Developing non-Chemical Flow Assurance Strategies for Petroleum Production Systems

By

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(11915)

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I. CERTIFICATION

CERTIFICATION OF APPROVAL

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BACHELOR OF ENGINEERING (Hons.)

(PETROLEUM ENGINEERING)

Approved by,

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(MR. AMIN SHOUSHTARI)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I 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.

(EDDIE MAZWAN BIN OTHMAN)

II. ABSTRACT

The challenge for flow assurance always arise in deepwater field development, thermal insulation system become concern in order to prepare for the worst due to tendency of hydrate and paraffin crystal formation which leads to blockage risk. Wax formation, hydrate formation, paraffin formation, aspalthenes formation, scale formation and others is common issues in oil and gas industries. Haunted with these challenges while balancing opex, capex and risk of uncertainty, non-chemical flow assurance risks management strategies can be the right solution instead of using conventional chemical solution.

Specific field favors passive techniques to retain heat such as wet insulation, dry insulation, flowline burial, flexible pipe and combined method. There are also field that not compatible with this techniques which require active heating system like coiled tubing, electric heating and hot fluid circulation. By using this two techniques which is non-chemical, it is a step forward reducing and even eliminating the use of chemical inhibitors injection which require topside facilities preparation where not all having enough space and even costly. Besides, it also can reduce safety issues when dealing with the chemical inhibitors.

This project will focus on the available passive type of non-chemical flow assurance by using of thermal insulation concept. Evaluation about the appropriate methods trough out research from some research papers will be included to highlight the efficiency of the method mentioned. A hypothetical data collected from trusted sources will be analyzed using production optimization software tool, PROSPER and the end result will be used to construct a work flow for the petroleum production system. The significance of this analysis should be able to contribute to petroleum technologist and even top management to see the important of thermal insulation towards having best flow assurance strategies. On top of that, the industry will aware of its reliability and feasibility while designing the flowlines and pipeline within the cost constrain.

III. ACKNOWLEDGEMENTS

Assalamualaikum and greetings.

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On top of that, I would like to thank my colleagues for all their hard work and cooperation in ensuring my project is done on time and successfully. Although there exists some misunderstanding and lots of technical problems, I managed to overcome each one and finally came up with the completed project.

Special thanks to Universiti Teknologi PETRONAS for giving the opportunities and resources for me to do this project and all parties that had also contributed directly and indirectly to the success of my Final Year Project. Once again thank you very much and may Allah repay all the kindness. I hope this project will contribute to all especially the oil and gas industry and wishing for continuation of this project in the future. Insya-Allah.

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VII. ABBREVIATIONS AND NOMENCLATURES

GSPU - Glass Syntactic Polyurethane

PP – Polypropylene

PIP – Pipe-in-Pipe

IPM - Integrated Production Modelling Toolkit

U-value - level of insulation

WAT - wax appearance temperature

HFT - Hydrate formation temperature

PVT – Pressure versus Temperature

IPR – Inflow Performance Relationship

VLP – Vertical Lift Performance

GOR – Gas Oil Ratio

CAPEX – Capital Expenditure

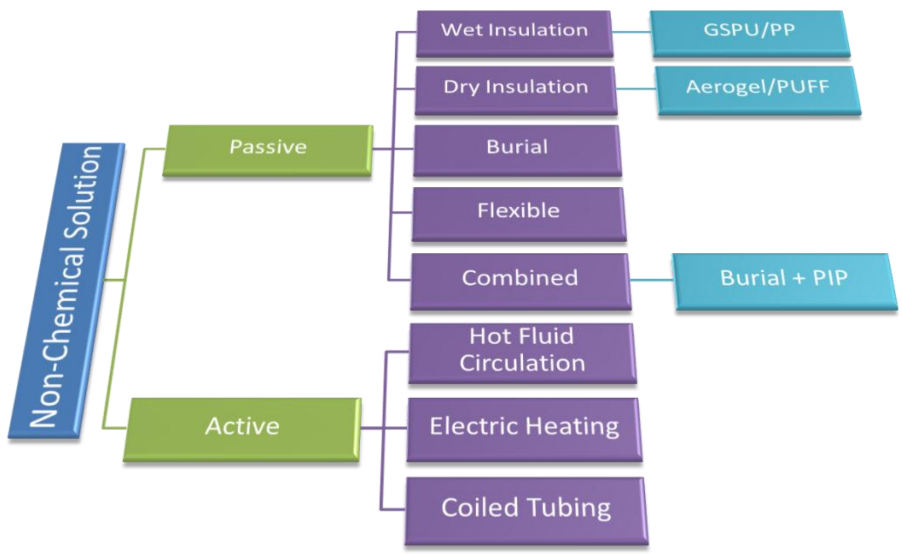
OPEX – Operational Expenditure

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 BACKGROUND STUDY



*Notes: **GSPU** - Glass Syntactic PolyUrethane ; **PP** – Polypropylene; **PIP** – Pipe-in-Pipe*

Figure 1.1: Non-chemical Solution for Flow Assurance

Flow assurance is a common issue especially for matured field. There are lots of challenges when dealing with downhole environment such as wax formation, hydrate formation, paraffin formation, aspalthenes formation, scale formation and others. Non-chemical solution is another method that could be used besides using chemical inhibitor as the major way to encounter these challenges.

Non-chemical techniques for flow assurance can be divided into two categories;

a) **Passive system**: wet insulation, dry insulation, flowline burial, flexible pipe and combined method.
b) **Active system**: coiled tubing, electric heating and hot fluid circulation.

Passive system does not require an input of energy such as work or heat to be effective. The material used having high resistance to heat transfer with low thermal conductivity. While *active system* requires input of energy in the form of work or heat. Thus, the heat will be supply directly through the pipeline. A comparison studies about the insulation systems will be included in this report to identify the characteristic of respective insulation methods.

After knowing the competence of the available insulation system in maintaining the temperature of produced fluids above the hydrate and wax formation temperature, the author will come up with a work or strategies in order to guide in choosing the best non-chemical solution for flow assurance. This rest of this report will explained about the progress of this project so far and some of them is still in research and needs some modification.

1.2 PROBLEM STATEMENT

Chemical solution impacts should be considered when dealing with budget constraint of certain project. Handling and maintenance of this technique involve high risk and need proper surveillance. Even safety measure should be highlighted when considering this method.

The main aim for chemical solution is total prevention of hydrates and wax issues. This method required topsides engineering and equipment maintenances. Whereas non-chemical solution concept is to maintain fluid temperature above hydrate and wax formation conditions using thermal management system. Clearly, chemical solution involves higher capex than non-chemical solutions as the requirements of the method used itself. Using thermal insulation in petroleum systems can be expensive but for a long time period it is much more efficient compared with maintenance needs when using chemical inhibitors.

Thus, mitigating flow assurance issues using non-chemical solution as an alternative method which is more feasible, economical and reliable compared to chemical solution. This project aims to develop a workflow of non-chemical solution. There will be studies about the evaluation of thermal insulation systems, and then an analysis from a set hypothetical data will be run using PROSPER to see the significant of chosen method. This will be used to choose the best method suitable for the field.

1.3 OBJECTIVES OF STUDY

The main target of this project is stated as below:

a) To optimize production using non-chemical solution as an alternative ways for flow assurance.
b) To integrate the data of wells and select the best non-chemical flow assurance strategies for petroleum production system.
c) To construct an organized work flow or strategies using non-chemical as the final output of the research as guidance for the industry.

1.4 SCOPE OF STUDY

Figure 1.2: Flow Assurance Scope of Study

Flow assurance covers many aspects of the production system; common one is blockages which result from the deposition of hydrates, wax, asphalthenes, sand and others. Normally, the chemical solution was chosen for flow assurance in mitigating those problems. Thus, this project will focus on the **non-chemical solution** based on **Passive System** which is *thermal insulation method* as the main solution with support of data analyzed from production optimization software tool, PROSPER. With the time limitation, only few methods of passive insulation method have been chosen in the study which is **wet insulation and pipe-in-pipe**.

1.5 RELEVANCY OF PROJECT

Controlling and balancing the CAPEX, OPEX and risk is not an easy job when dealing with flow assurance uncertainties. It required full commitment from every discipline in order to arrange the best strategy. Conventionally the chemical injection being used in to mitigate issues of flow assurance, thus developing non-chemical strategies for flow assurance is now a step forwards which the oil and gas industry should aware. They are proven to be feasible, economical and more reliable compared to chemical techniques as described earlier.

1.6 PROJECT FEASIBILITY

This project required research about the flow assurance studies which focus on non-chemical solution. A set of hypothetical data will be used to analyze in the production optimization software tools, PROSPER in order to construct a work flow for non-chemical solution flow assurance strategies. Besides, the PROSPER software is available at university lab which is at Block 15.Thus, the project it is feasible within the time frame given.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

Using non-chemical solution for flow assurance can be classified as one of the finest art of science and engineering perspective. Looking into the diversity of the integration between science and engineering aspect creates such ways in mitigating challenges of blockages by hydrates, wax, aspalthenes, and others as an alternative solution besides injecting the chemical into the passages which is conventional in oil and gas industry. Thermal insulation system is one of the best techniques which are feasible and economical compared which other available techniques.

Avoiding possibility the risks of hydrate formation and wax deposition is not an easy job. The temperature should be maintained above the hydrate and wax formation temperature. Besides, the subsea system design should provide sufficient cooldown time for shut-in and restart operation. Thus, the design must consider both steady state and transient condition. This statement agreed by most of the scholar on flow assurance that the industry must aware of the necessary of having best strategy handling the issues.

Advancement in technology nowadays witness non-chemical flow assurance solutions as part of method that can be used to maintain fluid temperature above the hydrate formation and wax appearance temperature (Mark & Shukla, 2012). He also suggests that by combining different non-chemical solutions, the OPEX and CAPEX can be reduced. Besides, it also can eliminate the need of chemical injection and maintenance costs. However, other alternative which is feasible and cost effective solutions is to have a combination of non-chemical solution.

Amir Alwazzan, 2012 suggest that 'each subsea development is unique in its reservoir characteristics, fluid properties, concept, tieback length, bathymetry, environmental and operating conditions, and strategies. This causes the effectiveness of each insulation technique to vary from one development to another'. Configuration of insulation methods which meet technical, economical, and environmental needs is the key success for deep water field development. He also said that thermal management strategy is chosen depending on the level of insulation (U-value), cool-down time, temperature range, and water depth.

He also state that, thermal mass plays a role in cool-down time where greater thermal mass having longer cool down time. Thus thermal insulation of flowline should be as effective as possible to minimize heat loss in the line. By doing this, it can provide longer cool down time in the riser. The selection of flowline and riser insulation would impact the capex. He suggests that, loading the flowline for maximum insulation is less expensive than loading the riser.

Frederic K. Wasden, 2003 agreed that by using continuous methanol injection is uneconomic for most oil system due to large amount requirements. He proposed other technique which is one of them is using electrical heating of flowlines, either continuously or intermittently. This method is an active system which is part of non-chemical solution besides passive system.

Moreover, syntactic foam is one of growing use of deepwater insulation system which offers number of advantages over more conventional materials, based largely on its unique fine-celled structure and high strength-to weight ratio. It provides the lowest density solution to any buoyancy or insulation requirement, at any depth. Features like low thermal conductivity, great compressive strength, can be adapted to any insulation requirement and cost effective should be considered the best characteristic of thermal insulator. (Watkins & Hershey, 2001)

O.L. Owodunni and J.A Ajienka,2007 mentioned they are few factors should be put into consideration for thermal insulation sensitivity study which are the effect of insulating material in the annulus, effect of changing the flow rate, effect of tubing configuration and cool down times. In order to achieve such unfavorable for hydrate and paraffin deposition, it is important to have a dynamic model of transient heat transfer, pressure distribution and flow conditions in the wellbore.

2.1 HYDRATES

‘Hydrates are formed when the temperature is below a certain degree in the presence of free water. This temperature is called **Hydrate formation temperature (HFT)**. Hydrates are like snow in appearance but not as solid as the ice. Water molecules form the main framework of the hydrate crystal while the gas molecules occupy void spaces-cages in the water crystal lattice.’ (M. A. Usman, 2012)

2.2 WAXES

‘Wax deposition often occurs in the liquid phase of black oils and condensates during the production. It happens when the operating condition fall below the cloud point temperature and pressure. When the fluid cools, wax components becomes less soluble until the higher molecular weight components solidify. Thus, **cloud point or wax appearance temperature (WAT)** is the temperature at which the first crystal of solute formed.’ (Owodunni and Ajienka, 2007)

2.3 PASSIVE INSULATION SYSTEMS (CHOSEN)

A. Wet Insulation

‘Wet insulation refers to all types that can be molded to the outer surface of a pipeline or equipment and, when submerged, do not require a protective barrier. The insulation is directly exposed to seawater and water may diffuse into the insulation. This insulation may be solid polymers such as polypropylene (PP) or syntactic foams such as glass syntactic polyurethane (GSPU).’ (Chapman and Shukla, 2012)

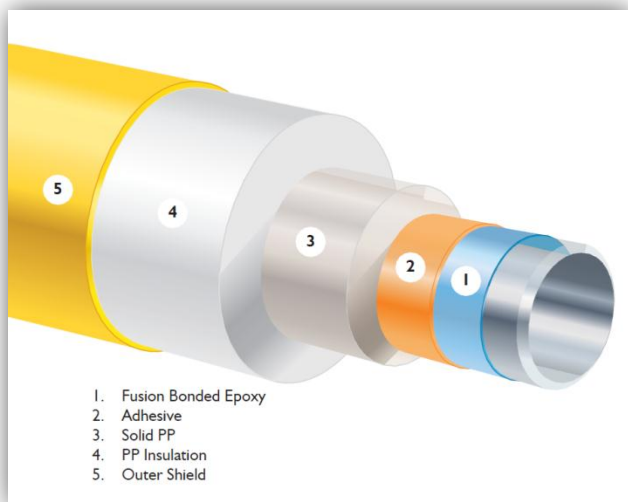


Figure 2.1: Wet Insulation (Polypropylene Insulation System)

B. Pipe-In-Pipe Insulation (Dry Insulation)

For a typical PIP configuration, the inner (carrier) pipe is insulated with a low conductivity dry insulation such as an aerogel or low density polyurethane foam. The outer pipe is typically steel but in shallow water instances can be polyethylene. (Chapman and Shukla, 2012)

Low density materials like polyurethane foam, poly-isocyanurate foam, extruded polystyrene, fiberglass, mineral wool, alumina silicate microspheres, and translucent gel (micro-porous silica) are most commonly used.

