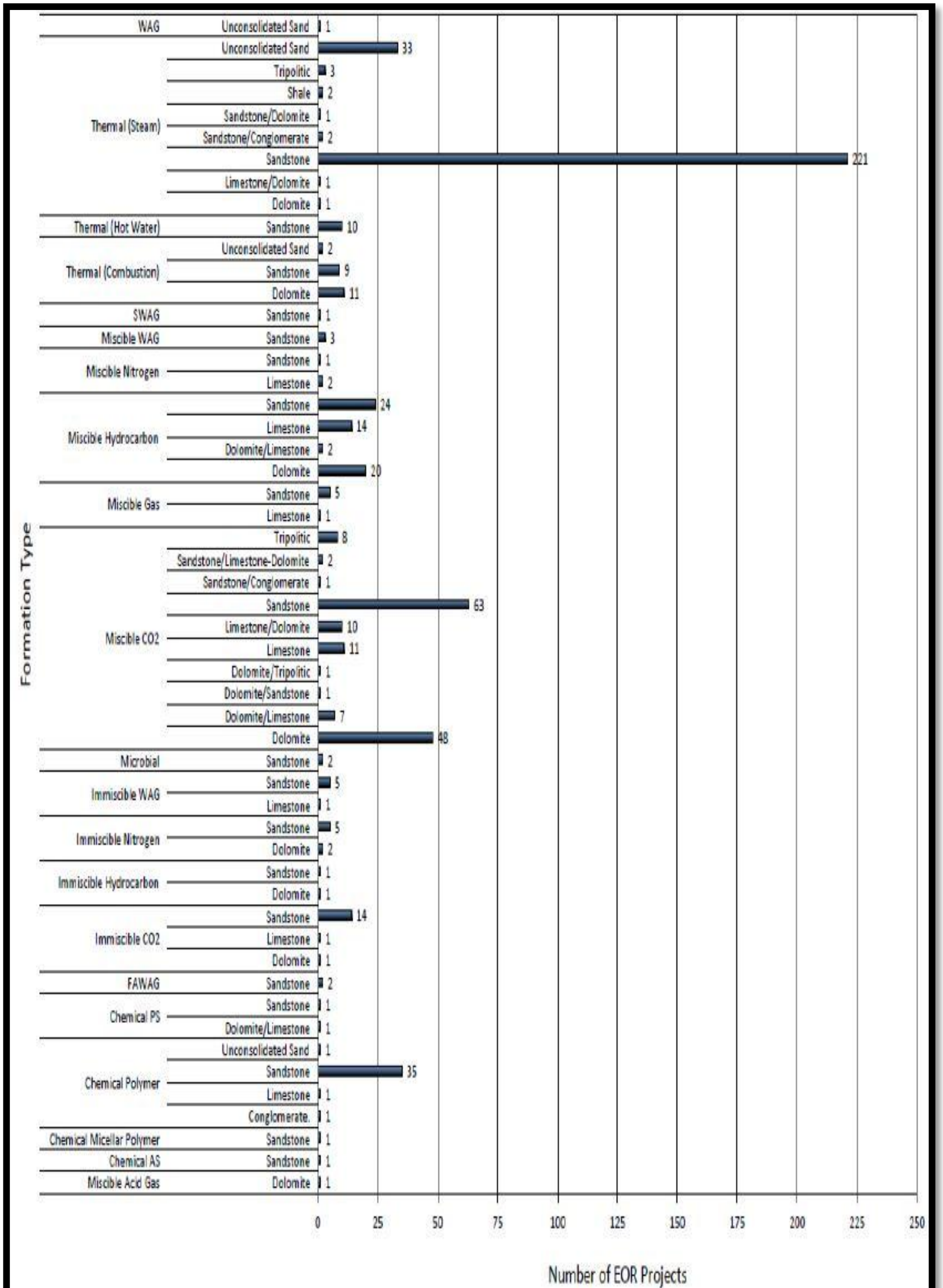

Figure 8: EOR methods and formation type distribution

