# Development of Decision Support System for Corrosion under Insulation (CUI) for Austenitic Stainless Steels and Carbon Steels

By

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6393

Dissertation submitted
In partial fulfilment of the requirement for the
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(MECHANICAL ENGINEERING)

JULY 2008

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CERTIFICATION OF APPROVAL

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Approved by,

_______________________
(Ir. Dr. Mokhtar Bin Che Ismail)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JULY 2008

# 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.

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MOHD KAMAL AIZAT BIN AHMAD

# ABSTRACT

CUI is hazardous because insulation can become wet or contaminated, accelerating corrosion process. Moreover, CUI is particularly serious because it is difficult to predict and to detect. This report is basically brief about the research done and fundamental concepts of the chosen topic, which is; Development of decision-support system for Corrosion under Insulation (CUI) for austenitic stainless steels and carbon steels. The aim of the research project is to develop a decision support system (DSS) to determine the probability of equipment failure due to CUI. The research study consists of two phase, first phase is developing decision support system (DSS) using Microsoft Visual Basic 6.0. Second phase is develop knowledge base database for Corrosion under Insulation (CUI) and combining it into the decision support system (DSS) to create a stand-alone software that can determine the probability of equipment failure due to CUI. The objectives of the stand-alone software are to help and assist people to make decision more precise and accurate.
The development of the Decision Support for Corrosion under Insulation (CUI) susceptibility is completed as scheduled.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Corrosion under insulation (CUI) refers to the external corrosion of piping and vessels that occurs underneath externally clad/jacketed insulation as a result of the penetration of water. By its very nature CUI tends to remain undetected until the insulation and cladding/jacketing is removed to allow inspection or when leaks occur. CUI is a common problem shared by the refining, petrochemical, power, industrial, onshore and offshore industries. [1] A study done by Exxon Mobil Chemical that was presented to the European Federation of corrosion in September 2003 indicated that:

- The highest incidence of leaks in the refining and chemical industries is due to CUI and not to process corrosion.
- Between 40% - 60% of piping maintenance costs are related to CUI.

Inspection of insulated piping, vessels, and other components is a major challenge and can be both costly and time-consuming. The American Petroleum Institute code, API 581 identifies corrosion under insulation as a special concern and requires that an appropriate amount of external visual inspection be conducted on piping systems within susceptible temperature ranges. The use of risk based inspection (RBI) assessment conducted in accordance with API RP 581 provides a methodology for prioritizing CUI-related maintenance and inspection activities.

Risk Based Inspection (RBI) is a systematic process for factoring risk into decisions concerning how, where and when to inspect a process plant. The intent of RBI is to focus inspection resources on critical equipment in ways which will prevent failures, particularly catastrophic ones. It is a tool that can help make process plants safer and more reliable in a cost effective way.

## 1.2 Problem Statement

Corrosion under Insulation is a multi-billion dollar problem that destroys expensive industrial infrastructure. In order to predict the probability of equipment failure subject to CUI, the guidelines in API 581 have been followed so far. CUI depends on several factors such as operating temperature, atmospheric conditions, coating quality, type of materials etc. The decision making process to asses the probability of failure is quite tedious if it is done manually. A decision support system (DSS) can help to expedite such decision making process.

The intent of using RBI is to manage the probability of failure in piping and vessels while establishing an optimum inspection program. At the same time, a significant portion of the risk in the plant can be addressed by focusing on a relatively few items in the unit. The factors that are usually considered in a RBI analysis include:

- Location of equipment,
- Temperature, materials of construction,
- Age of the equipment,
- The type and condition of the coating system,
- Insulation type and risk potential in terms of process,
- Environment and safety.

## 1.3 Significance of Study

Decision Support System (DSS) is very important in predicting probability of equipment failure subjected to CUI because it assist inspection personnel in the decision making process. Using Decision Support System (DSS) for CUI, the assessment of probability of failure is more accurate, consistent and reliable. Decision making process to assess probability of failure is very tedious and required vast experience to examine it. New inspection personnel probably cannot get the same result as experience inspection personnel. With the help of Decision Support System (DSS), the Decision making process will be much easier and more reliable.

## 1.4 OBJECTIVE & SCOPE OF STUDY

The objectives to be achieved by the end of this project are:

- To develop a user interface for CUI prediction using Microsoft Visual Basic 6.0.
- To develop a database for CUI prediction using Microsoft Visual Basic 6.0 programming.

The scope of works should consider a detail of developing decision support system (DSS) and designing database for Corrosion under Insulation (CUI). The decision support system (DSS) is developed using Microsoft Visual Basic 6.0.

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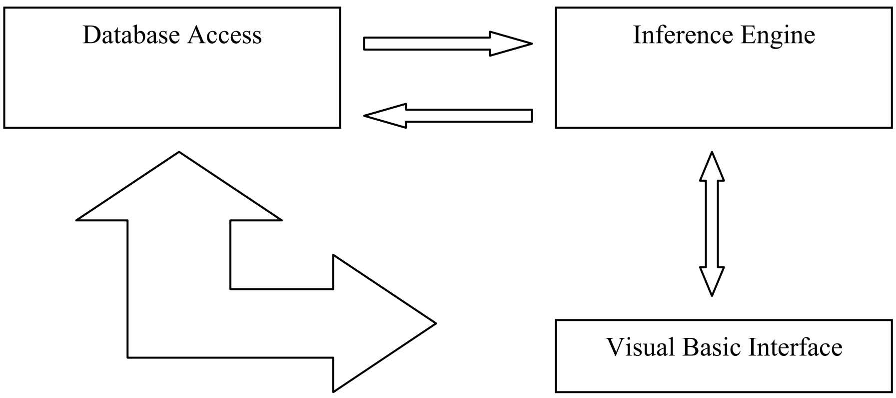



Figure 1.1: Basic Flow of the Decision Support System (DSS)

# CHAPTER 2

# LITERATURE REVIEW AND THEORY

## 2.1 Introduction

External damage can occur on most process plant equipment. The result is a gradual thinning of some materials or may result in stress corrosion cracking of other materials. Perhaps the most serious cases of external damage involve corrosion under insulation (CUI). This form is especially hazardous because insulation can become wet or contaminated, accelerating the corrosion. Another reason that CUI is particularly serious is that it is very difficult to detect. [1]

Corrosion under Insulation is a multi-billion dollar problem that destroys expensive industrial infrastructure and causes continuous scheduled manufacturing plant and facility downtime to conduct inspections for failure and unexpected downtime when equipment failure occurs. Corrosion under Insulation CUI are industry headaches, even after many decades these are issues that are unable to be addressed with any real sense of confidence or solutions.

Pipes Under insulation corrodes both externally and internally. In either scenario these forms of corrosion lead to "Product" or Hydrocarbon leakages. These pipes are always shielded from the naked eye and so often go unnoticed. The implication of corrosion on these critical pipes is insurmountable. These leakages often cause fires, explosions and even fatalities. In any case, the problem can be reduced or eliminated by proper inspection for corrosion, proper installation and maintenance of insulation, or by proper selection, application, and maintenance of protective coatings.[1]

## 2.2 Fundamental Concept

Intruding water is the key problem in CUI. Water can enter a system either directly or indirectly by capillary action. Moisture may be external or may be present in the insulation material itself. Corrosion may attack the jacketing, the insulation hardware, or the underlying equipment. Corrosion under insulation (CUI) resulted from the collection of water in the vapor space (or annulus space) between the insulation and the metal surface. [2]

Sources of water may include rain, water leaks, condensation, cooling water tower drift, deluge systems, and steam tracing leaks. CUI causes wall loss in the form of localized corrosion. CUI generally occurs in the temperature range between -12°C and 121˚C, with temperature range of 49˚C to 93°C being the most severe environment. [2]

For high temperature equipment, water entering an insulation material and diffusing inward will eventually reach a region of dryout at the hot pipe or equipment wall. Next to this dryout region is a zone in which the pores of the insulation are filled with a saturated salt solution. When a shutdown or process change occurs and the metal-wall temperature falls, the zone of saturated salt solution moves into the metal wall.

Upon reheating, the wall will temporarily be in contact with the saturated solution, and stress-corrosion cracking may begin. The drying/wetting cycles in CUI associated problems are a strong accelerator of corrosion damage since they provoke the formation of an increasingly aggressive chemistry that can lead to the worst corrosion problems possible, e.g. stress corrosion cracking, and premature catastrophic equipment failures.

## 2.3 Mechanism of Corrosion under Insulation

The mechanism of corrosion under insulation involves three requirements:

- Availability of oxygen.
- High temperature.
- Concentration of dissolved species.