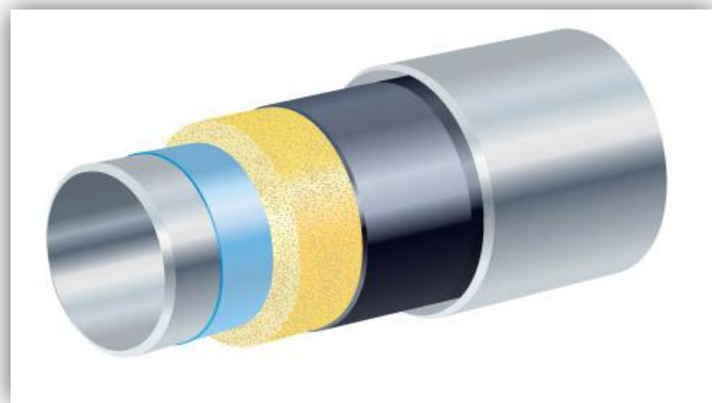


Figure 2.2: Pipe-in-Pipe Insulation (Polyurethane Foam)

2.4 PROSPER SOFTWARE

PROSPER is a well performance, design and optimization program which is part of the Integrated Production Modeling Toolkit (IPM). This tool is the industry standard well modeling with the major operators worldwide. PROSPER provides unique matching features, which tune PVT, multiphase flow correlations and IPRs to match measured field data, allowing a consistent well model to be built prior to use in prediction (sensitivities or artificial lift design).

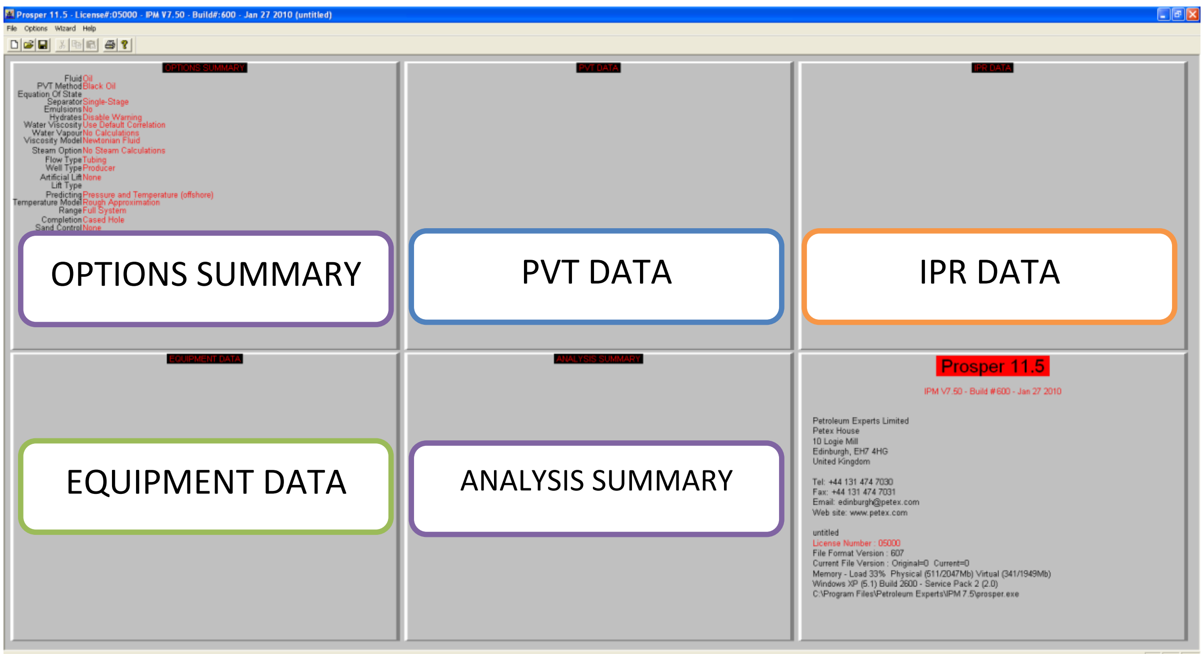


Figure 2.3: PROSPER Interface

CHAPTER 3
METHODOLOGY

3.0 METHODOLOGY

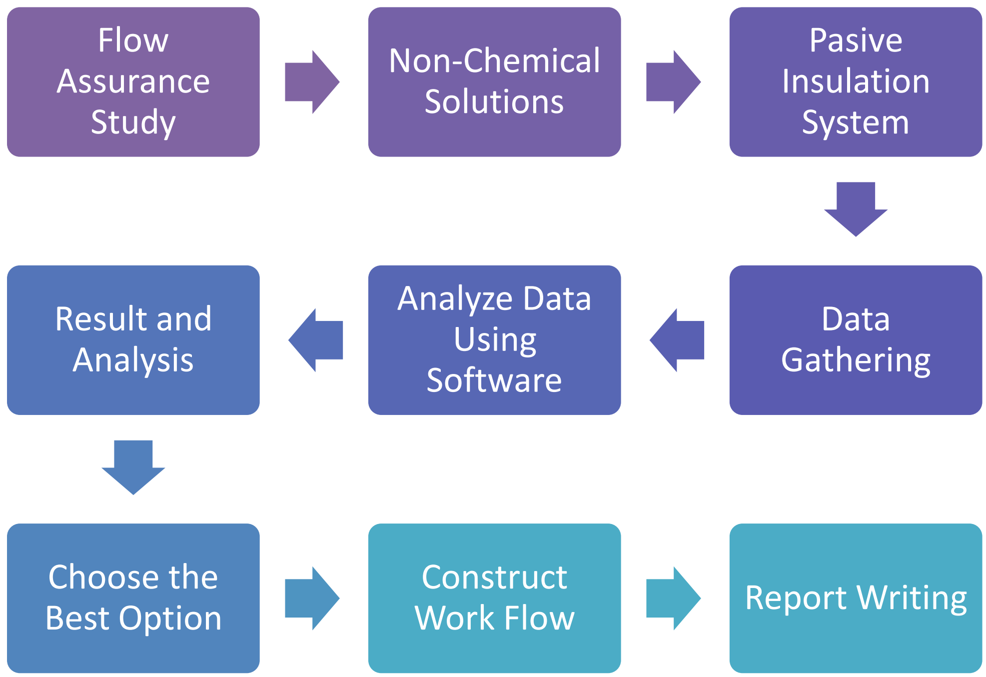


Figure 3.1: Project Activities Sequence

Project Procedures

1) The first step towards setting the non-chemical flow assurance strategies for petroleum system is to understand the main idea of flow assurance itself by doing preliminary study. Studies about the hydrate and wax formation temperature to understand the behavior of the pressure and temperature that favors the condition to occur.
2) Next, the study is narrowed in minor scope which is to identify available non-chemical solutions or technologies that being implemented nowadays. The passive system for non-chemical solution will be focus on for this project instead of active system. The chosen insulation methods are Wet Insulation and Pipe-In-Pipe.

3) A hypothetical data will be collected to assist next step of research. Then, by using production optimization software tool, PROSPER the well's data will be analyzed. The result from the analysis as support will be the key to decide the best option available for non-chemical solution flow assurance strategies. In this case, Wet Insulation and Pipe-in-Pipe insulation method.
4) After that, work flow for the passive system will be constructed to see the effectiveness and reliability based on the field data studied from the software.
5) Lastly, after all the analysis from the result being completed. Next task will be the report writing to conclude all findings and recommendation.

3.1 PROJECT ACTIVITIES

During the period of *FYP 1* the activities mostly focus on data and sources gathering. The source mostly taken from the internet browsing includes technical papers, article from journals and books.

For *FYP 2* the project will proceed with data analysis where production optimization software tools will be used. The result from the analysis will be used to create a work flow to generate the non-chemical flow assurance strategies.

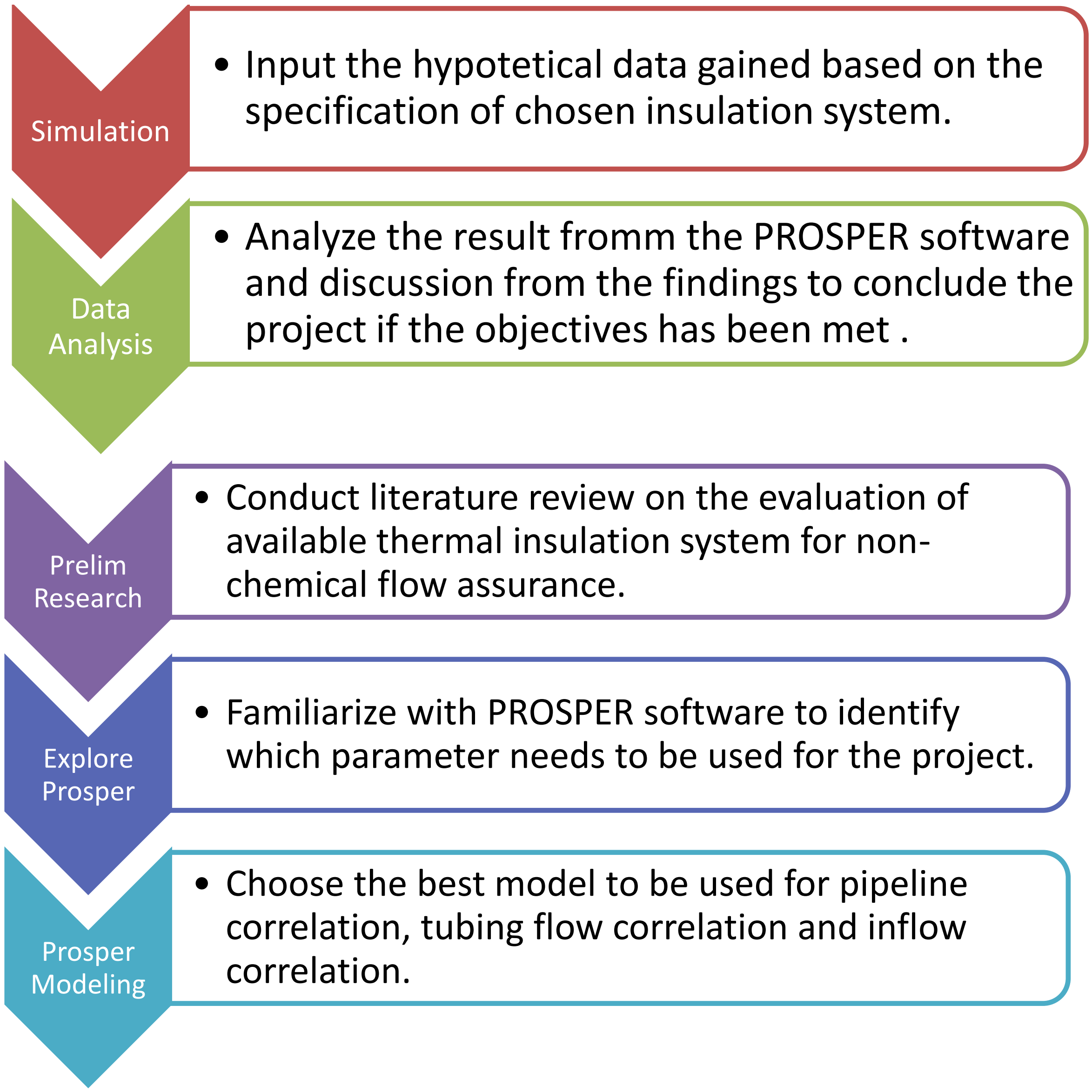


Figure 3.2: PROSPER Software Sequences

3.2 KEY MILESTONE

FYP 1 starts in June 2012 until September 2012. While *FYP 2* will be proceed from September 2012 until December 2012.

3.3 GANTT CHART

Please refer *Appendix 1* for Gantt chart of the project.

3.4 TOOL REQUIRED

Production optimization software tool, PROSPER which is product of PETEX, Petroleum Experts. PROSPER is a well performance, design and optimization program for modeling most types of well configurations found in the field. All the configuration of the field data will be analyzed at the computer lab (Block 15) using PROSPER. The following will tell little bit description about PROSPER software.

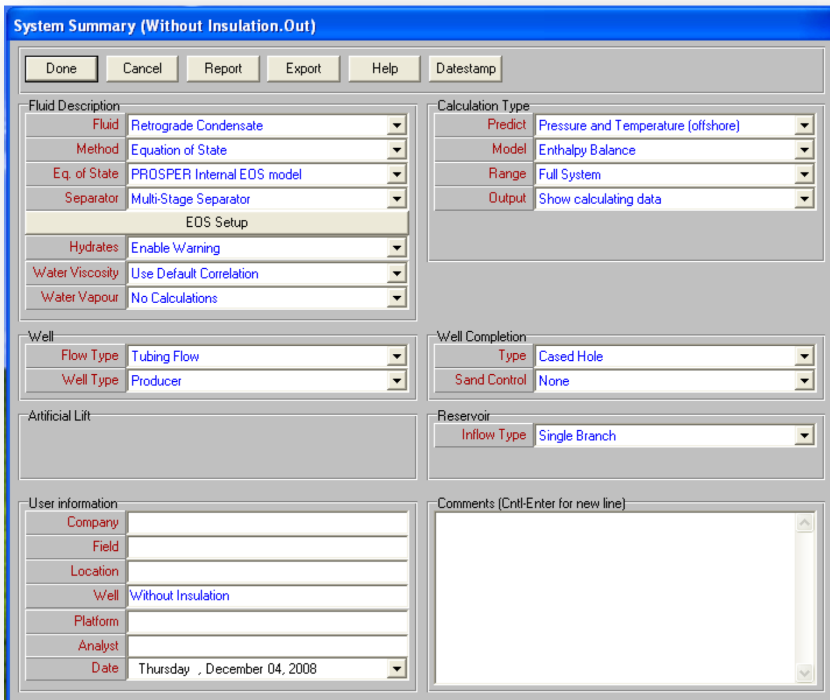


Figure 3.3: Options Summary window

From Figure 8, option summary is the first thing that user needs to input about whole PROSPER modeling. User must specify about the Fluid Description, Well, Calculation Type, Well Completion and Reservoir.