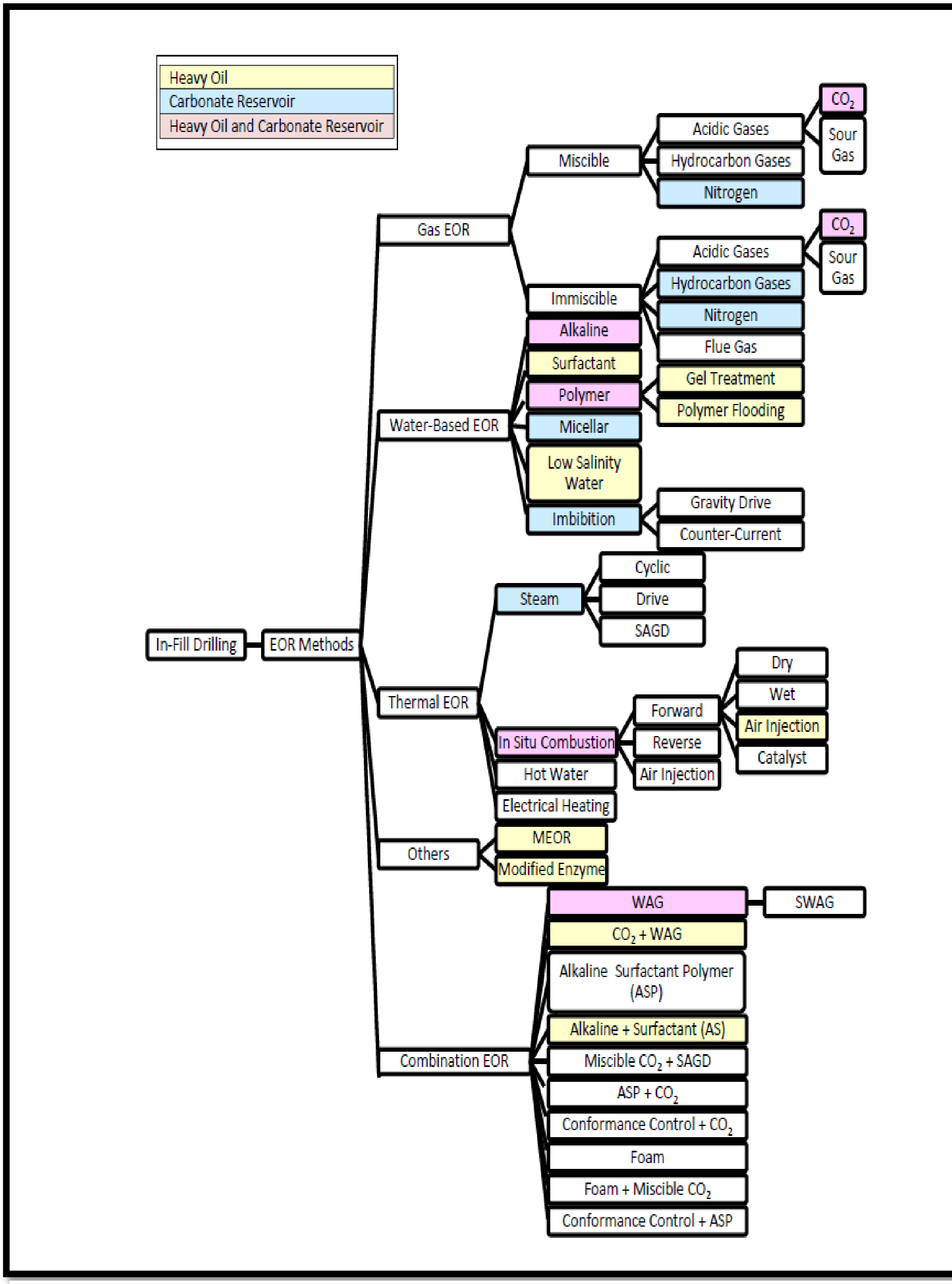

Figure 9: Simplified EOR method flow chart