Normally, as the temperature increases, the amount of oxygen dissolved in solution decreases as the boiling point is reached resulting in reduced corrosion rates. However, on the surface covered by insulation, a poultice effect is created which holds in the moisture which essentially makes it a closed system. In fact the measured corrosion rates associated with corrosion under insulation follow trends to higher corrosion rates commonly associated with only pressurized systems. [3]

As a general rule, plants located in areas with high annual rainfalls or warmer, marine locations are more prone to external corrosion than plants located in cooler, drier, mid-continent locations. Regardless of the climate, units located near cooling towers and steam vents are highly susceptible to external corrosion, as are units whose operating temperatures cycle through the dew point on regular basis. Certain areas and systems are more susceptible to external corrosion than others. Examples of highly suspect areas include:

a. Areas exposed to mist overspray from cooling towers,
b. Areas exposed to steam vents,
c. Areas exposed to deluge systems,
d. Areas subject to process spills, ingress of moisture, or acid vapors,
e. Carbon steel systems, operating between -12°C and 121°C. External corrosion is particularly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture,
f. Carbon steel systems that normally operate in-service above -4°C but are in intermittent service or are subjected to frequent outage. [4]

## 2.4 Decision Support System (DSS)

Decision support system is a class of computer-based information systems including knowledge based systems that support decision making activities. It is a system that can help and assist people to make decision more precise, accurate and also enables easy access to relevant information. For this project, the Decision-support system is to assist determining probability of equipment failure due to Corrosion under Corrosion (CUI).

A decision is a choice between alternatives based on estimates of the values of those alternatives. Supporting a decision means helping people working alone or in a group gathers intelligence, generate alternatives and make choices. Supporting the choice making process involves supporting the estimation, the evaluation and/or the comparison of alternatives. In practice, references to DSS are usually references to computer applications that perform such a supporting role.

DSS consist of:

*The Database*
The database contains information about internal data and external data that will contribute to the decision making process. This data is in most cases more extensive than traditional relational models. The database must consider the input data to the system and the outputs to the user.

*The Model Base*
This module contains a set of algorithms that makes decisions based on the information in the database. This information is then summarized and displayed as tables or graphs.

*The Interface*
This is what the user will use to interface with the system. This is complimented with an interactive help and navigation screen. [6]

# CHAPTER 3

# METHODOLOGY

There are two steps to be conducted throughout the project which are:

- Decision support system (DSS) development for CUI prediction
- Development of a database for CUI prediction.

## 3.1 Decision Support System (DSS) Development for CUI Prediction

For the beginning, the research project will be focusing on development of Decision Support System (DSS) for CUI prediction. The DSS will be developed using Microsoft Visual Basic 6.0. It is an extremely powerful programming language that can be use to design applications, designed to make user-friendly programs easy to develop. Visual basic is used by millions of software developers.

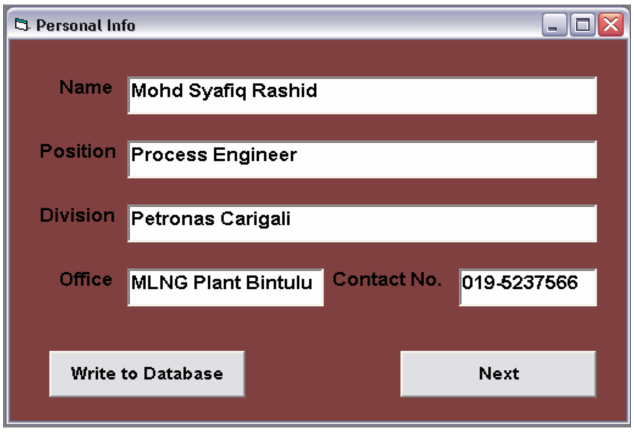



Figure 3.1: Example of Input screen of Visual Basic Program

Microsoft Visual Basic 6.0 allows development of more structured and object-oriented interfaces that can interact with users which is called Graphical User Interfaces (GUI). The DSS development using Microsoft Visual Basic 6.0 will be discussed further in the section below in the third consideration, develops the DSS.

There are several things that need to be considered before the development of DSS:

- Data management / data collection
- Decision making process / Decision trees
- Develops the DSS

*3.1.1 Data management / data collection*

Generally, this stage involve preliminary works for the project such as searching for materials, sources and references for developing the DSS. The materials and sources are collected mainly from books in Information Resource Centre, thesis, journals and online resources from internet. This stage is very important in order to get clear view and picture on what is CUI all about and how to develop the DSS.

To develop the CUI susceptibility software, guidelines and standards from API 581 is followed closely in because API 581 is worldwide standards that is widely used in Oil and Gas Industry. Corrosion under Insulation susceptibility is evaluated using likelihood analysis. Likelihood analysis begins with a database of generic failure frequencies for refining and process equipment. These generic frequencies are then modified by two terms, the equipment modification factor (FE) and the management systems modification factor (FM) to yield an adjusted failure frequencies.

Equipment Modification Factor (FE) examines detail specific to each equipment item and to the environment in which the item operates, in order to develop a modification factor unique to that piece of equipment. The management System Evaluation Factor (FM) adjust for the influence of the facilities management system on the mechanical integrity of the plant. This adjustment is applied equally to all equipment items.

Modification factors with a value greater than 1 will increase the adjusted failure frequency, and those with a value less than 1.0 will decrease it. Both modification factors are always positive numbers. The Generic Failure Frequency and management Systems Evaluation Factor are given and fixed in the API 581. In order to calculate the likelihood analysis, the Equipment Modification Factor (FE) must be determined first.

*3.1.2 Decision making process / decision tress*

The DSS is developed according to the flow chart list out in the API 581 Risk-Based Inspection Base Resource Document. Below is the flow chart for external damage screening and the prediction of CUI for Carbon Steels and Stainless steels.

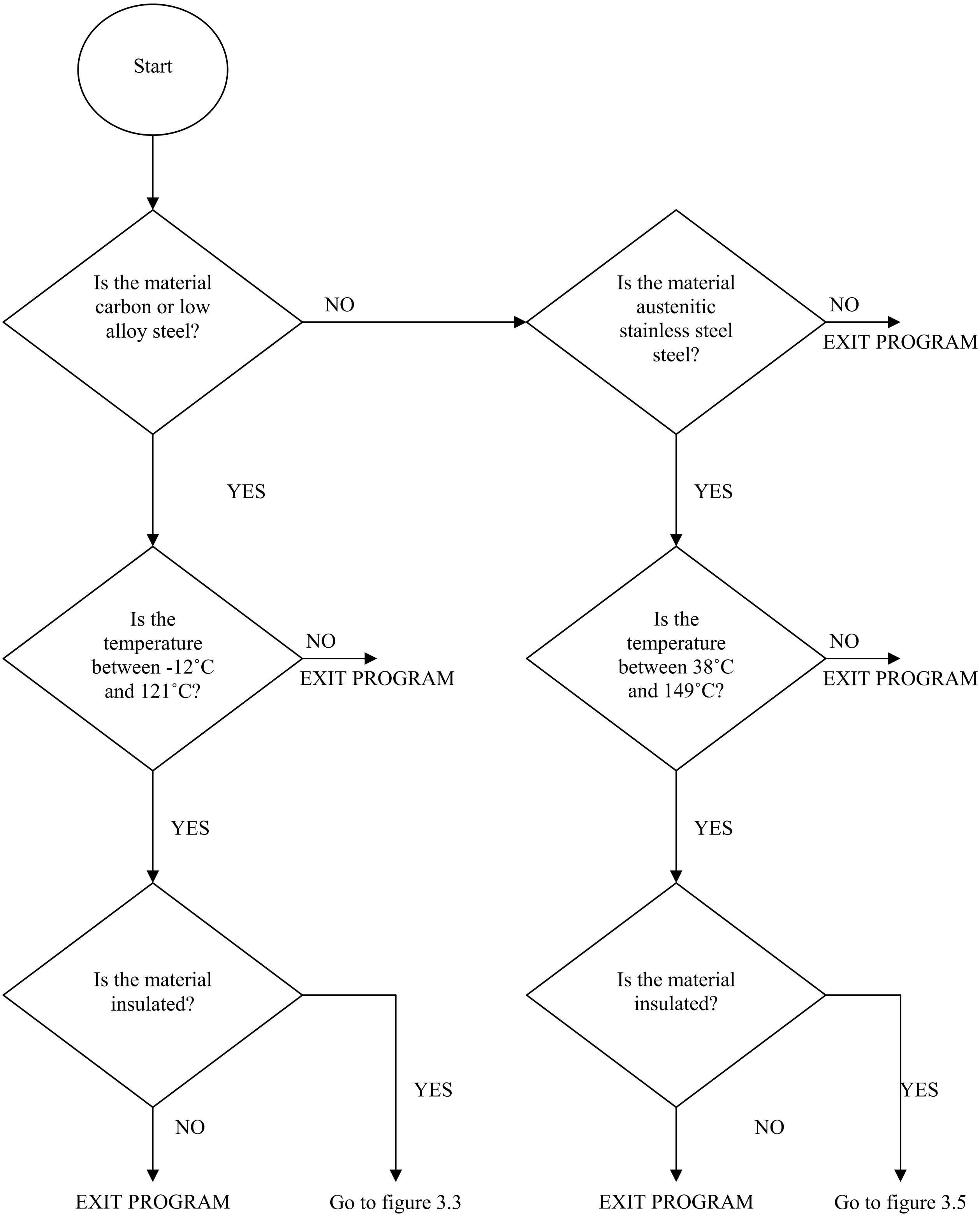



Figure 3.2: Flowchart for External Damage [9]