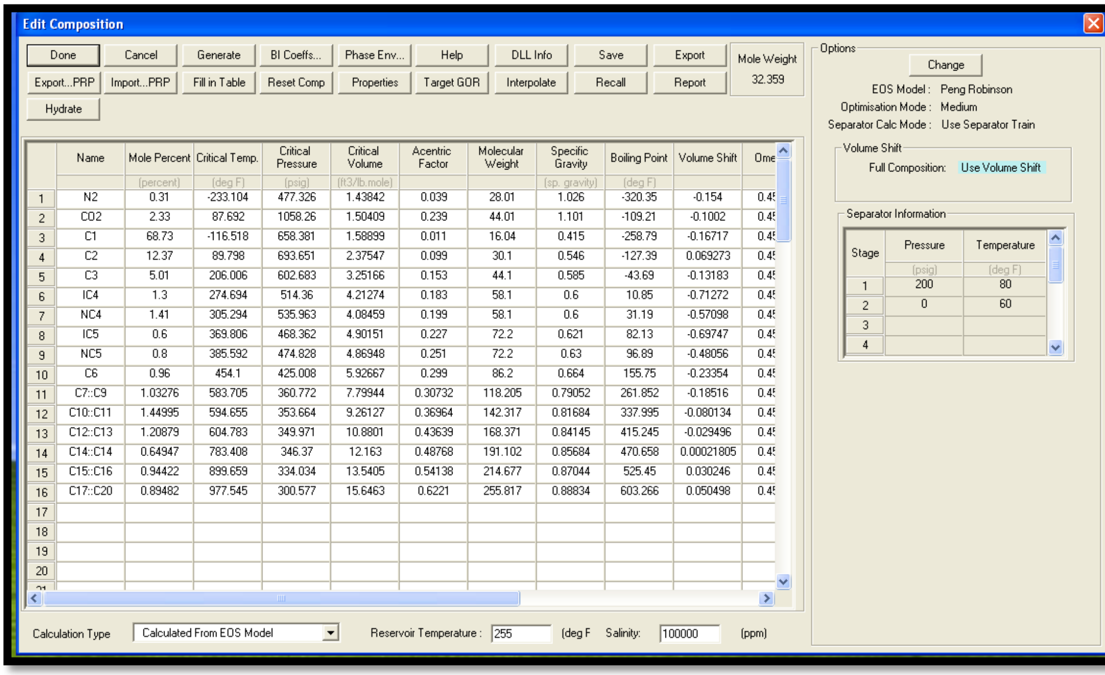


Figure 3.4: PVT Data window

Figure 9 shows where should the PVT Data acquire should be input before further modeling continues like reservoir temperature and salinity. Here where user will input the composition of the model and generate hydrate and wax consideration, target GOR and phase envelope.

Besides, user needs to specify the Equation of State (EOS) Model and also the separator information. For this project, Peng Robinson EOS model will be used with medium optimization mode by using separator train for separator calculation mode.

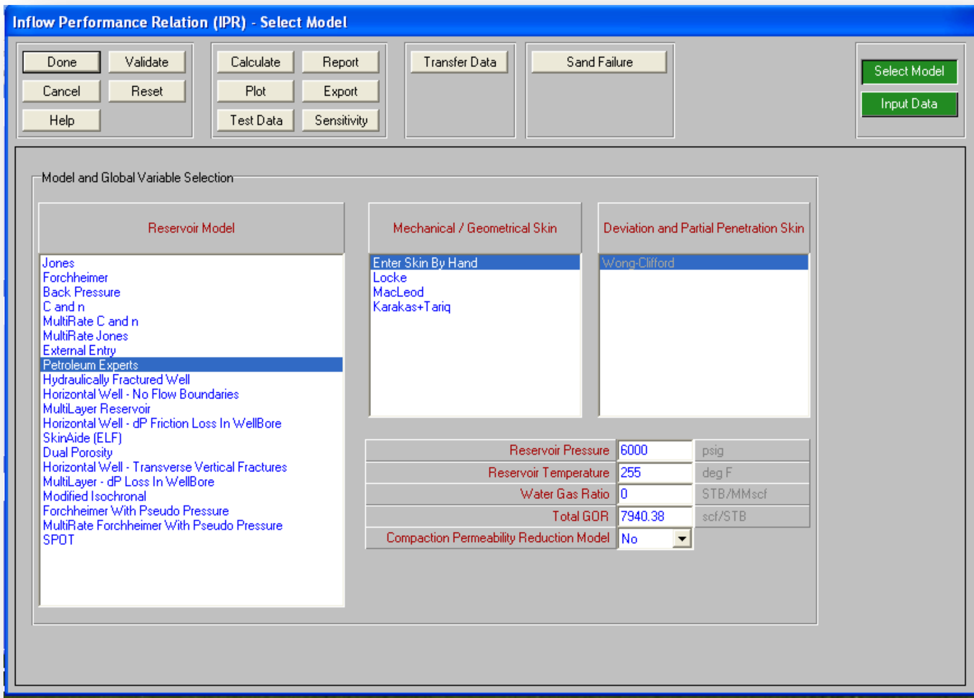


Figure 3.5: Inflow Performance Relation (IPR) window

Figure 10 shows where the IPR calculation will be made based on the parameter has been input. Reservoir model must be chosen before IPR calculation and plot being done. Then for the respective reservoir model requires some data to be input before calculation can be proceed. For this project, the author using Petroleum Experts for reservoir model by enter skin by hand for mechanical/geometrical skin. IPR will be calculated to find the well operating point which determined by intersection of IPR and vertical lift performance (VLP). The operating point defines the operating flow rate and pressure at specific node.

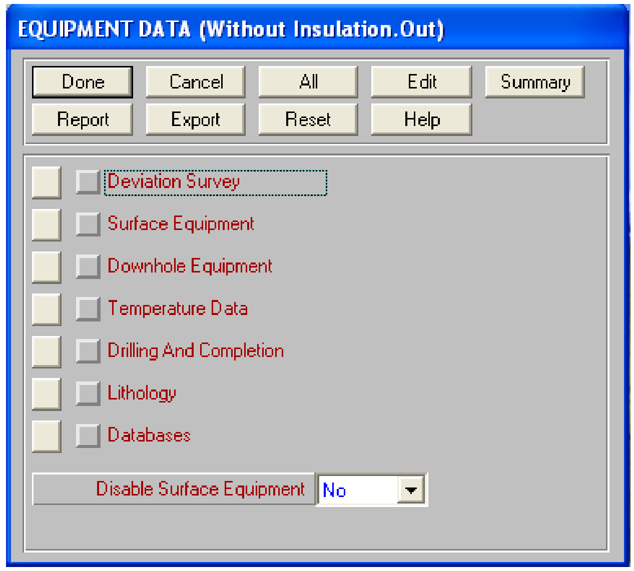


Figure 3.6: Equipment Data window

Figure 11 shows the Equipment Data main option where user has to input the required data as shown in the figure before proceed to other calculation. There are deviation survey, surface equipment, downhole equipment, temperature data, drilling and completion, lithology and database.

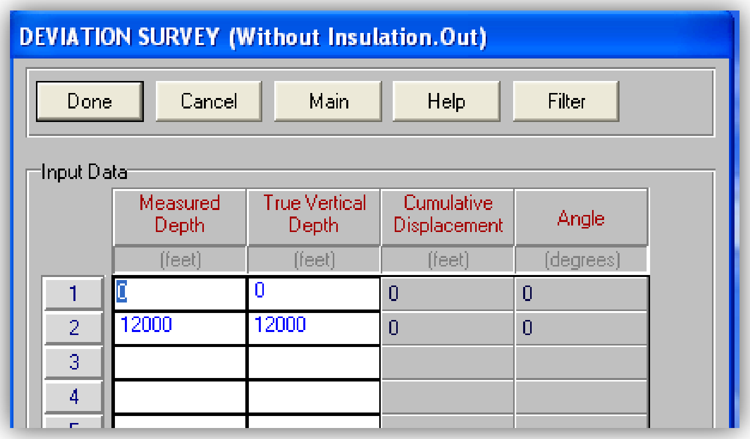
While the Analysis Summary is the checklist of the calculation that will be made for the whole PROSPER modeling, where the after the calculation has been done a tick will be appear on it. Besides, from there user can directly access the calculation or analysis that needs to be check on.

Most of the function in the PROSPER software can be categorized as user friendly. All the calculation can be made based on our own selected correlations. The sensitivity analysis also can be made for 2 variables and 3 variables to see the performance of the well based on our input data.

3.5 PROSPER MODELING

3.5.1 Equipment Data

Deviation Survey



For deviation survey in this case, vertical well where the Measured Depth is equal to True Vertical Depth with 0 degree angle.

For surface equipment there are Platform, Riser and Tieback used.

Figure 3.7: Deviation Survey

Surface Equipment

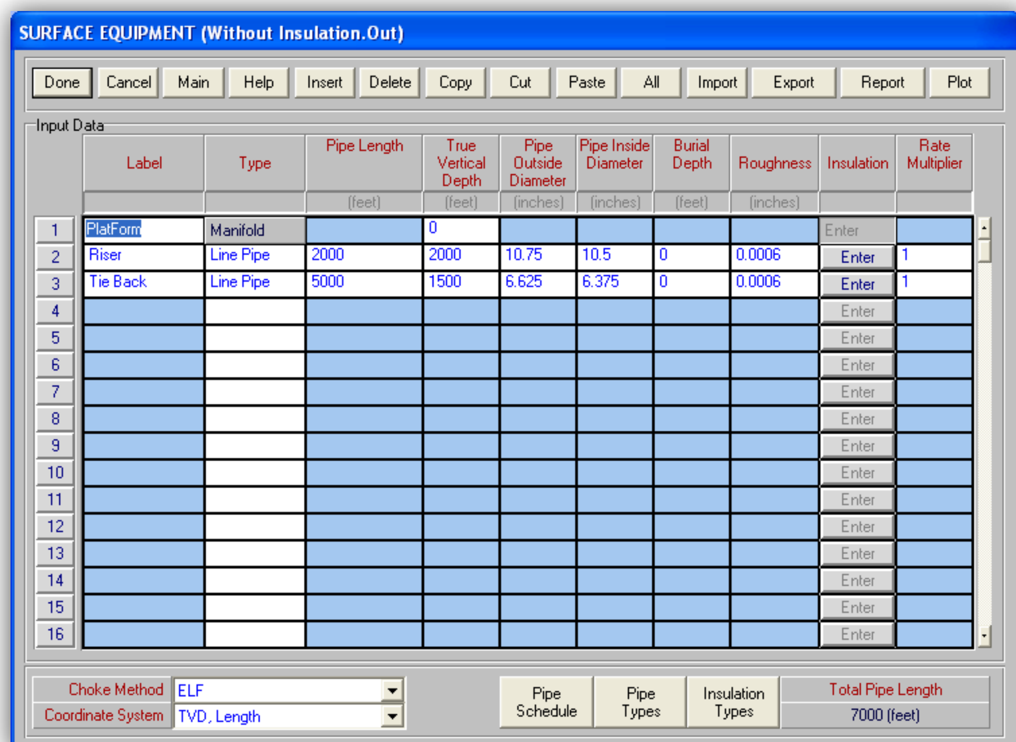


Figure 3.8: Surface Equipment

Downhole Equipment

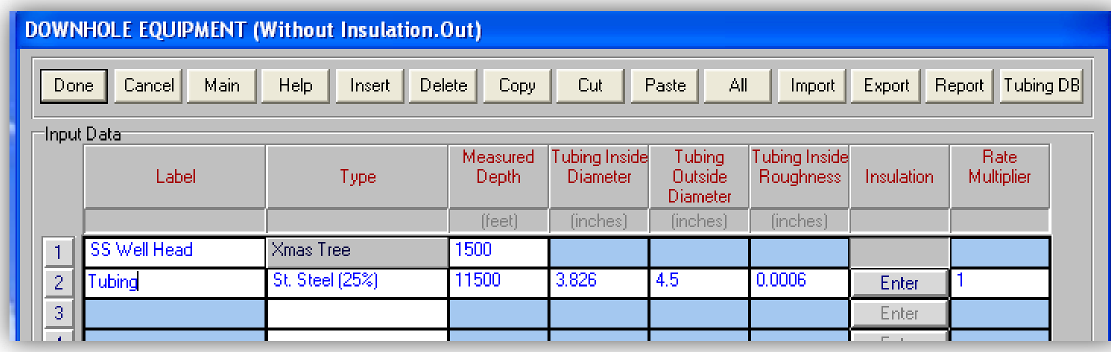


Figure 3.9: Downhole Equipment

Temperature Data

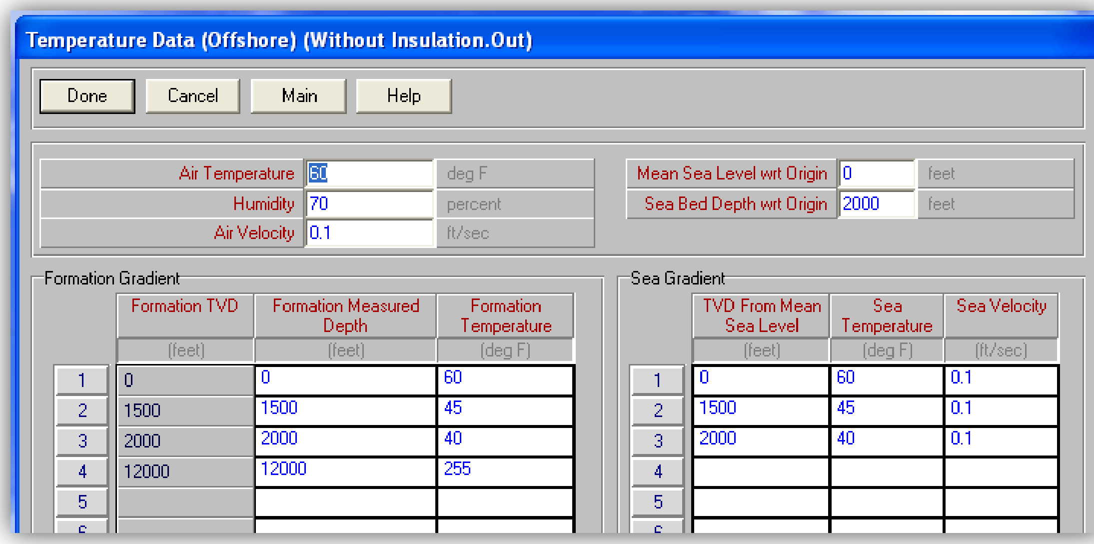


Figure 3.10: Temperature Data

Downhole equipment used are wellhead and tubing. Insulation type varies for 3 cases in this project. Refer to *Appendix 3* for insulation system information. While temperature data require air temperature, humidity, air velocity, men sea level with respect to origin and sea bed depth with respect to origin. Besides, formation gradient and sea gradient also need to be input for thermal calculation of the well. For the drilling and completion and the lithology the details as shown below:

Drilling and Completion

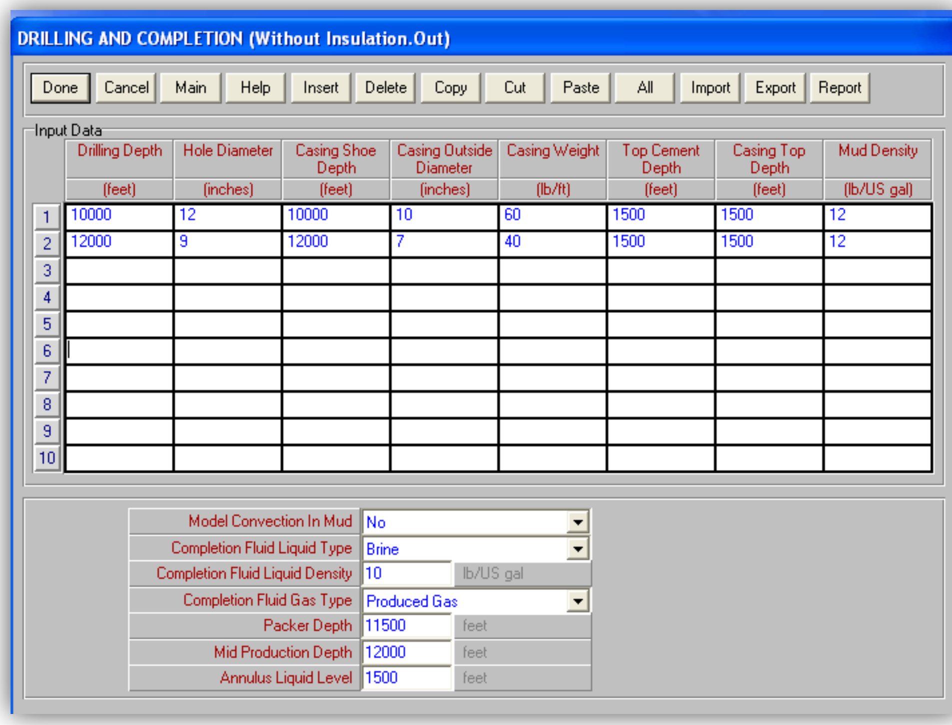


Figure 3.11: Drilling and Completion

Lithology

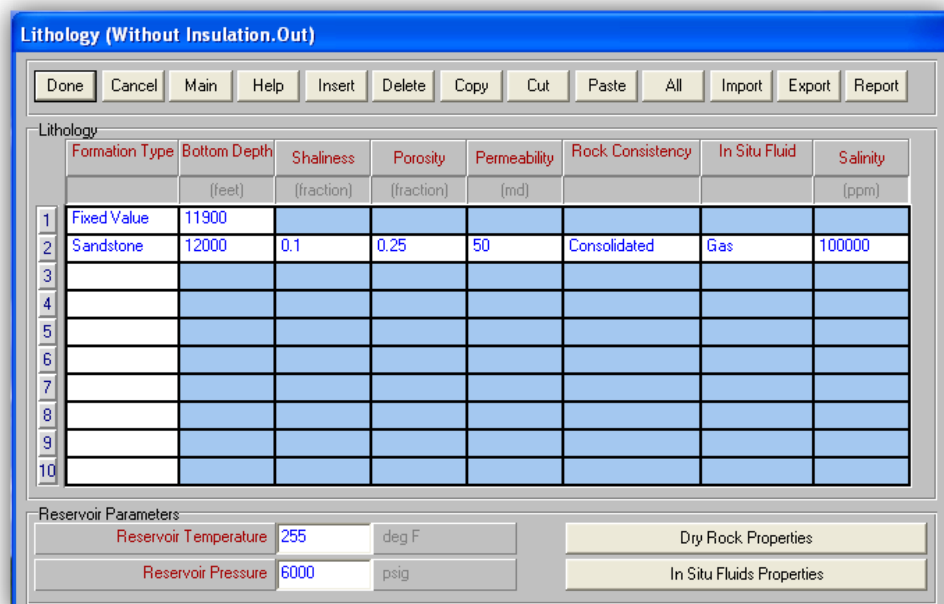


Figure 3.12: Lithology

3.5.2 IPR Data

IPR model:	Petroleum Experts
Static Reservoir Pressure:	6000 psig
Reservoir Temperature:	255 degF
Water Gas Ratio:	0 stb/MMscf
Total GOR:	7940.38 scf/stb
Compaction Permeability Reduction model:	No
Skin model:	Enter skin by hand
Permeability:	50 mD
Reservoir Thickness (True stratigraphic thickness):	50 ft
Drainage Area:	300 acres
Dietz shape factor:	31.6
Well bore radius (Drill bit radius):	0.354 ft
Perforation interval:	30 ft
Time since production:	1 days
Reservoir porosity:	0.25
Connate water saturation:	0.25
Non-Darcy Flow Factor:	Calculated
Permeability entered:	Total permeability
Mechanical skin:	5

This are IPR data used for IPR calculation based on the reservoir model selected.

3.5.3 Surface Equipment Drawing

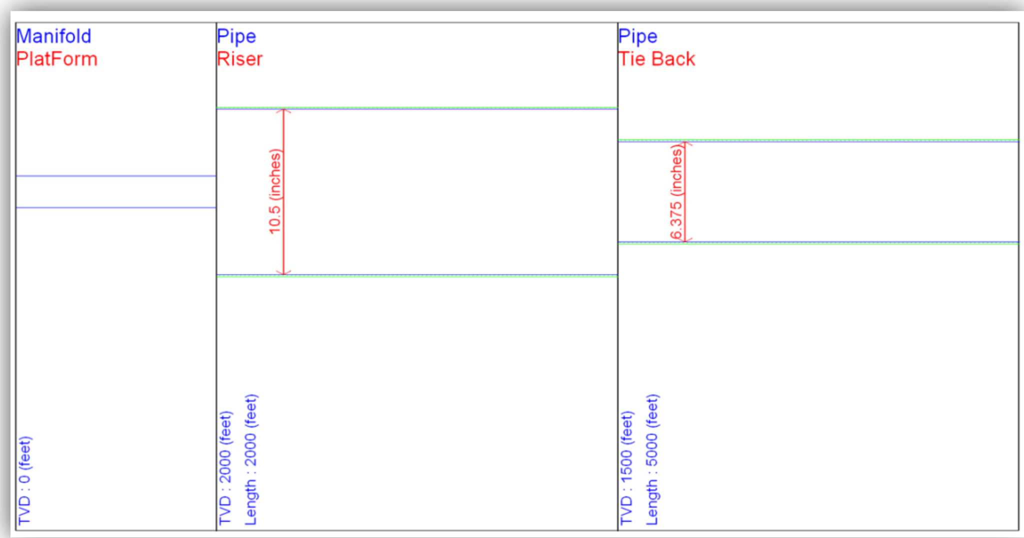


Figure 3.13: Surface Equipment

3.5.4 Downhole Equipment Drawing

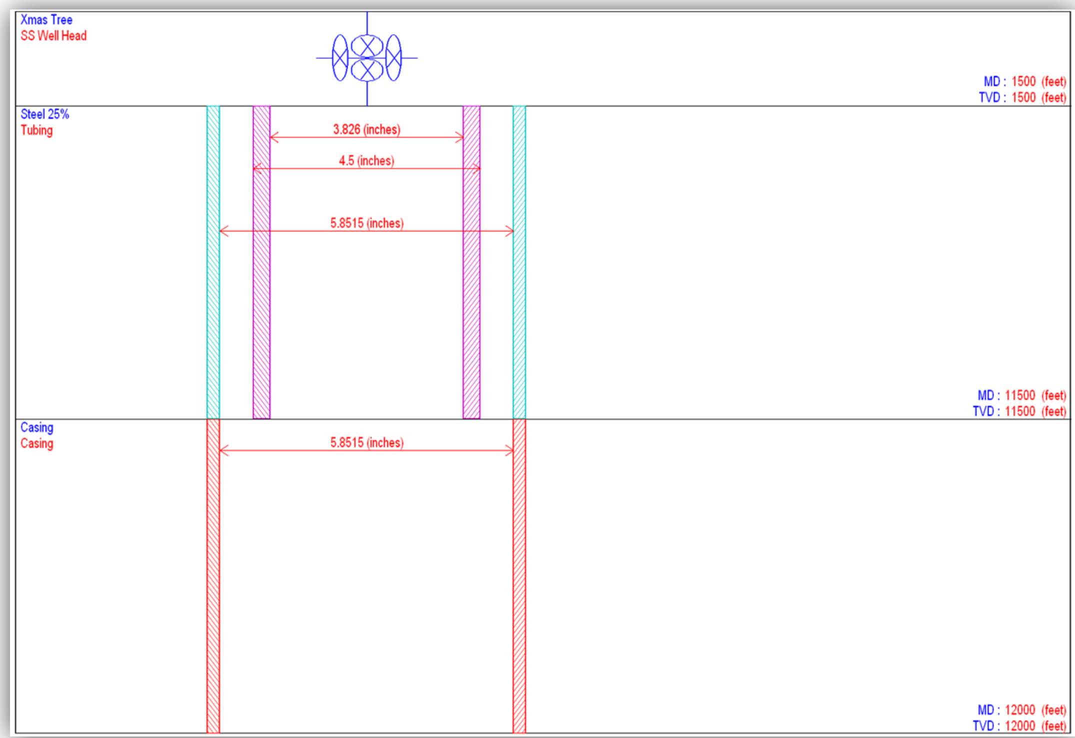


Figure 3.14: Downhole Equipment

3.5.5 PVT Data

Refer to *Appendix 2: PVT Data*. The data used to study the behavior of the composition of well and to study the wax and hydrate formations temperature and pressure profile. The result summarized by the phase envelope generated based on the calculation as shown in the next chapter.

CHAPTER 4
RESULT AND DISCUSSION

4.0 RESULT AND DISCUSSION

4.1 Comparative Study about Wet Insulation & Pipe Insulation

The comparative study can be shown in the following *Table 4.1* which is mentioned by Faluomi and Arcipreti (2007).

Table 4.1: Main characteristics of selected insulation systems

Insulation Type	Advantages	Disadvantages	Performances
Wet insulation	• Simple • Low cost • Large application	• Limited insulation thickness • limited cooldown	U (W/m2K) > 1 – 2
Pipe-in-Pipe	• small U • conventional installation	• expensive • might not be reeled	U (W/m2K) > 0.5

They also suggest that the required thermal performances of a flowline or tubing system to manage the considered flow assurance issues are the following:

- A specified steady state minimum flow temperature at the host, considering the entire life of the design, based on hydrates, wax, etc.
- The ability to handle both planned and unplanned shutdowns without plugging
- Satisfactory cool-down conditions during (transient) shutdown, satisfactory warm-up characteristics, and manageable cold re-starts.
- The ability to achieve a safe long-term shut-in state that properly re-starts
- The ability to remediate hydrate or wax plugs

Based on the *Figure 4.1*, from their researches they conclude the hydrate and wax formation temperature and pressure profile which shows the well operative conditions and flowline or tubing operative conditions.

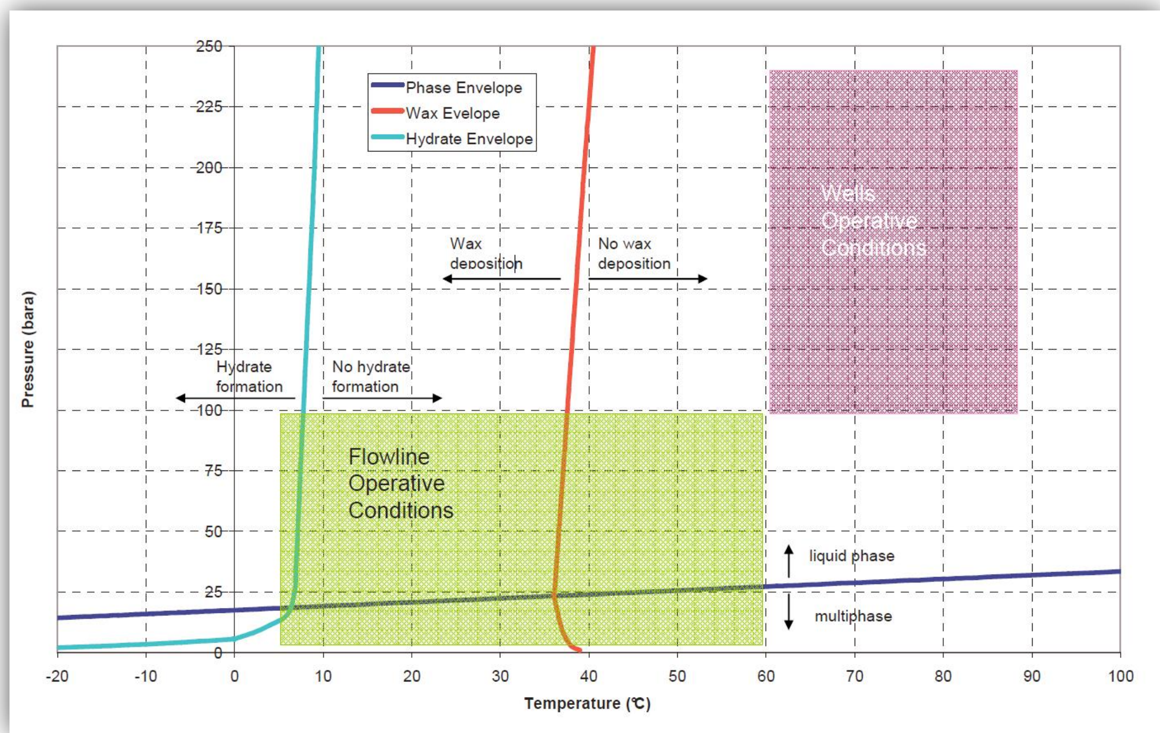


Figure 4.1: Production System Envelope versus Plugging Risk Zones

The pressure and temperature of the well fluids which includes free water needs to be maintained from the region shows above to prevent the hydrate and wax formation. Thus, the systems require design that able to stay in the operative condition. Hydate management system must emphasize about:

- the minimum overall heat transfer coefficient, to produce in steady state conditions outside hydrate formation zone
- minimum cooldown duration (defined as the time needed by the coldest point of the flowline or tubing to enter into hydrate zone) defined equal to the time required to implement and terminate an operative procedure to bring the production system outside hydrate zone forever (i.e. depressurization)

Faluomi and Arcipreti (20007) also agreed that as hydrocarbon fluids are produced from the reservoir, they will eventually cool and undergo changes in pressure. As a consequence of these changes, the high molecular weight components of the oil have a tendency to precipitate as solids. Among these are saturates or paraffin which can crystallize as waxes and have the potential to cause a host of operational problems anywhere throughout the production and export system. Typically insulated system systems are designed to operate at steady state conditions such that the minimum fluid temperatures are above the wax appearance temperature.