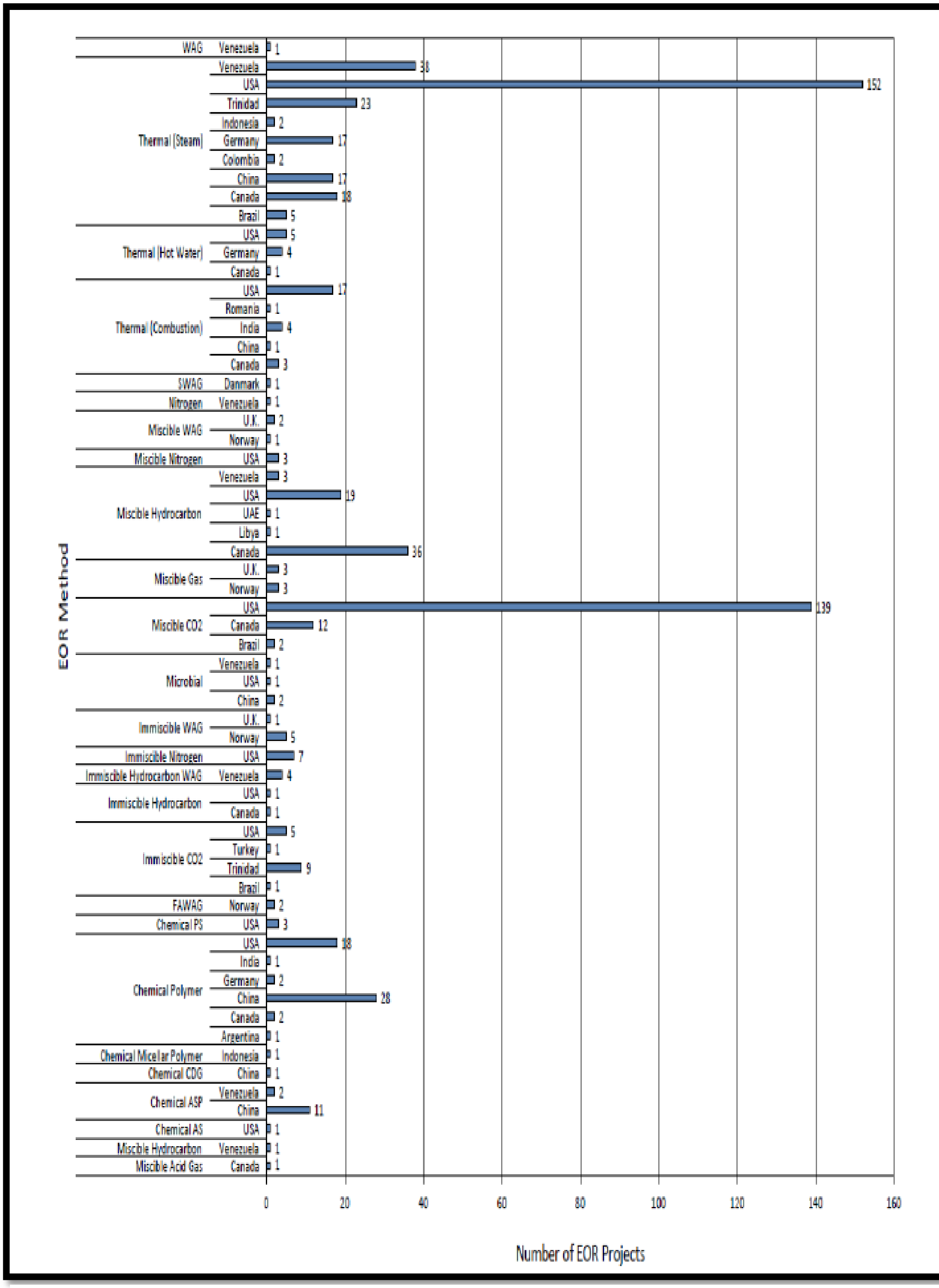

Figure 10: EOR methods and country distribution