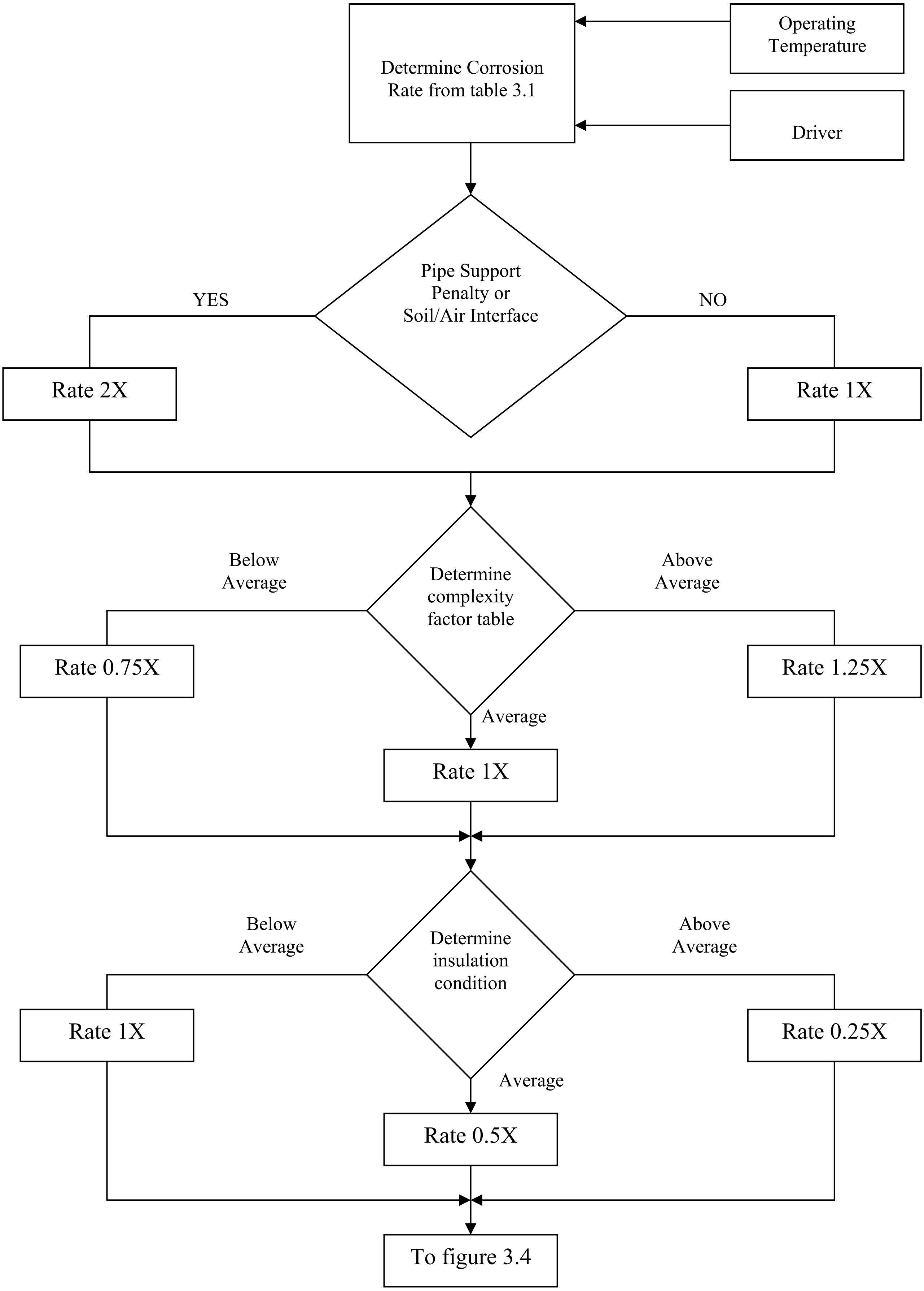



Figure 3.3: Flowchart of CUI for Carbon Steel [9]

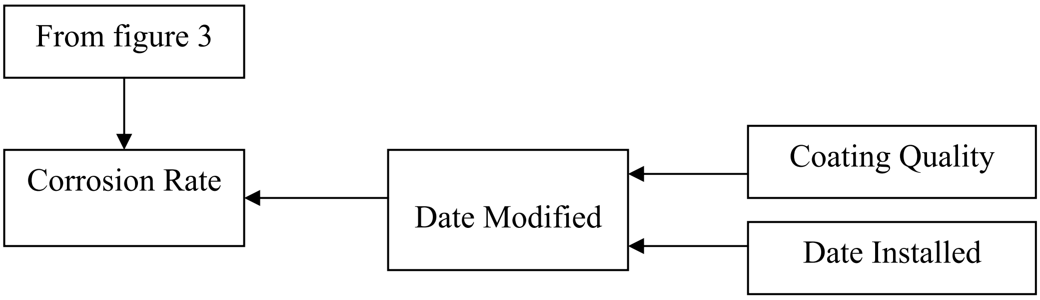
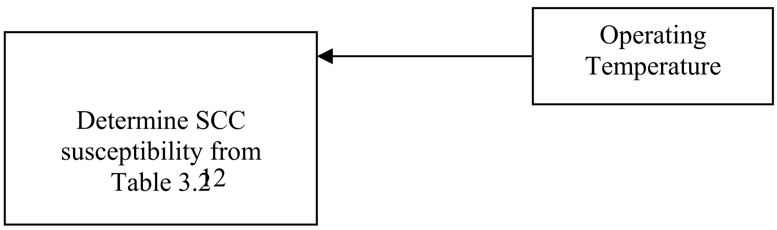



Figure 3.4: Flowchart of CUI for Carbon Steel (Cont) [9]

| | Driver | | |
|---|---|---|---|
| Operating temperature ˚C | Marine/Cooling tower drift area (mmpy) | Temperate (mmpy) | Arid/Dry (mmpy) |
| <-12 | 0 | 0 | 0 |
| -12 to 16 | 0.127 | 0.0762 | 0.0254 |
| 16 to 49 | 0.0508 | 0.0254 | 0 |
| 49 to 93 | 0.254 | 0.127 | 0.0508 |
| 93 to 121 | 0.0508 | 0.0254 | 0 |
| >121 | 0 | 0 | 0 |

Table 3.1: Basic assumptions and methods for CUI for Carbon Steels [9]