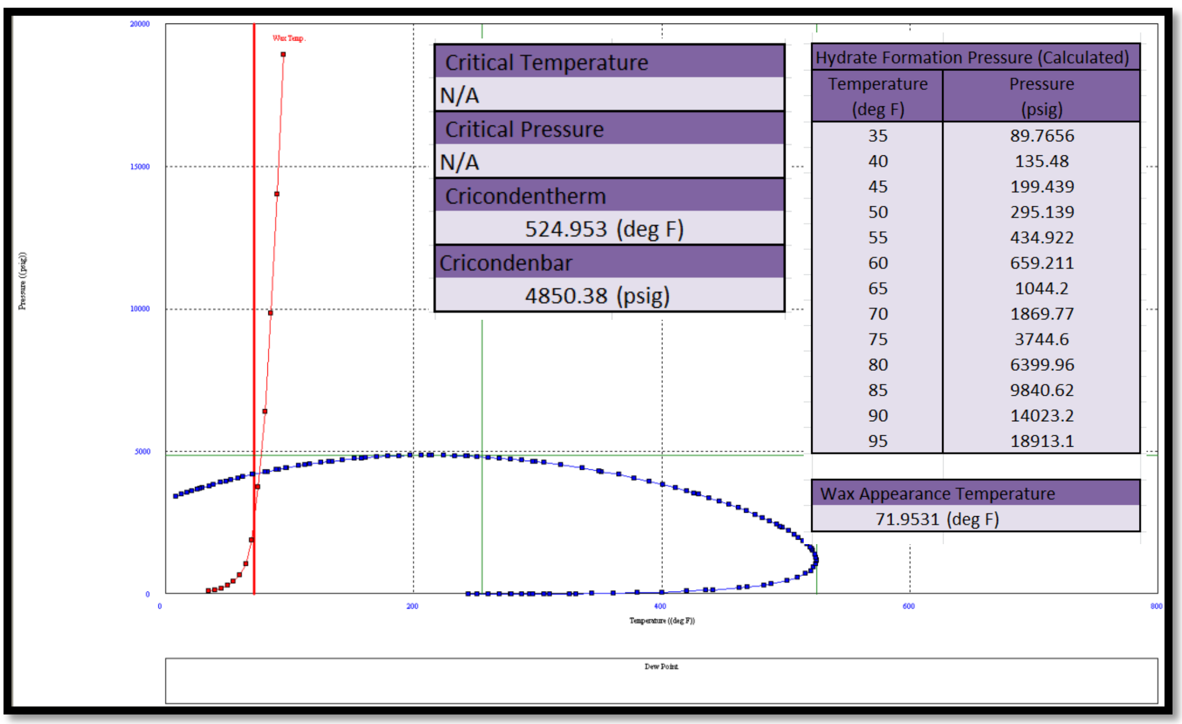


Figure 4.2: Phase Envelope Results

For this project, *Figure 4.2* shows the phase envelope that has been calculated and generated based on the composition data of the field. The red line shows the hydrate formation curve that has been calculated and using the PROSPER while the **Wax Appearance Temperature (WAT)** calculated is **71.9531 deg F**. Cricondentherm calculated is 524.953 deg F and Cricondenbar is 4850.38 psig.

4.2 Inflow Performance Relationship (IPR)

Boyun,William,Lyons and Ali (2007) mentioned that fluid properties change with the location-dependent pressure and temperature in the oil and gas production system. To simulate the fluid flow in the system, it is necessary to break the system into discrete nodes that separate system elements (equipment sections). Fluid properties at the elements are evaluated locally. Nodal analysis is performed on the principle of pressure continuity; there is only one unique pressure value at a given node regardless of whether the pressure is evaluated from the performance of upstream equipment or downstream equipment. The field selected for this project is producing condensate oil and the results are simulated into 3 cases which are:

a) **without using thermal insulation (base case),**
b) using **Pipe-in-Pipe insulation (Dry Insulation)**
c) and **Wet Insulation (Polyurethane Insulation System).**

Since these 3 cases using the same field data, the IPR will be having the same graph shown in Figure 4.3. This field having **Absolute Open Flow (AOF)** about **120.563 MM scf/day** with skin factor of 5 under Reservoir Temperature of 255 deg F.

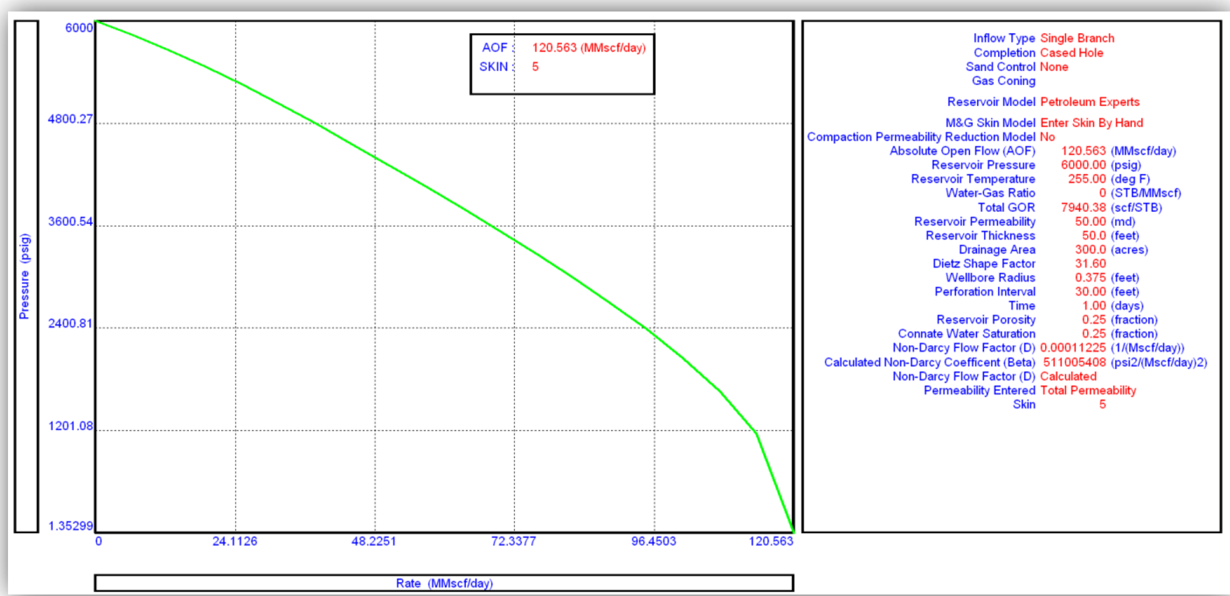


Figure 4.3: IPR Plot

4.3 Case 1: Without Using Thermal Insulation (Base Case)

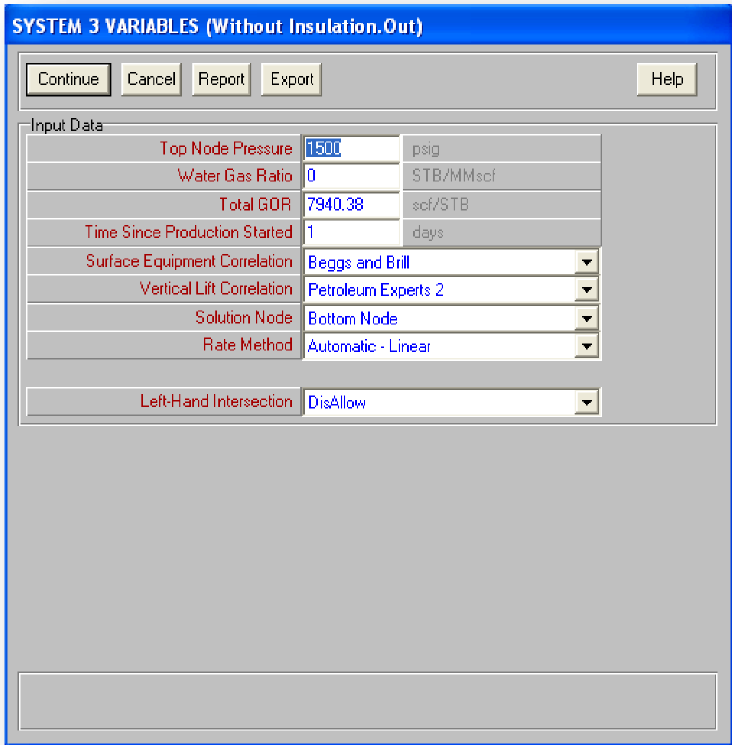


Figure 4.4: System 3 Variables Calculation

Using top node pressure of 1500 psig and configuration as shown in *Figure 4.4*, the study for base case has been simulated into Inflow (IPR) versus Outflow (VLP) Curve shown in *Figure 4.5*. The well depth of this well is 12000 ft.

The yellow line at the VLP shows hydrate formation detected for this well. This hydrate will cause the production of oil decreased due to plugging line. For this well, there are hydrate problem found along the VLP; from the bottomhole to the surface. From the result, the gas production calculated is **57.592 MM scf/day** and oil rate of **7253.1 stb/day.** The solution node observed is 4034.553 psig and other details described in the figure at right side of the graph.

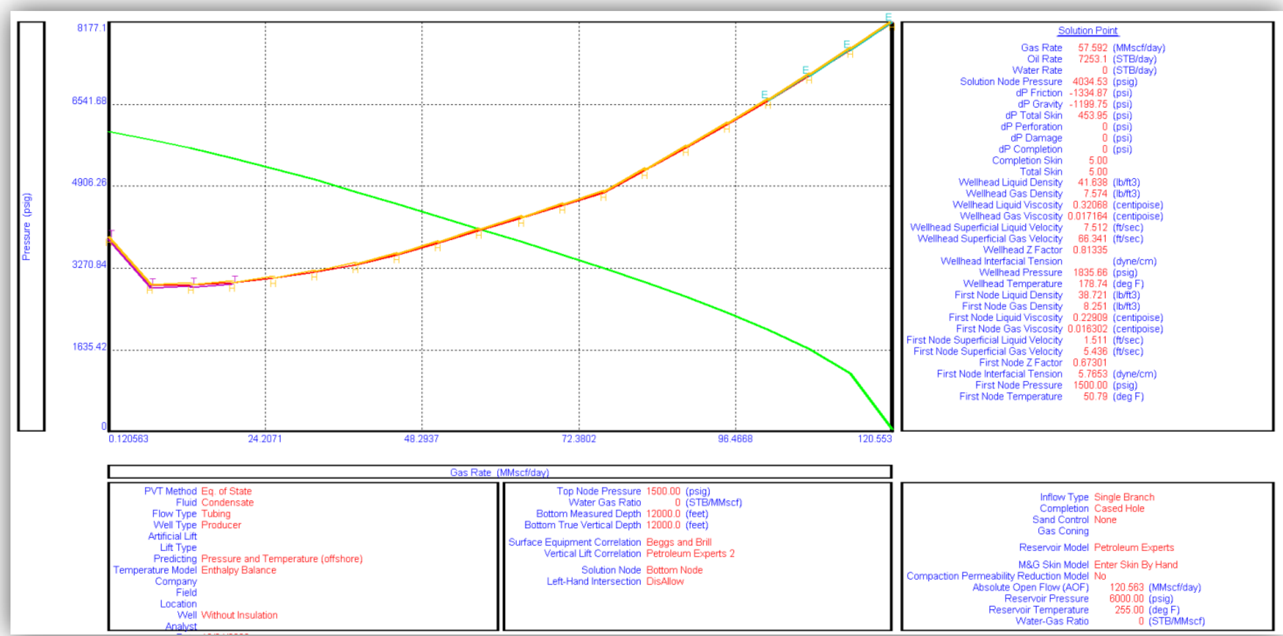


Figure 4.5: Inflow (IPR) versus Outflow (VLP) without thermal insulation

4.4 Case 2: Pipe-in-Pipe insulation (Dry Insulation)

The base case from case 1 will be used to compare the effect of thermal insulation at tubing for this well. For case 2 which is Pipe-in-Pipe insulation there will be divided into 3 categories of analysis. There are:

i. Completely PIP insulation for the well system
ii. Riser with downhole equipment PIP insulation
iii. Tie back with downhole equipment PIP insulation

These 3 types of analysis aim to study the effect of Pipe-in-Pipe insulation for surface equipment and downhole equipment where the manipulated variables are the riser and tie back.