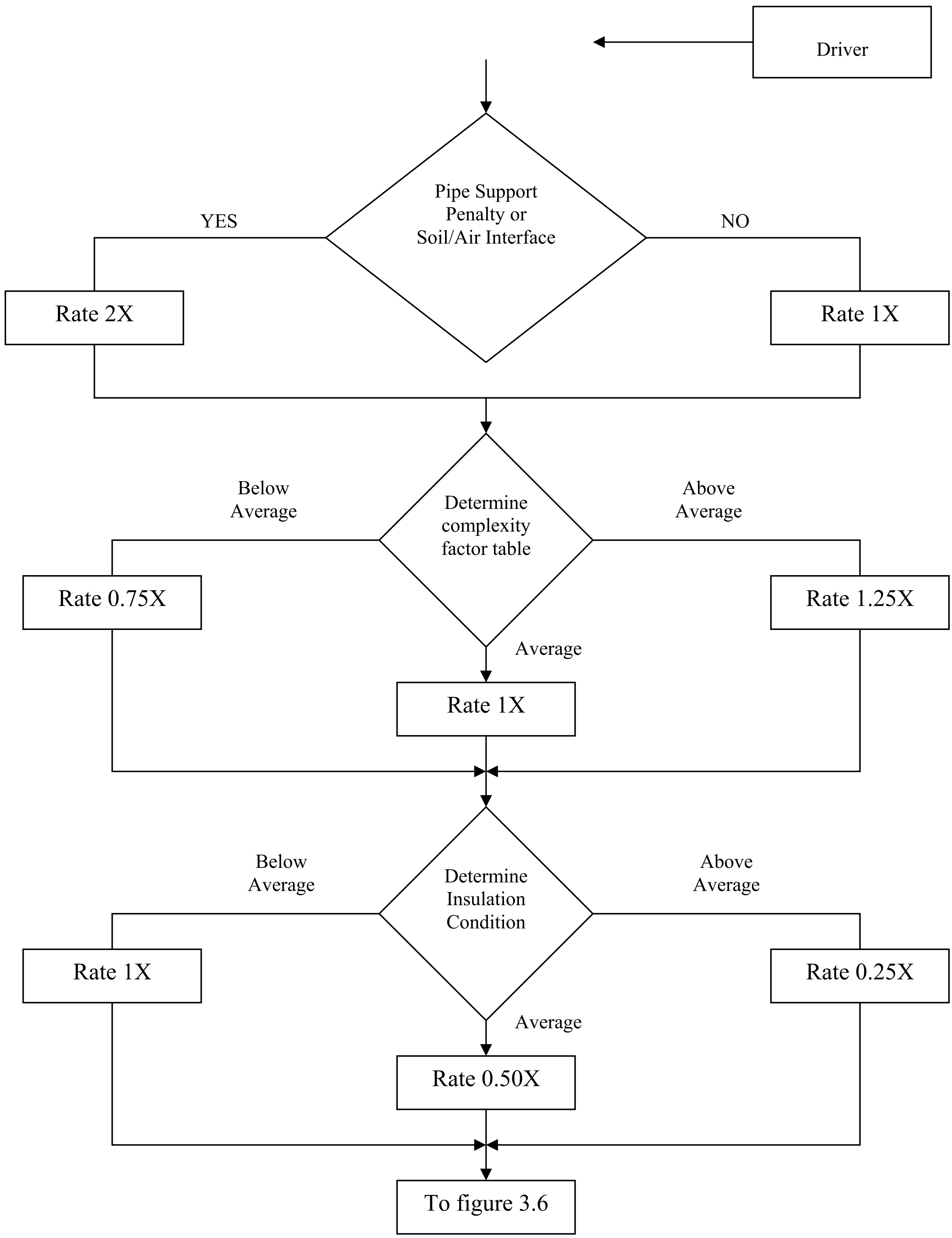



Figure 3.5: Flowchart of External CUI SCC for Austenitic Stainless Steels [9]

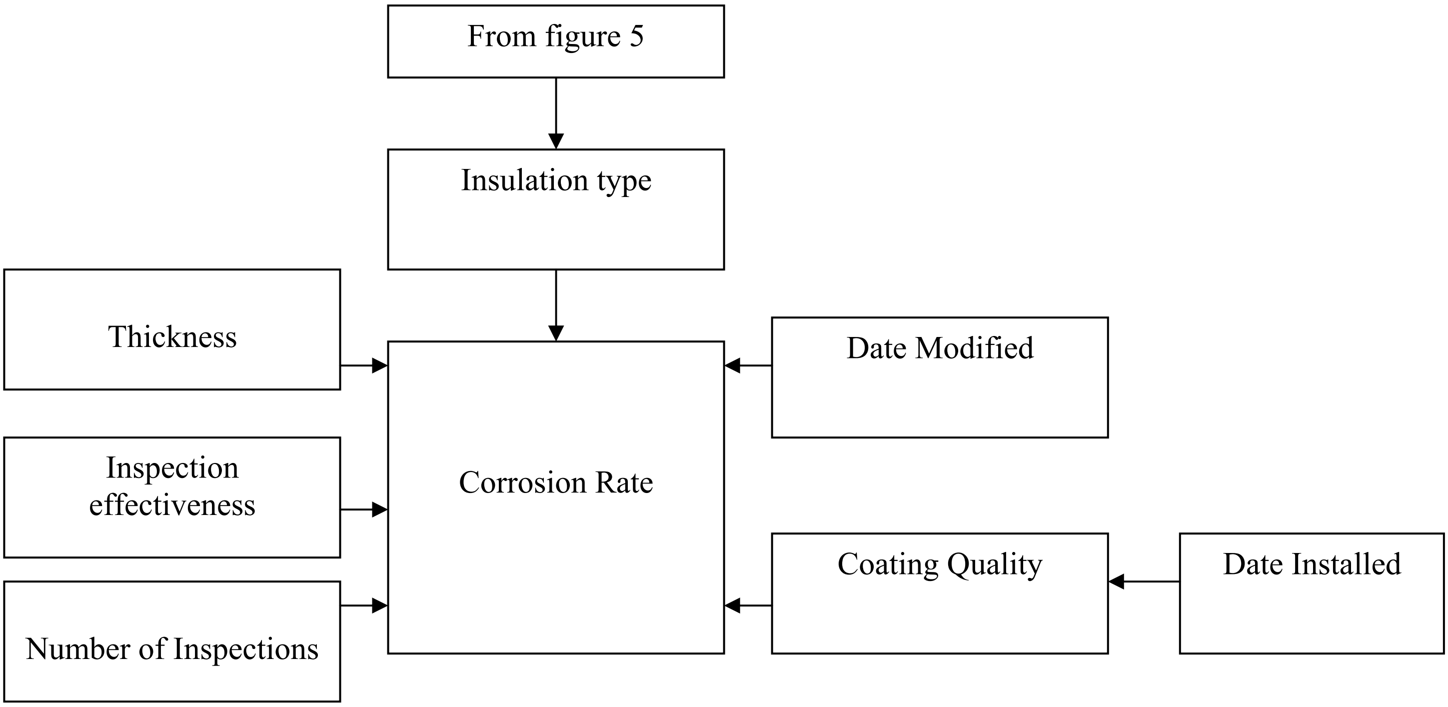



Figure 3.6: Flowchart of External CUI SCC for Austenitic Stainless Steels (cont) [9]

| | Driver | | |
|---|---|---|---|
| Operating temperature ˚C | Marine/Cooling tower drift area | Temperate | Arid/Dry |
| <204 | none | none | none |
| 60 to 93 | high | medium | low |
| 93 to 149 | medium | low | none |
| >149 | none | none | none |

Table 3.2: SCC Susceptibility of Austenitic Stainless Steels [9]

The Corrosion Rate for Corrosion under Insulation (CUI) susceptibility for both Carbon Steels and Stainless Steels is measured in mmPY unit which is millimetre Per Year of penetration.

### *3.1.3 Develop the DSS*

After Completing with the decision trees / flow chart, development of the DSS can be done using Microsoft Visual Basic 6.0. It is an extremely powerful programming language that can be use to design applications. Microsoft Visual Basic 6.0 allows development of more structured and object-oriented interfaces that can interact with users which is called Graphical User Interfaces (GUI). [1] Microsoft Visual Basic 6.0 is a full-object oriented language; all objects can have events, methods, and properties that can be manipulated to assist in programming.

### 3.2 Development of Database for CUI Prediction

After completed the interface development, the project will be about developing the database for corrosion under insulation (CUI) using Microsoft Visual Basic 6.0 and combining the GUI with the database created to calculate the Corrosion under Insulation (CUI) susceptibility.

In order to complete the task, comprehensive knowledge and deep understanding about Microsoft Visual Basic 6.0 is very important which is acquire from further reading of the books and materials related to it. It is also essential to consult lecturer from Information Technology Department (IT) if there is any problem or bug occur to the project. The results of the project are discussed further in the result and discussion section below.

## 3.3 Gantt - Chart

| No. | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Selection of Project Topic | | | | | | | | Mid-semester Break | | | | | | | |
| 2 | Preliminary Research Work on DSS and CUI | | | | | | | | | | | | | | | |
| 3 | Submission of Preliminary Report | | | | √ | | | | | | | | | | | |
| 4 | Literature Review | | | | | | | | | | | | | | | |
| 5 | Project work – development of DSS | | | | | | | | | | | | | | | |
| 6 | Submission of Progress Report | | | | | | | | | √ | | | | | | |
| 7 | Seminar | | | | | | | | | √ | | | | | | |
| 8 | Project work continues – development of DSS | | | | | | | | | | | | | | | |
| 9 | Submission of Interim Report | | | | | | | | | | | | | | | √ |
| 10 | Oral Presentation | | | | | | | | | | | | | | | √ |
| | | | | | | | | | | | | | | | | |

√ Suggested milestone

Process

Figure 3.7: Proposed Milestone for the First Semester of 2-Semester Final Year Project

| No. | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project work-Knowledge database development | | | | | | | | Mid-semester Break | | | | | | | |
| 2 | Submission of progress report I | | | | | | | | | | | | | | | |
| 3 | Project continue-Knowledge database development | | | | √ | | | | | | | | | | | |
| 4 | Submission of progress report II | | | | | | | | | | | | | | | |
| 5 | Seminar (Compulsory) | | | | | | | | | | | | | | | |
| 6 | Project Continue-Combine Database and DSS | | | | | | | | | √ | | | | | | |
| 7 | Poster Exhibition | | | | | | | | | √ | | | | | | |
| 8 | Submission of Dissertation | | | | | | | | | | | | | | | |
| 9 | Oral Presentation | | | | | | | | | | | | | | | √ |
| 10 | Submission of Project Dissertation | | | | | | | | | | | | | | | √ |

√ Suggested milestone

Process

Figure 3.8: Proposed Milestone for the 2nd Semester of 2-Semester Final Year Project

# CHAPTER 4

# RESULTS AND DISCUSSION

The development of the Decision Support for Corrosion under Insulation (CUI) susceptibility is completed as scheduled. Basic assumptions and methods used to design the DSS for CUI is attached in the **Appendix**. Below is the Graphical user Interfaces (GUI) flow designed for the Decision Support System (DSS) for Corrosion under Insulation (CUI) susceptibility.