4.4.1 Complete PIP insulation for the well system

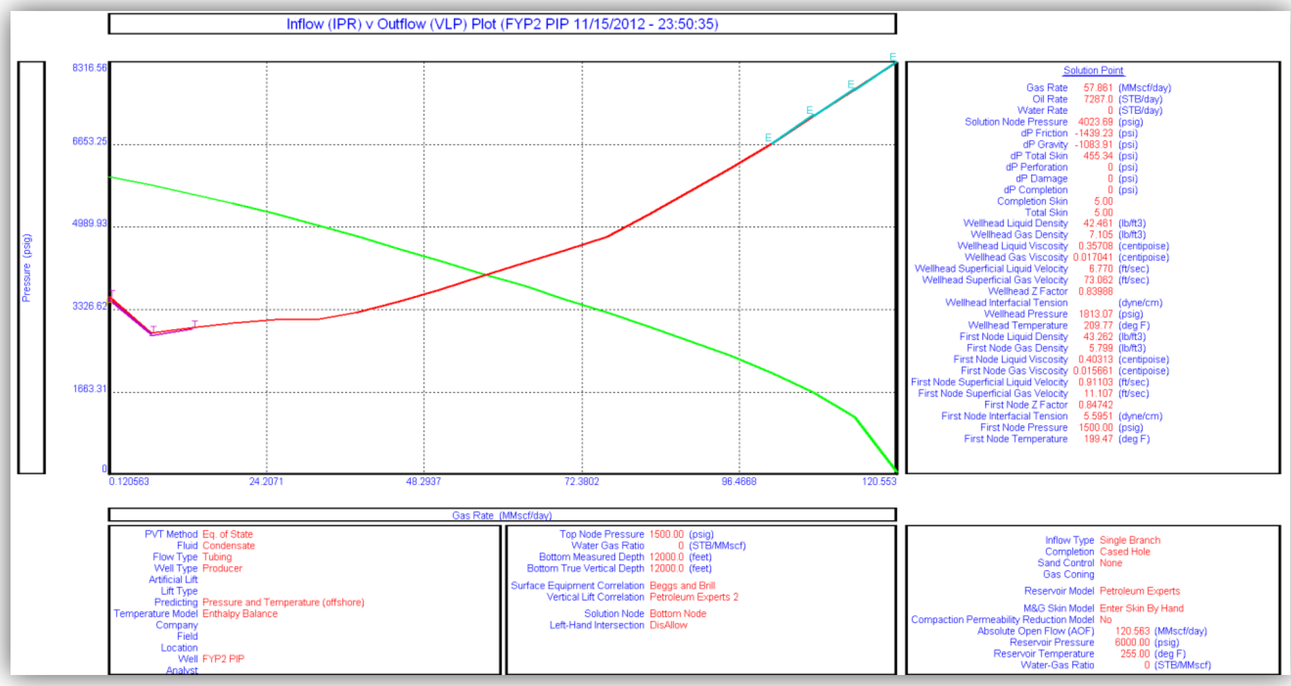


Figure 4.6: Effect of completely PIP insulation

From *Figure 4.6*, the effect of having completely PIP insulation can be observed that there are **no hydrate formation** along the VLP curve (red curve). The calculation has yield gas rate of **57.861 MM scf/day** with oil rate of **7287 MM scf/day**. The solution node observed is 4023.69 psig and other details described in the figure at right side of the graph.

4.4.2 Riser with downhole equipment PIP insulation

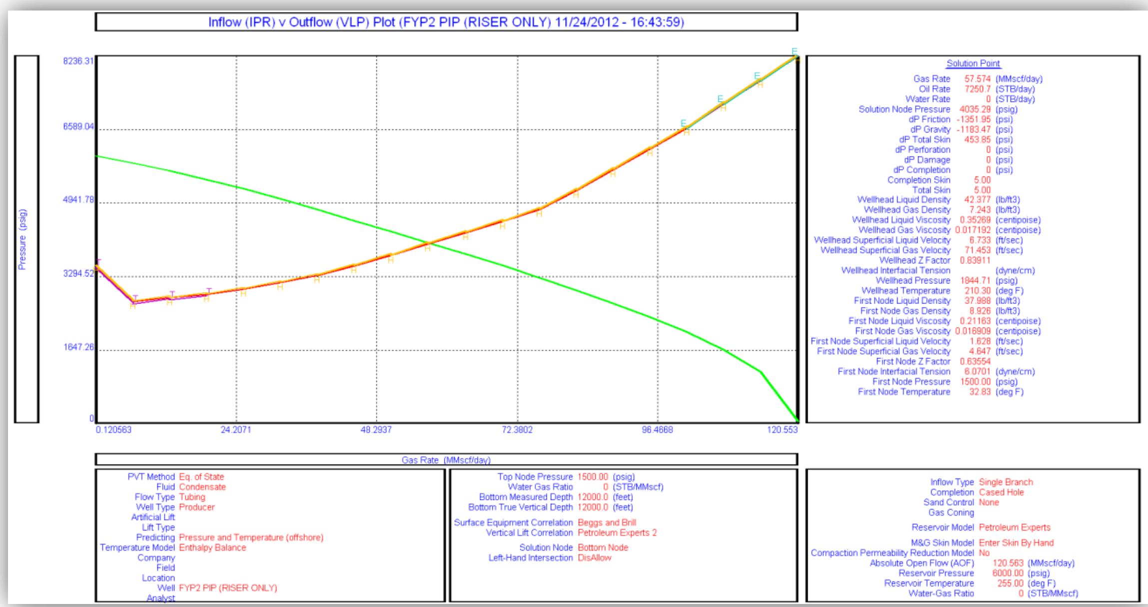


Figure 4.7: Effect of Riser with downhole equipment PIP insulation

From *Figure 4.7*, the Effect of Riser with down equipment insulation can be observed that there are hydrate formation along the VLP curve (red curve) from the beginning until to the surface. The calculation has yield gas rate of **57.574 MM scf/day** with oil rate of **7250 MM scf/day**. This shows that if the riser insulated without insulate the tie back would cause hydrate formation for this well, thus making the production decrease because of the plugging. It is not a good option to use the thermal insulation when neglecting the tie back insulation or considering full thermal insulation system. The solution node observed is 4035.29 psig and other details described in the figure at right side of the graph.

4.4.3 Tie back with downhole equipment PIP insulation

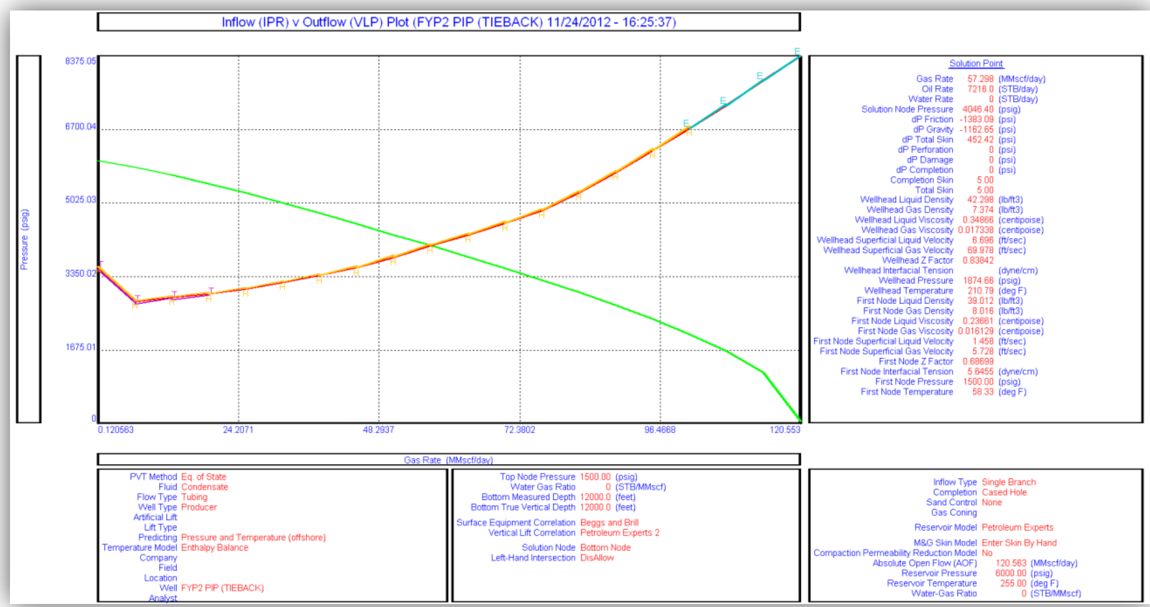


Figure 4.8: Effect of Tie Back with downhole equipment PIP insulation

While for *Figure 4.8* shows the effect of Tie Back with downhole equipment PIP insulation where the gas rate is **57.298 MM scf/day** and oil rate is **7216 MM scf/day**. It is observed that there are hydrate formation occur along the VLP curve as shown in the yellow line. Compared to riser only insulated mentioned earlier, the hydrate problem ends earlier before come to surface. Thus, the insulation system not suitable for this well and full system insulation should be considered to avoid the plugging. The solution node observed is 4046.40 psig and other details described in the figure at right side of the graph.

4.5 Case 3: Wet Insulation (Polyurethane Insulation System)

For case 3 which is Wet Insulation it will be divided into 3 categories of analysis. There are:

i. **Completely Wet Insulation for the well system**
ii. **Riser with downhole equipment Wet Insulation**
iii. **Tie back with downhole equipment Wet Insulation**

These 3 types of analysis aim to study the effect of Wet Insulation for surface equipment and downhole equipment where the manipulated variables are the riser and tie back.

4.5.1 Complete Wet Insulation for the well system

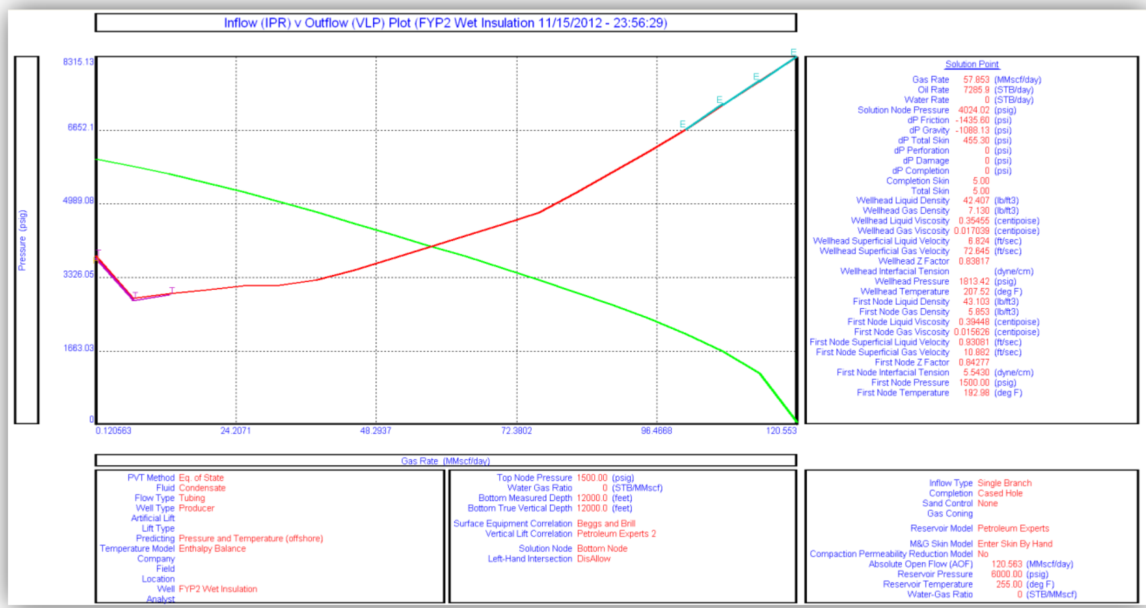


Figure 4.9: Effect of Completely Wet Insulation

From *Figure 4.9*, the effect of having completely Wet Insulation can be observed that there is **no hydrate formation** along the VLP curve (red curve). The calculation has yield gas rate **of 57.853 MM scf/day** with oil rate of **7285.9 MM scf/day**. The solution node observed is 4024.02 psig and other details described in the figure at right side of the graph.

4.5.2 Riser with downhole equipment Wet Insulation

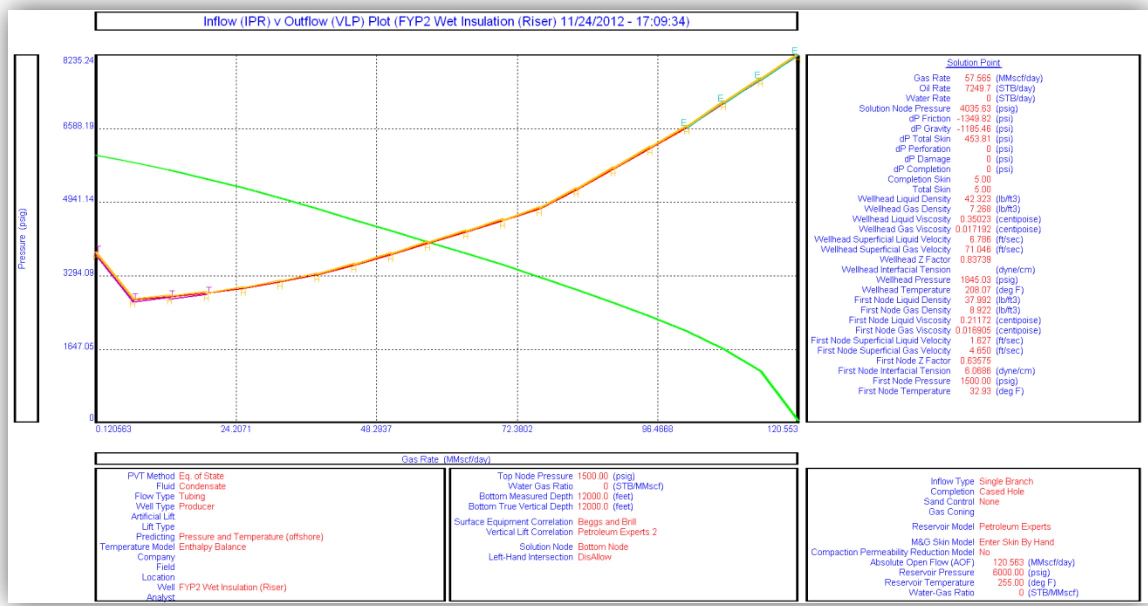


Figure 4.10: Effect of Riser with downhole equipment Wet insulation

From Figure 4.10, the Effect of Riser with downhole equipment Wet insulation can be observed that there are hydrate formation along the VLP curve (red curve) from the beginning until to the surface. The calculation has yield gas rate of **57.565 MM scf/day** with oil rate of **7249.7 MM scf/day**. Same like in case 2, this shows that if the riser insulated without insulate the tie back would cause hydrate formation for this well, thus making the production decrease because of the plugging. Thus, thermal insulation without tie back insulation or considering full thermal insulation system is not the best option for hydrate formation prevention. The solution node observed is 4035.63 psig and other details described in the figure at right side of the graph.

4.5.3 Tie back with downhole equipment Wet Insulation

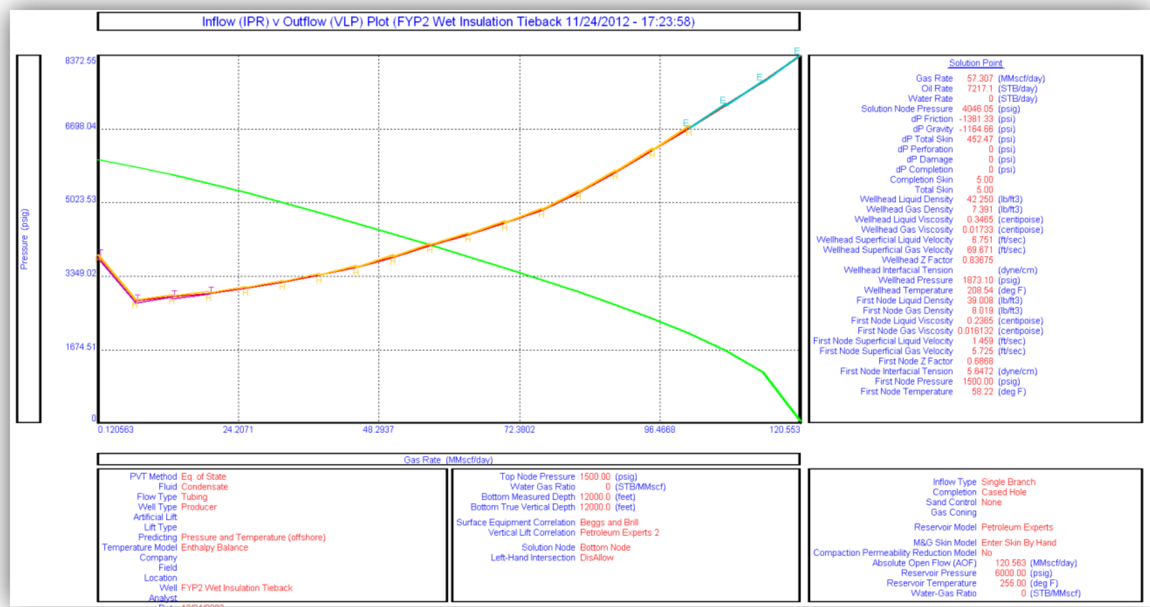


Figure 4.11: Effect of Tie Back with downhole equipment Wet insulation

While for *Figure 4.11* shows the effect of Tie Back with downhole equipment Wet insulation where the gas rate observed is **57.307 MM scf/day** and oil rate is **7217.1 MM scf/day**. Same like in case 2, it is found that there are hydrate formation occur along the VLP curve as shown in the yellow line where the hydrate problem ends earlier before come to surface. The insulation system option is not suitable for this well and full system insulation should be considered to avoid the plugging. The solution node observed is 4046.05 psig and other details described in the figure at right side of the graph.

4.6 Analysis Summary

To evaluate the best thermal insulation system for specific well's data has been choose to simulate the effect of having thermal insulation at the tubing. Passive system has been chosen for this analysis; wet insulation and dry insulation (Pipe-in-Pipe). The best insulation for selected well favor completely PIP insulation for the well system among others available options.

By simulating the well using PIP configuration yields increment greater than the base case which is about 0.47%. As compared with Wet Insulation increment only about 0.45%. Even the different not much significant in value, the result shows that mitigating hydrate using thermal insulation would give optimized performance of well for future by preventing blockage without any chemical inhibitors which require topside facilities and risk involve. As mentioned earlier the advantages and disadvantages of both methods, now it's come to the final decisions to choose the most optimum and efficient choice considering the cost and risk management of the whole field development.

Table 4.2 summarize the whole simulation results, the suitable candidate for thermal insulation for this field is using completely PIP insulation for the well system. The result yields 7287 stb/day oil rate and 57.861 MMscf/day of gas rate without hydrate formation. This well should consider PIP insulation from the beginning of the production to avoid plugging problem with optimum configuration and production.

Table 4.2: Analysis Summary of PROSPER

<table>
<tr><th colspan="2">Case</th><th>Oil Rate (stb/day)</th><th>Gas Rate (MMscf/day)</th><th>Hydrate Formation</th></tr>
<tr><td colspan="2">1) Without Using Thermal Insulation (Base Case)</td><td>7253.1</td><td>57.592</td><td>Yes</td></tr>
<tr><td rowspan="3">2) Pipe-in-Pipe insulation (Dry Insulation)</td><td>Completely PIP insulation for the well system</td><td>7287</td><td>57.861</td><td>No</td></tr>
<tr><td>Riser with downhole equipment PIP insulation</td><td>7250</td><td>57.574</td><td>Yes</td></tr>
<tr><td>Tie back with downhole equipment PIP insulation</td><td>7216</td><td>57.298</td><td>Yes</td></tr>
<tr><td rowspan="3">3) Wet Insulation (Polyurethane Insulation System)</td><td>Completely Wet Insulation for the well system</td><td>7285.9</td><td>57.853</td><td>No</td></tr>
<tr><td>Riser with downhole equipment Wet Insulation</td><td>7249.7</td><td>57.565</td><td>Yes</td></tr>
<tr><td>Tie back with downhole equipment Wet Insulation</td><td>7217.1</td><td>57.307</td><td>Yes</td></tr>
</table>

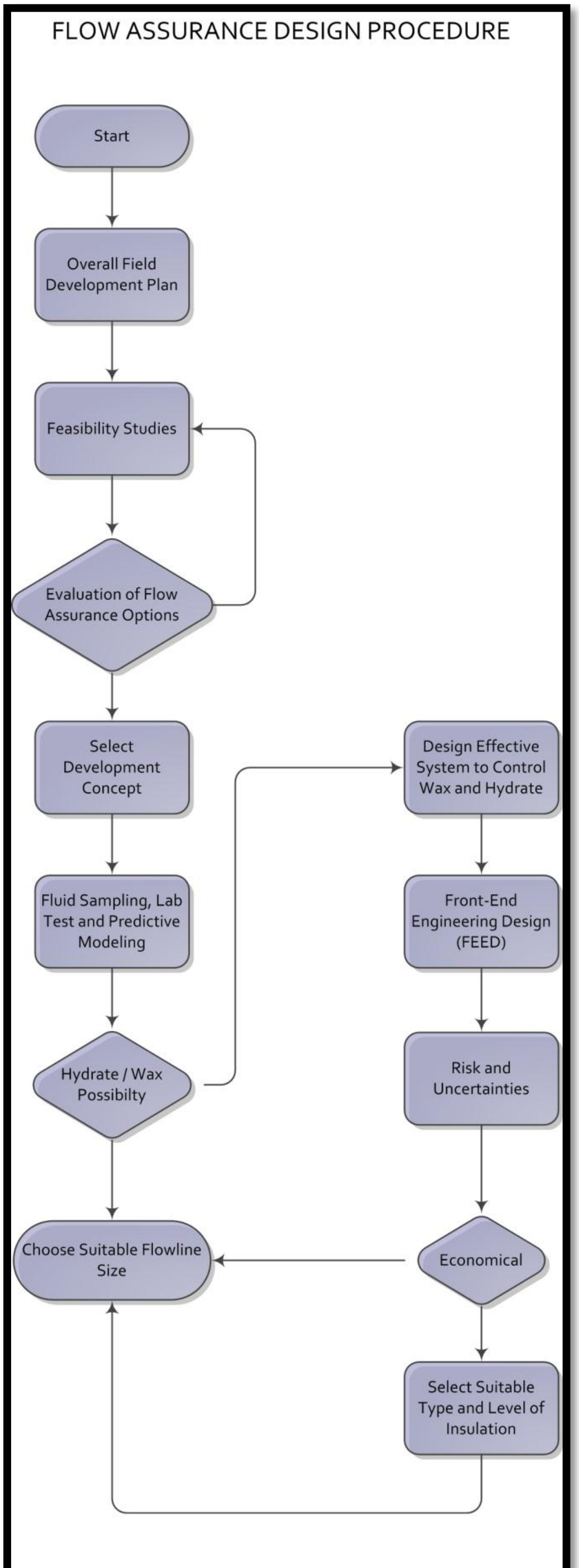


Figure 4.12: Flow Assurance Design Procedure

Figure 4.12 shows the overall flow assurance design procedure. The procedure can be described as below:

I. Start the flow assurance design with an overall Field Development Plan overview to determine the feasibility of the project.
II. After determining the feasibility of the project, the technical team requires to select the development concept which requires evaluation of the flow assurance options based on cost and risk aspect.
III. By finalizing the development concept, proceed with proposing suitable flowline or tubing size via going through with system selection analysis. Fluid sampling, lab test and predictive modeling will be considered for this stage.
IV. If there existence of hydrate or wax further investigation is necessary for consideration of prevention techniques.
V. For choosing effective system, the process wills undergoes trough Front-End Engineering Design (FEED) which is deeper analysis for the potential problem; includes thermal insulation.
VI. Consideration on risk and uncertainties is required for economical studies which define the suitable type and level of insulation for the whole system.
VII. Choosing the suitable flowline or tubing size will be the last step before it comes to project management to make the decision.

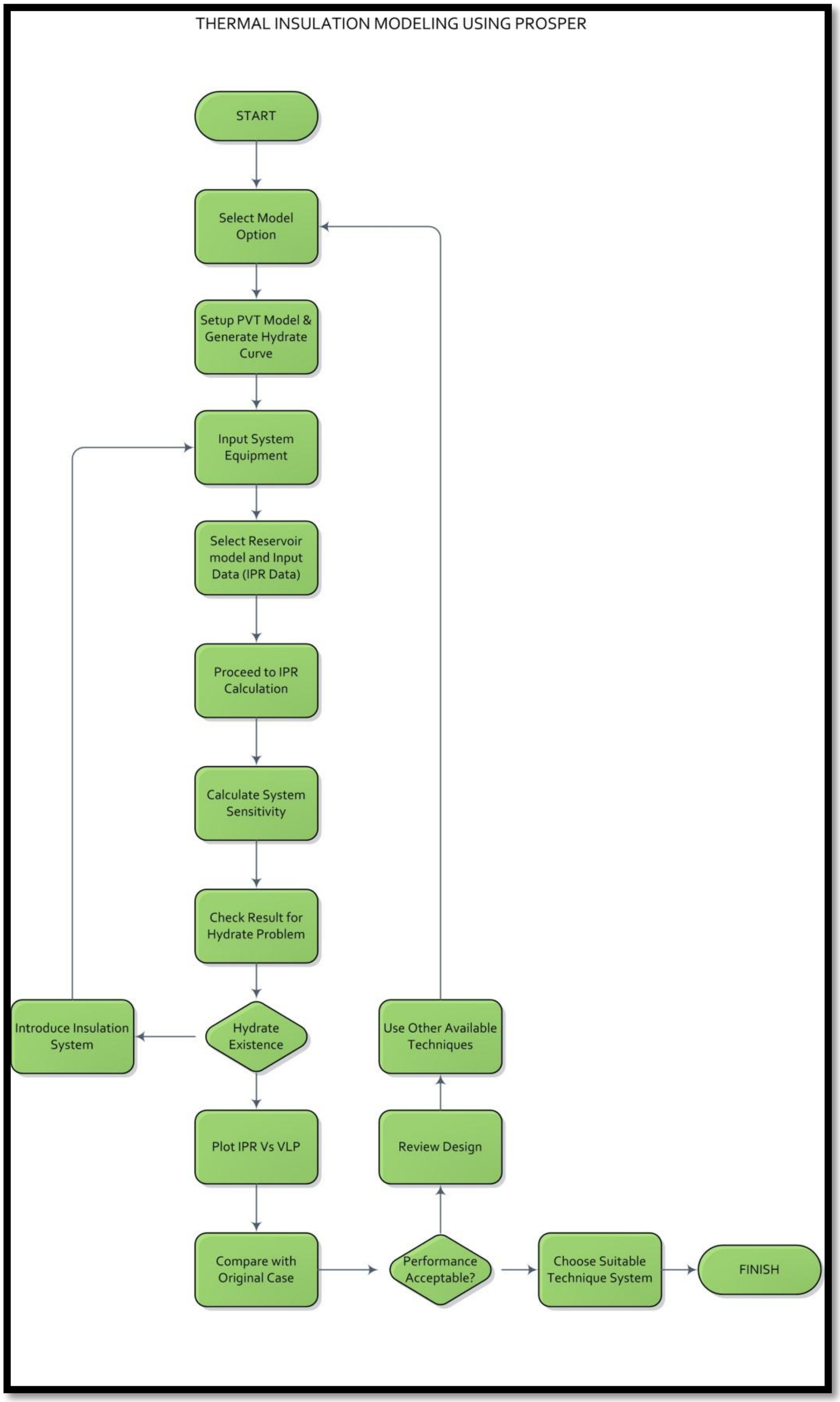


Figure 4.13: Thermal Insulation Modeling Using PROSPER

All the analysis is done using PROSPER production optimization software. *Figure 4.13* shows the procedure of PROSPER Modeling for thermal insulation for flow assurance study. There modeling sequences can be described as below:

a) Start with selecting model option based on the field data using equation of state model.
b) Setup PVT model and generate hydrate curve based on the composition of the field.
c) Input the system equipment data.
d) Select reservoir model and input data base on available data.
e) Proceed to Inflow Performance Relationship (IPR) calculation.
f) Run sensitivity analysis to check for possible hydrate and wax formation.
g) Plot IPR versus Vertical Lift Performance (VLP).
h) Set the based case if there is hydrate or wax problem and proceed to new case by input insulation type and thickness.
i) Repeat step until IPR versus VLP to see the hydrate or wax problem and compare with the base case.
j) If the performance can be accept, then proceed with the suitable insulation system to be use at the well.
k) If the performance is not suitable for thermal insulation, review the design of the well for other possible and available techniques and repeat the modeling.

CHAPTER 5

CONCLUSION

5.0 CONCLUSION

Based on researches, a conclusion can be made that recent advances in non-chemical flow assurance solutions and technologies can be practical to develop thermal management for the mitigation of hydrate and wax problems for deepwater field developments. Mark Chapman (2012) mentioned that, PIP insulation combined with electrical heating can help prevent and remediate these solid depositions and minimize capex/opex by avoiding the use of chemical inhibitors, minimizing pigging frequency, and avoiding dual pipelines.

He suggest that it is because of operational flexibility and high efficiency, thermal mechanisms can effectively manage hydrate and wax formations in deepwater oil and gas field development throughout the production operations of field life. Faluomi and Arcipreti (2007) had using the Steady state heat transfer package and the pipeline cool-down package to study about the different insulation system which to analyses the passive system; wet insulation and pipe in pipe and time need to enter in the hydrate zone formation respectively.

For insulation material selection, the main criterion is to identify the risk region appropriately if the material is to be chosen. The type of insulation could be varies depends on the simulation result. Even economics plays important roles to determine the suitable insulation for the specific well based on budget constraint. Owodunni and Ajienka (2007) suggest also about controlling flowrate to prevent deposit risks if the poor insulation characteristic involved.