## 4.1 Equipment and Material Selection

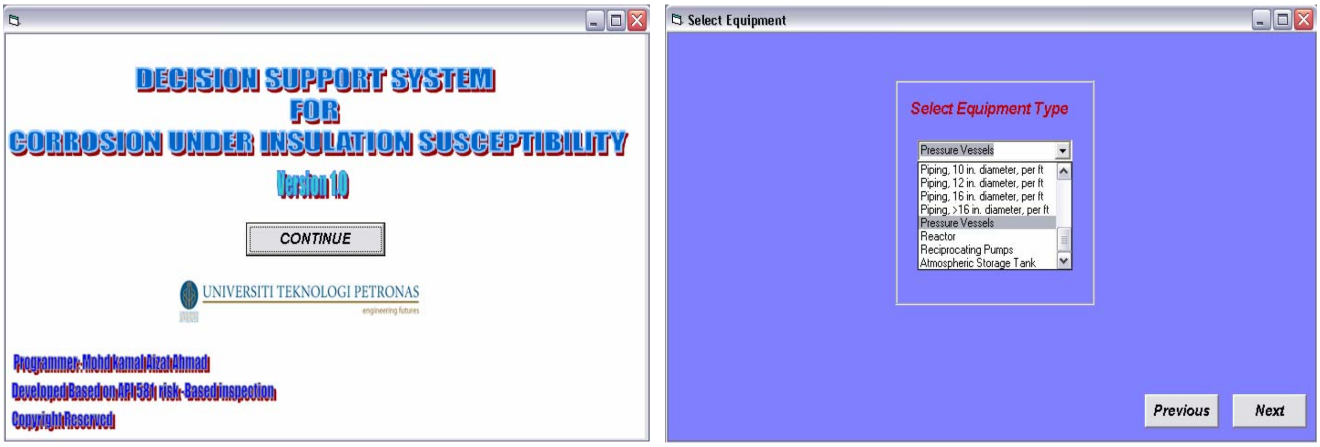



Figure 4.1: Interface Selecting Equipment Type

After clicking the Click to continue button at the first interface, the interface will prompt user to select the equipment type to be assessed. Next, the software will prompt user to select the material for the equipment. The software only evaluates Carbon Steels and Stainless Steels only.

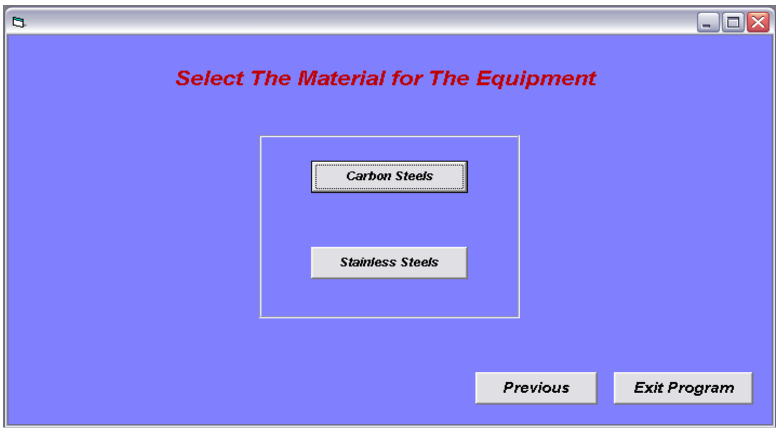



Figure 4.2: Interface Selecting Material of Equipment

## 4.2 Environment Temperature and Insulation

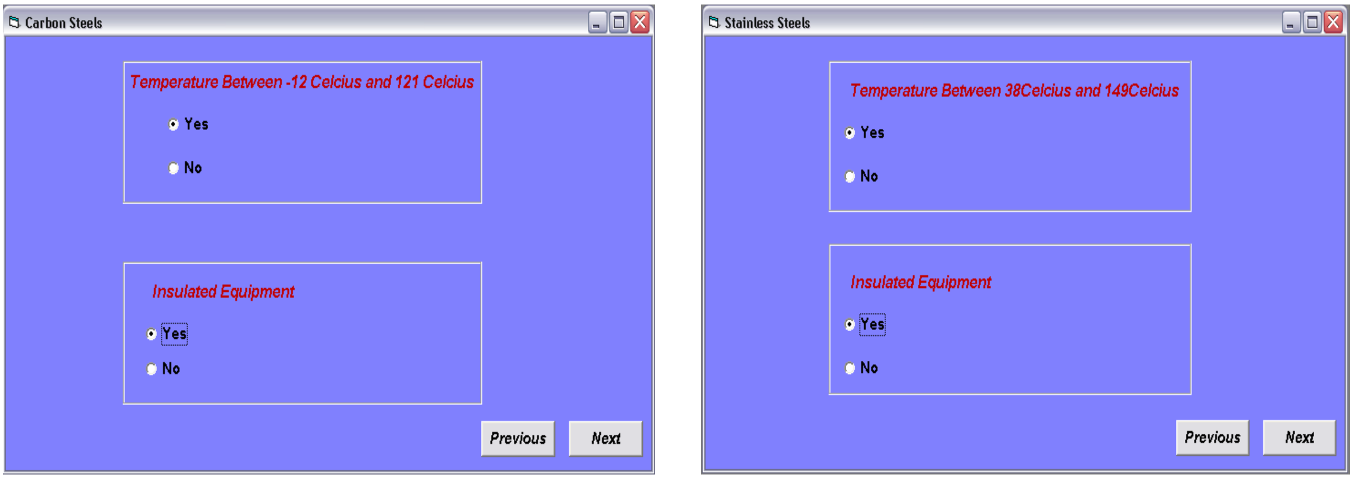



Figure 4.3: Interface to determine environment temperature and Insulation

After selecting the material of the equipment, the software will prompt the user to select the environment temperature range and to determine whether the equipment is insulated or not.

If the material is not insulated or the temperature is not in the range given that can initiate Corrosion under Insulation, the software will tell the user that the equipment is not susceptible to Corrosion under Insulation (CUI).

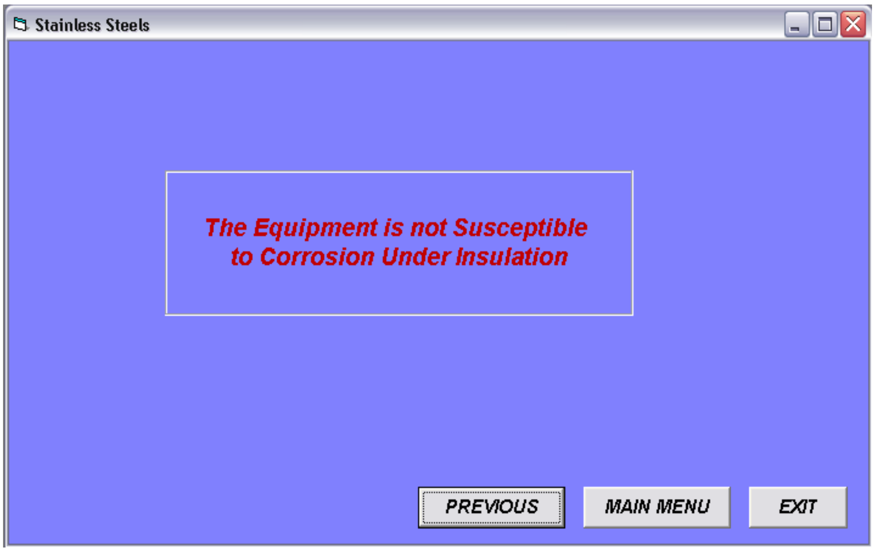



Figure 4.4: Interface showing equipment not susceptible to CUI

### 4.3 Corrosion under Insulation (CUI) for Carbon Steels

After user had determine the environment temperature range and whether the equipment is insulated or not, the software will further prompt user several interface to gather data in order to calculate the CUI susceptibility of the equipment. Carbon Steels is subjected to gradual thinning.

#### *4.3.1 Operating Temperature and Environment of Equipment*

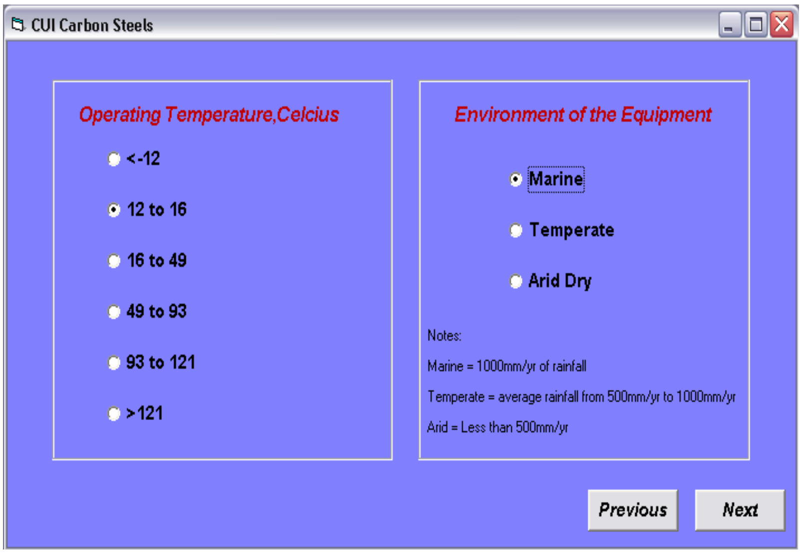



Figure 4.5: Interface to Determine Operating temperature and Environment

The Operating Temperature and the environment of the equipment are needed in order to determine the initial corrosion rate. The corrosion rate is then modified by other factors. The marine environment is where the rainfall is about 1000mm/year while temperate environment is where the rainfall is from 500mm/year to 1000mm/year and arid environment is where the rainfall is less than 500mm/year.

### *4.3.2 Pipe Support, Soil interface and Complexity Factor of equipment*

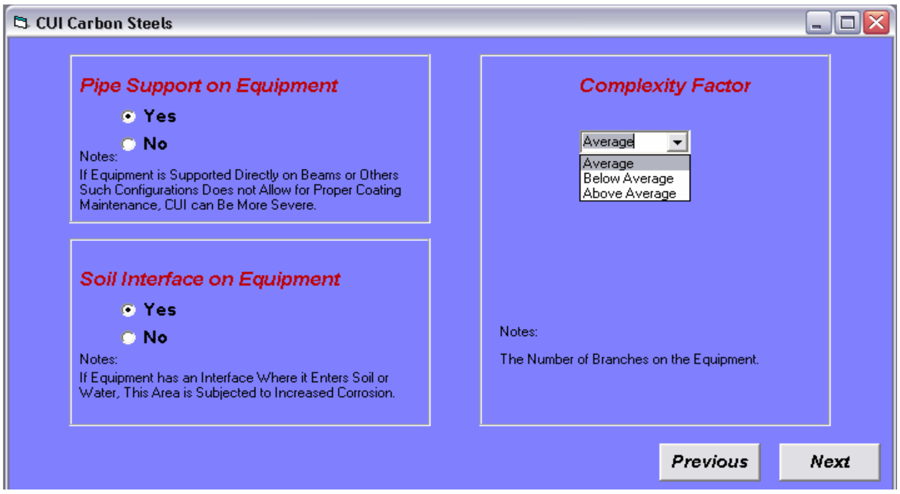



Figure 4.6: Interface to Determine Pipe Support, Soil Interface and Complexity Factor

The equipment is said to have pipe support if it is supported directly on beams or others. Such configurations do not allow for proper coating maintenance and can lead CUI to be more severe. The Equipment is said to have soil interface if it has an interface where it enters soil or water. This area is subjected to increased corrosion. Complexity factor is the number of branches on the equipment. The complexity factor is measure by three levels – average, below average and above average.

### *4.3.3 Pipe Support, Soil interface and Complexity Factor of equipment*

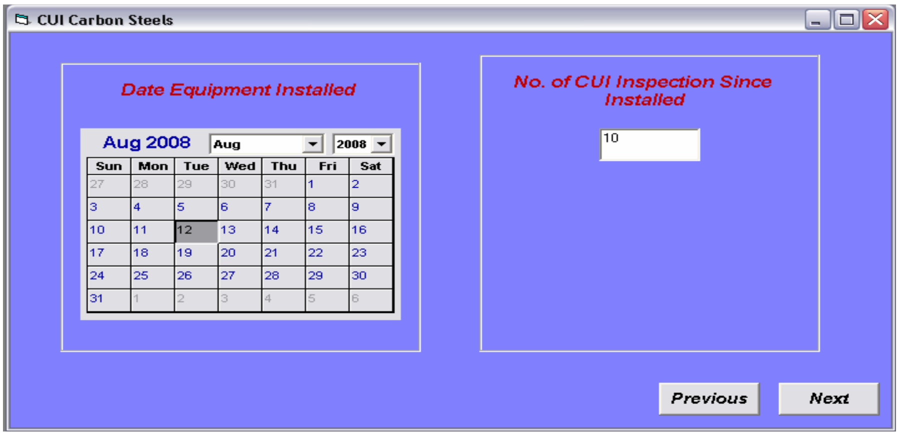



Figure 4.7: Interface to Determine Date Equipment Installed and No of Inspection Made

Date of equipment installed is to determine the operating life of the equipment. Number of inspection made is to determine the confidence level for the equipment.

### 4.3.4 *Equipment Insulation Condition and Coating Quality*

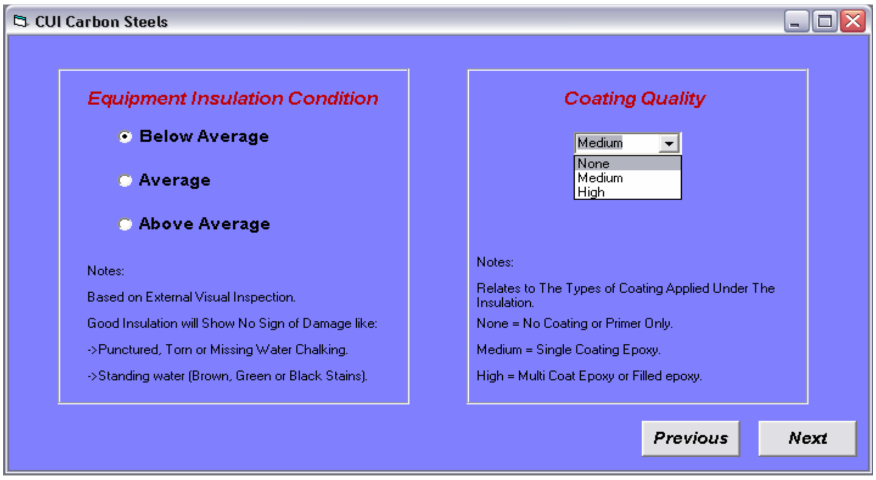



Figure 4.8: Interface to Determine Insulation Condition and Coating Quality

The equipment insulation condition is based on external visual inspection. Good insulation will show no sign of damage like punctured, torn or missing water chalking and standing water (brown, green or black stains). Coating quality is related to the types of coating applied under the insulation. There are three levels of coating quality:

- None = No coating or primer only.
- Medium = Single coating epoxy.
- High = Multi coat epoxy or filled epoxy.

### 4.3.5 *Corrosion Rate for Carbon Steels*

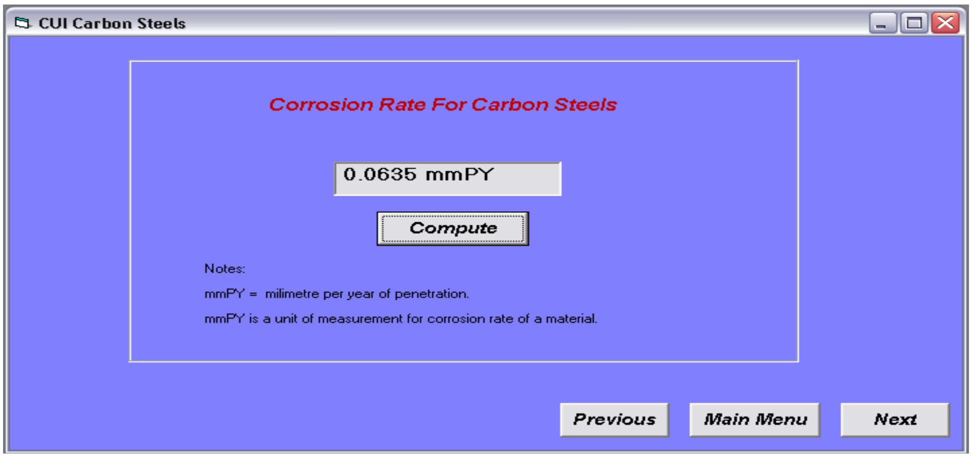



Figure 4.9: Interface to compute Corrosion Rate for Carbon Steels

The unit for corrosion rate is mmPY which is millimetre per year of penetration. The coding for the calculation is attached in the **Appendix**.