They also recommend that the completion design can give impact on flow assurance, thus must consider for good insulation properties at the annulus. However, for this project; shutdown condition can't be studied because lack of material. Longer cool down time is good for preventing hydrate and wax formation during well shut in period. Further investigation on the thermal insulation could be the best way on proving the effectiveness and its reliability towards developing the best *non-Chemical Flow Assurance Strategies for Petroleum Production Systems.*

CHAPTER 6

RECOMMENDATION

6.0 RECOMMENDATION

Modeling thermal insulation system using PROSPER require deep knowledge of flow assurance on the behavior of hydrate and wax formation. This project only focuses on the passive insulation system because of the limitation of time and resources. For better results for continuation of the project, it is recommended to have comparison between the active and passive system of thermal insulation. Certain field doesn’t fit to have the passive system that may need combination with the active system. Of this project able to continues, there will be good to have combination of passive and active modeling. From here, the results would be promising in the same time would balance capex and opex for the whole system configuration based on the proposed techniques.

Besides, for the future planning for this project the best way to further the understanding of hydrate and wax behavior is to study about the shut-in condition. The effect of insulation during shut-in condition which is before the wax and hydrate formation as known as cool down time for insulated well. However all the modeling results should be integrated with other modeling software’s results to compare the reliability and effectiveness of the technique proposed because we can’t depending 100% only on a modeling result.

CHAPTER 7

REFERENCES

7.0 REFERENCES

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CHAPTER 8

APPENDICES

8.0 APPENDICES

APPENDIX 1: Gantt Chart for FYP 2

Timelines for FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■	Mid-Semester Break								
2	Submission of Progress Report							●									
3	Project Work Continues									■	■	■	■	■			
4	Pre-SEDEX											●					
5	Submission of Draft Report												●				
6	Submission of Dissertation (soft bound)													●			
7	Submission of Technical Paper													●			
8	Oral Presentation														●		
9	Submission of Project Dissertation (Hard Bound)																●

● Suggested milestone

■ Process

APPENDIX 2: PVT DATA

Composition Data

PVT Data

Reservoir Temperature (deg F)	255
Water Salinity (ppm)	100000

Name	Mole Percent %	Critical Temp (Deg F)	Critical Pressure (psig)	Critical Volume (ft3/lb.mole)	Acentric Factor	Molecular Weight	Specific Gravity (Sp. Gravity)	Boiling Point (deg F)	Volume Shift	Omega A	Omega B	Parachor	Costald Volume (ft3/lb.mole)	Costald AF
N2	0.31	-233.104	477.326	1.43842	0.039	28.01	1.026	-320.35	-0.154	0.45724	0.0778	60.4	0	0.039
CO2	2.33	87.692	1058.26	1.50409	0.239	44.01	1.101	-109.21	-0.1002	0.45724	0.0778	78	0	0.239
C1	68.73	-116.518	658.381	1.58899	0.011	16.04	0.415	-258.79	-0.16717	0.45724	0.0778	70	0	0.011
C2	12.37	89.798	693.651	2.37547	0.099	30.1	0.546	-127.39	0.069273	0.45724	0.0778	115	0	0.099
C3	5.01	206.006	602.683	3.25166	0.153	44.1	0.585	-43.69	-0.13183	0.45724	0.0778	155	0	0.153
IC4	1.3	274.694	514.36	4.21274	0.183	58.1	0.6	10.85	-0.71272	0.45724	0.0778	181.5	0	0.183
NC4	1.41	305.294	535.963	4.08459	0.199	58.1	0.6	31.19	-0.57098	0.45724	0.0778	200	0	0.199
IC5	0.6	369.806	468.362	4.90151	0.227	72.2	0.621	82.13	-0.69747	0.45724	0.0778	225	0	0.227
NC5	0.8	385.592	474.828	4.86948	0.251	72.2	0.63	96.89	-0.48056	0.45724	0.0778	245	0	0.251
C6	0.96	454.1	425.008	5.92667	0.299	86.2	0.664	155.75	-0.23354	0.45724	0.0778	282.5	0	0.299
C7::C9	1.03276	583.705	360.772	7.79944	0.30732	118.205	0.79052	261.852	-0.18516	0.45724	0.0778	360.825	0	0.30732
C10::C11	1.44995	594.655	353.664	9.26127	0.36964	142.317	0.81684	337.995	-0.080134	0.45724	0.0778	421.4	0	0.36964
C12::C13	1.20879	604.783	349.971	10.8801	0.43639	168.371	0.84145	415.245	-0.029496	0.45724	0.0778	481.994	0	0.43639
C14::C14	0.64947	783.408	346.37	12.163	0.48768	191.102	0.85684	470.658	0.00021805	0.45724	0.0778	531.406	0	0.48768
C15::C16	0.94422	899.659	334.034	13.5405	0.54138	214.677	0.87044	525.45	0.030246	0.45724	0.0778	579.908	0	0.54138
C17::C20	0.89482	977.545	300.577	15.6463	0.6221	255.817	0.88834	603.266	0.050498	0.45724	0.0778	659.778	0	0.6221

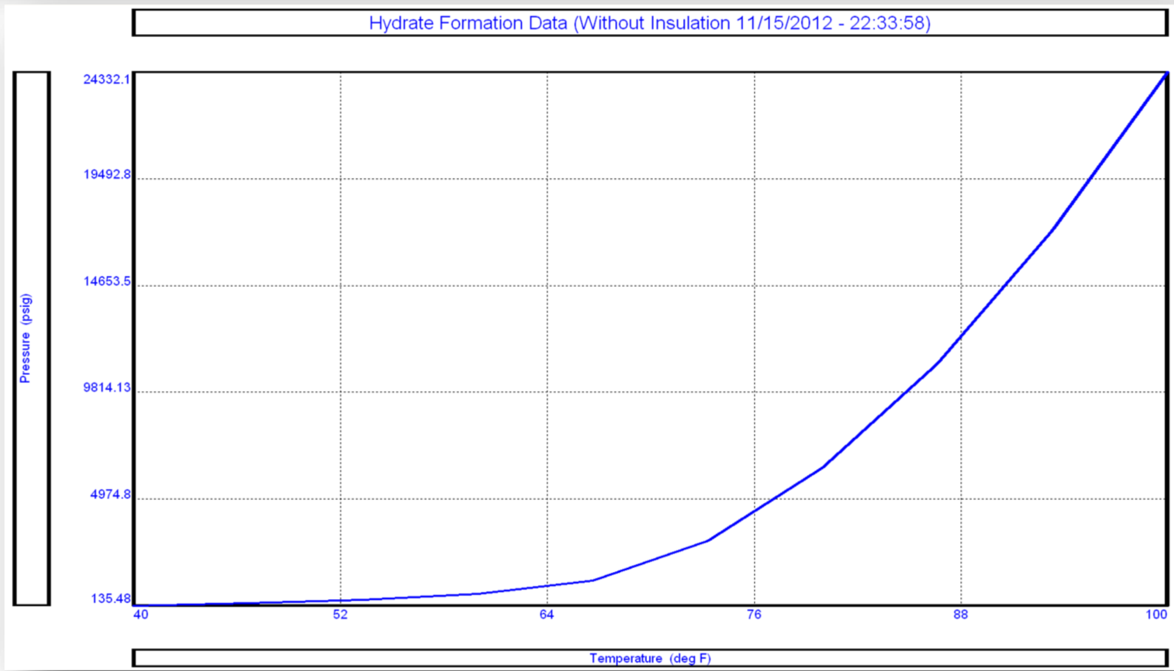
EOS Model	Peng-Robinson
Volume Shift	Use Volume Shift
Calculation Type	Calculated From EOS Model
Optimisation Mode	Medium

Separator Info

	Sepatator 1	Separator 2
Pressure (psig)	200	0
Temperature (deg F)	80	60

Hydrate Formation Data (Generated)

Pressure (psig)	Temperature (deg F)
135.48	40
227.42	46.6667
380.594	53.3333
656.418	60
1245.06	66.6667
3052.24	73.3333
6379.66	80
11097.5	86.6667
17156.2	93.3333
24332.1	100

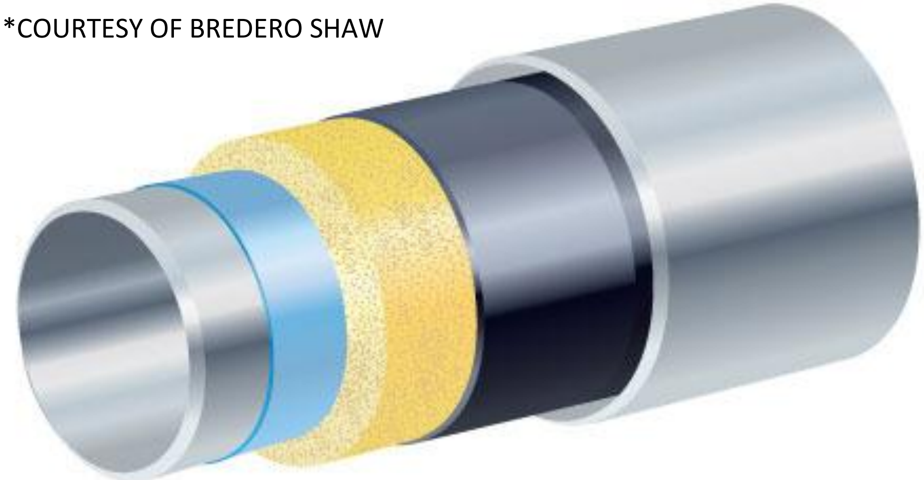


Pipe-In-Pipe

PU Foam Insulated Pipe-In-Pipe

Pipe-in-Pipe is a low density polyurethane foam product applied by either injection moulding or spray application for use in pipe-in-pipe systems providing highly efficient insulation performance in both shallow and deepwater applications.

*COURTESY OF BREDERO SHAW



Features & Benefits

- Low K-value
- Wide U-value performance
- Temperature range performance
- High manufacturing throughputs
- Consistent properties

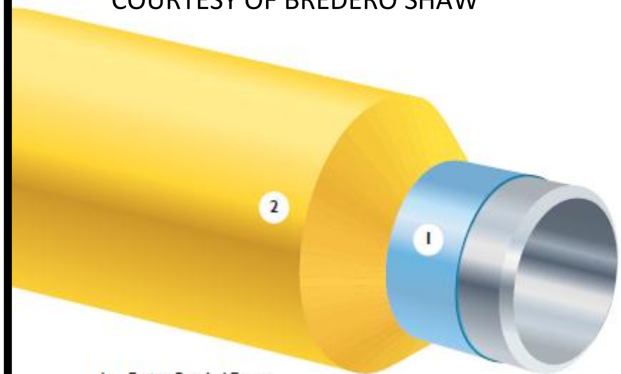
Typical Plant Capabilities and Product Properties

CAPABILITY/PROPERTY	Shallow Water Pipe-In-Pipe (S)	Deep Water Pipe-In-Pipe (D)
Minimum Pipe Diameter	150 mm (6")	150 mm (6")
Maximum Pipe Diameter	406.4 mm (16")	406.4 mm (16")
Minimum Operating Temperature	-35°C (-30°F)	-35°C (-30°F)
Maximum Operating Temperature	150°C (302°F)	130°C (266°F)
Minimum Pipe Length	9 m (30')	9 m (30')
Maximum Pipe Length	13 m (43')	13 m (43')
OHTC ("U" Value)	< 1.0 W/m².K (0.58 BTU/ft².hr.F)	< 1.0 W/m².K (0.58 BTU/ft².hr.F)
Maximum Water Depth	Design Department	Design Department
K-Value	0.021 W/m.K (0.0121 BTU/ft.hr.F)	0.021 W/m.K (0.0121 BTU/ft.hr.F)

ThermoFlo®

Polyurethane Insulation Systems

*COURTESY OF BREDERO SHAW



1. Fusion Bonded Epoxy
2. Syntactic Polyurethane

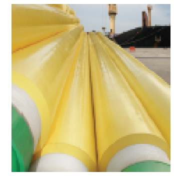
Product Description

ThermoFlo® is a polyurethane-based insulation coating designed for offshore flow assurance. The product can be customized to meet stringent specifications for both shallow and deep water and can be installed using all subsea pipe-lay methods including reeling, J-lay and S-lay.

Applications

Subsea Pipelines

Small Diameter Pipelines



Superior Insulation Properties

- Provides superior insulation properties in subsea pipelines for flow assurance applications.
- Achieved through a combination of material formulation and processing technology designed to meet strict thermophysical performance tolerances.

Flexible Installation

- Can be installed using all subsea laying methods including reeling, S-lay and J-lay.
- High degree of flexibility and has been successfully reeled at thicknesses up to 106 mm (4.2").
- The elastomeric nature of the material provides excellent impact resistance and fatigue life.

Engineered Solutions

- Engineered to meet a specific project requirement by varying thickness and material formulation for both shallow water and deep water applications.
- The compressive and creep response of ThermoFlo® materials have been subjected to extensive external and internal testing and modelling, resulting in a product line where the dimensional changes and thermophysical properties are predictable over time.

Used for Pipelines and Complex Structures

- In addition to pipeline insulation, ThermoFlo® products are extremely versatile allowing for applications on complex structures. Examples of these are trees, jumpers and manifolds where thicknesses up to 150 mm (6") have been applied.

Typical Plant Capabilities and Product Properties

Capability/Property	Shallow Water ThermoFlo® (S)	Deep Water ThermoFlo® (D)
Minimum Pipe Diameter	100 mm (4")	100 mm (4")
Maximum Pipe Diameter	600 mm (24")	600 mm (24")
Minimum Operating Temperature	-55°C (-67°F)	-55°C (-67°F)
Maximum Operating Temperature	90°C (194°F) Wet 115°C (240°F) Dry	90°C (194°F) Wet 115°C (240°F) Dry
Minimum Pipe Length	1 m (3')	1 m (3')
Maximum Pipe Length	13 m (43')	13 m (43')
OHTC ("U" Value)	> 1.8 W/m².K (0.317 BTU/hr.ft².F)	> 2.0 W/m².K (0.352 BTU/hr.ft².F)
Maximum Water Depth	300 m (1000')	2800 m (9200')
K-Value	0.13 W/m.K (0.058 BTU/ft.hr.F)	0.155 - 0.17 W/m.K (0.087 - 0.099 BTU/hr.ft.F)

Values shown are typical and may vary from plant to plant. Consult Bredero Shaw for special requirements.

ThermoFlo®_rev012