## 4.4 Corrosion under Insulation (CUI) for Stainless Steels

After user had determine the environment temperature range and whether the equipment is insulated or not, the software will further prompt user several interface to gather data in order to calculate the CUI susceptibility of the equipment. Stainless Steels are subjected to stress corrosion cracking (SCC).

### *4.4.1 Operating Temperature and Environment of Equipment*

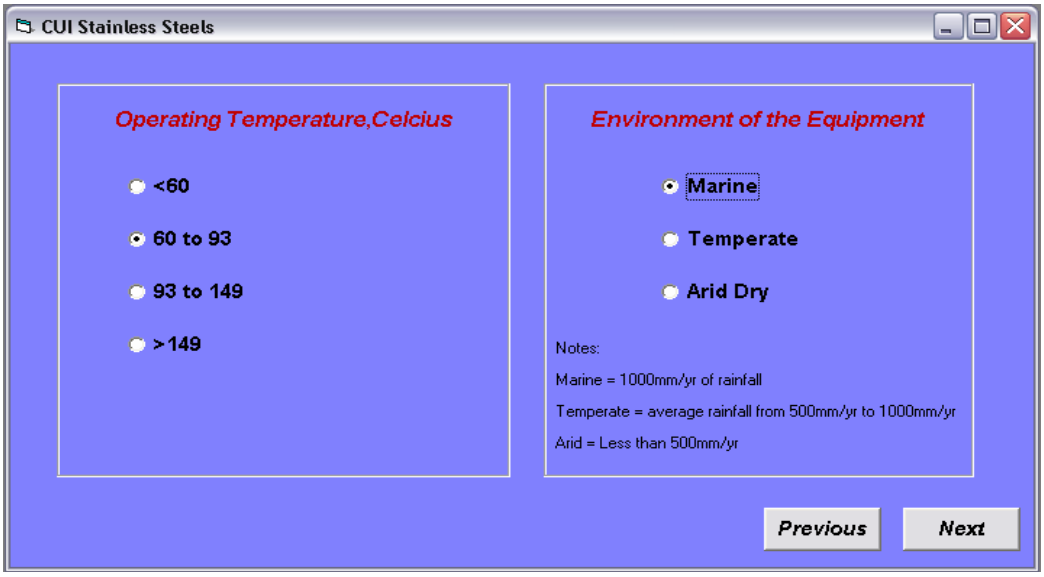



Figure 4.10: Interface to Determine Operating temperature and Insulation

The Operating Temperature and the environment of the equipment are needed in order to determine the initial corrosion rate. The corrosion rate is then modified by other factors. The marine environment is where the rainfall is about 1000mm/year while temperate environment is where the rainfall is from 500mm/year to 1000mm/year and arid environment is where the rainfall is less than 500mm/year.

*4.4.2 Pipe Support, Soil interface and Complexity Factor of equipment*

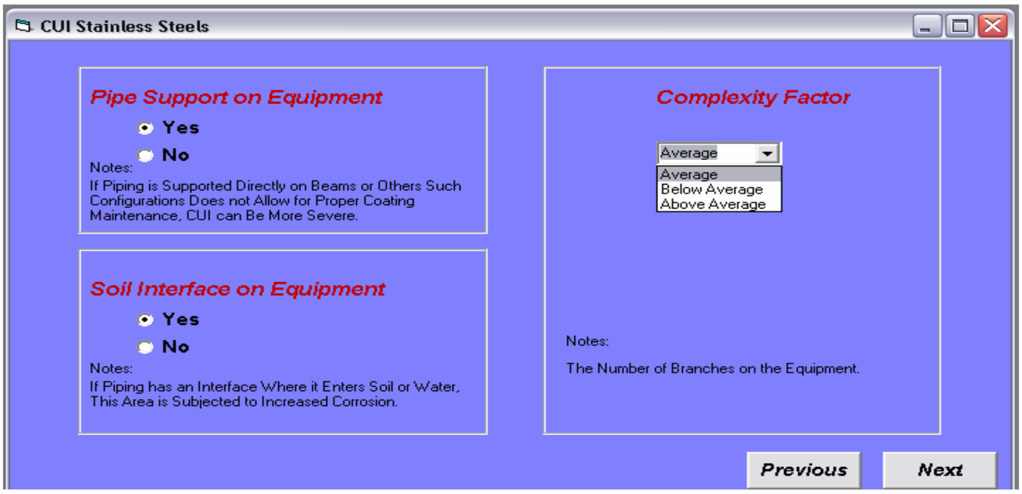



Figure 4.11: Interface to Determine Pipe Support, Soil Interface and Complexity Factor

The equipment is said to have pipe support if it is supported directly on beams or others. Such configurations do not allow for proper coating maintenance and can lead CUI to be more severe. The Equipment is said to have soil interface if it has an interface where it enters soil or water. This area is subjected to increased corrosion. Complexity factor is the number of branches on the equipment. The complexity factor is measure by three levels – average, below average and above average.

*4.4.3 Pipe Support, Soil interface and Complexity Factor of equipment*

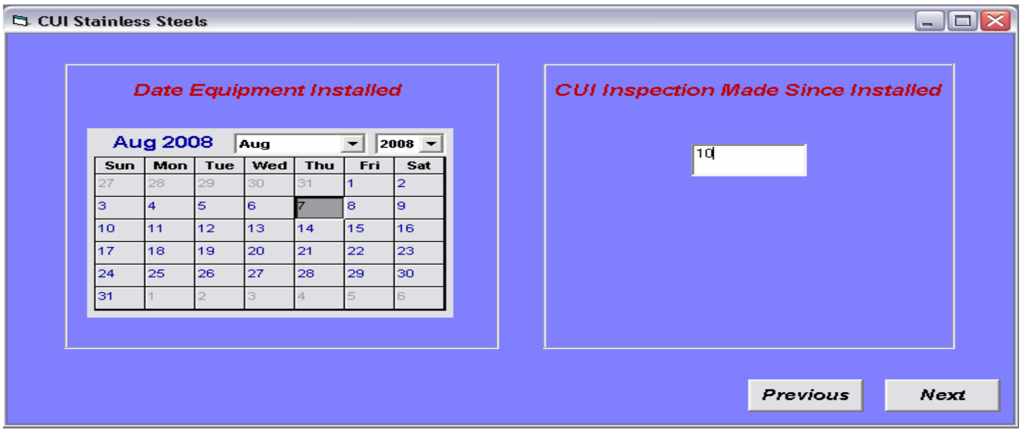



Figure 4.12: Interface to Determine Date Equipment Installed and No of Inspection Made

Date of equipment installed is to determine the operating life of the equipment. Number of inspection made is to determine the confidence level for the equipment.

### *4.4.4 Equipment Insulation Condition and Coating Quality*

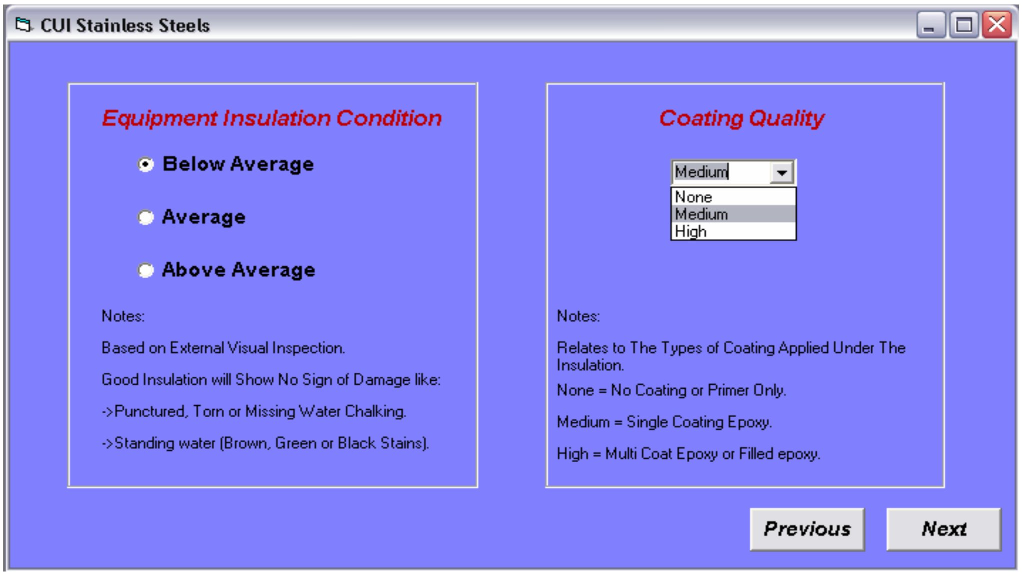



Figure 4.13: Interface to Determine Insulation Condition and Coating Quality

The equipment insulation condition is based on external visual inspection. Good insulation will show no sign of damage like:

- Punctured, torn or missing water chalking
- Standing water (brown, green or black stains).

Coating quality is related to the types of coating applied under the insulation. There are three levels of coating quality:

- None = No coating or primer only.
- Medium = Single coating epoxy.
- High = Multi coat epoxy or filled epoxy.

### *4.4.5 Insulation Condition and Inspection Effectiveness*

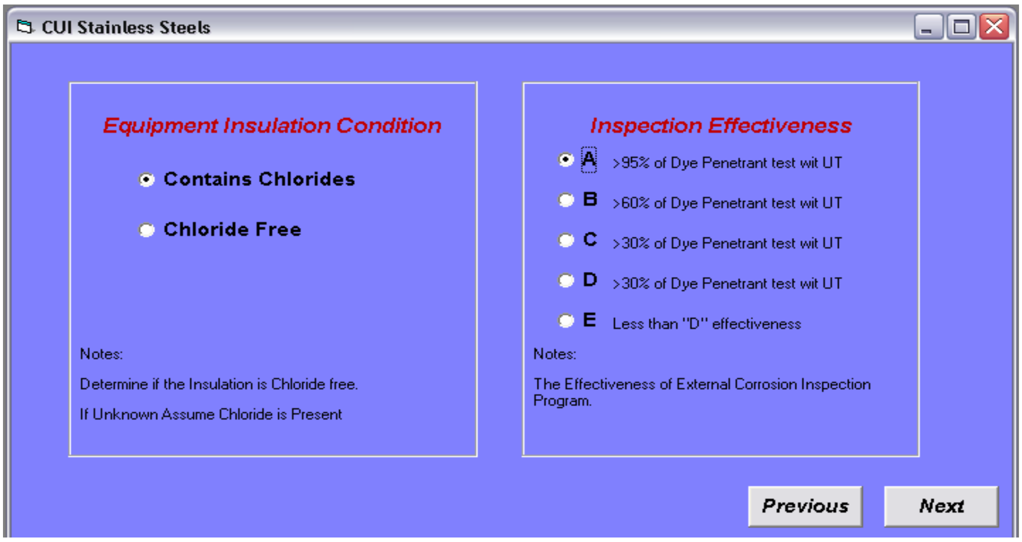



Figure 4.14: Interface to Determine Insulation Condition and Inspection Effectiveness

If insulation contains chloride, it will accelerate the corrosion process. If unknown condition, assume chloride is present.

### *4.4.6 Corrosion Rate for Stainless Steels*

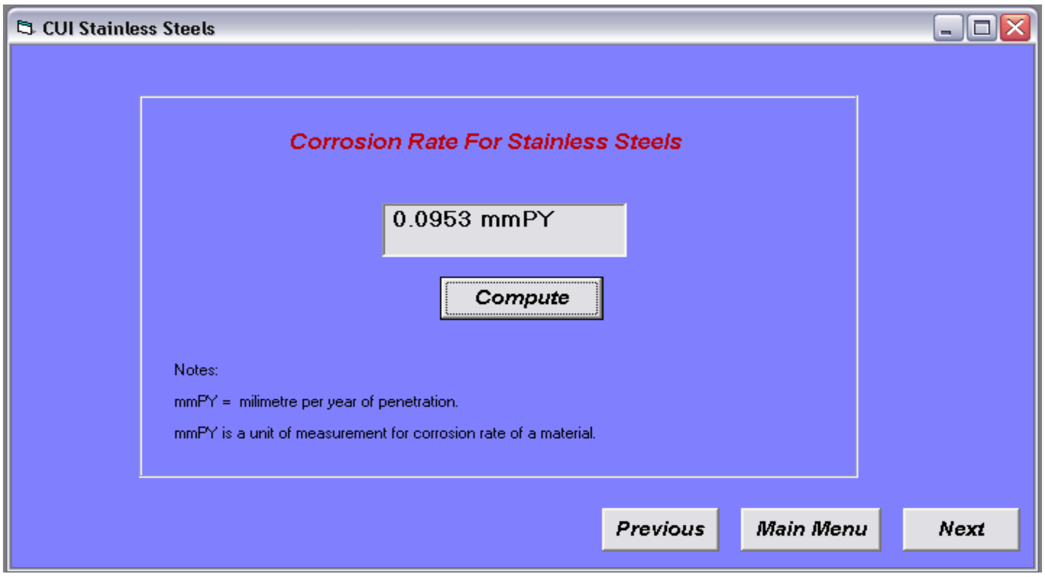



Figure 4.15: Interface to compute Corrosion Rate for Stainless Steels

The unit used for corrosion rate is mmPY which is millimetre per year penetration. The coding for the calculation is attached in the **Appendix**.

## 4.5 Incorporating Field and Equipment Data in DSS database

The Decision Support System (DSS) for the Corrosion under insulation susceptibility is very flexible. The database of the DSS can be modified if any changes need to be made, for example is the corrosion rate for the material need to be altered, it can be done by adjusting the database by adjusting the programming code using Microsoft Visual Basic 6.0. Additional corrosion factors can also be added to improve the reliability of the DSS. Only authorized personnel can have the access and the right to modify the database. The programming code can be referred in **APPENDIX**.

# CHAPTER 5

# CONCLUSION

Based on all the collected literature review on CUI, thanks to all the people involved the Decision Support System (DSS) is developed successfully as scheduled. With the present of DSS, the decision making process for Corrosion under Insulation (CUI) prediction will be become much easier, accurate and reliable. It is hoped that the DSS will be worth and used widely especially in Risk-Based Inspection (RBI) for Oil and Gas Industry.

Corrosion under Insulation is a multi-billion dollar problem that destroys expensive industrial infrastructure and causes continuous scheduled manufacturing plant and facility downtime to conduct inspections for failure and unexpected downtime when equipment failure occurs. Mitigation of CUI can be accomplished through good insulation practices and proper coatings. Proper Insulation and maintenance of insulation simply prevent penetration of water through equipment insulation.

# CHAPTER 6

# FUTURE WORK

There are several improvements that can be made to the Decision Support System in order to improve its reliability and accuracy for Corrosion under Insulation (CUI) prediction. Below are some of the future works that can be done by next Final Year Project students to improve the reliability of the software.

## 6.1 Narrowing the Operating Temperature Range for Corrosion Rate

The operating temperature range is too big, that mean the value corrosion rate is less accurate. By narrowing the temperature range, the value of the corrosion rate will be more accurate. This can be done by experimental work which will make the CUI prediction more reliable and accurate.

## 6.2 Add / Modified Corrosion Factors Related to Malaysia Environment

The corrosion factors in the API 581 are designed based on European environment, so it may affect the value of the corrosion factors. The environment in Malaysia is slightly different so some modifications are needed to make the CUI prediction more accurate. For example the rainfall is slightly higher in Malaysia because of its Monsoon seasons.

# REFERENCES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[11] http://www.intercorr.com/cuipp.htm

[12] http://www.corrosion-doctors.org/Forms-crevice/CUI.htm

[13] http://www.asnt.org

# APPENDIX

(a) Programming Code for Carbon Steels CUI susceptibility Calculation

```
Private Sub cmdCompute_Click()
cmdNext.Enabled = True
Dim rate As Single, rateSupport As Single, rateSoil As Single, rateComplex As Single
Dim Insection As Single, rateInsulated As Single, rateCoating As Single
picRate.Cls
If (frm1_1.opt1Temp.Value = True) And (frm1_1.optMarine.Value = True) Then
rate = 0
ElseIf (frm1_1.opt1Temp.Value = True) And (frm1_1.optTemperate.Value = True) Then
rate = 0
ElseIf (frm1_1.opt1Temp.Value = True) And (frm1_1.optArid.Value = True) Then
rate = 0
ElseIf (frm1_1.opt2Temp.Value = True) And (frm1_1.optMarine.Value = True) Then
rate = 0.127
ElseIf (frm1_1.opt2Temp.Value = True) And (frm1_1.optTemperate.Value = True) Then
rate = 0.0762
ElseIf (frm1_1.opt2Temp.Value = True) And (frm1_1.optArid.Value = True) Then
rate = 0.0254
ElseIf (frm1_1.opt3Temp.Value = True) And (frm1_1.optMarine.Value = True) Then
rate = 0.0508
ElseIf (frm1_1.opt3Temp.Value = True) And (frm1_1.optTemperate.Value = True) Then
rate = 0.0254
ElseIf (frm1_1.opt3Temp.Value = True) And (frm1_1.optArid.Value = True) Then
rate = 0
ElseIf (frm1_1.opt4Temp.Value = True) And (frm1_1.optMarine.Value = True) Then
rate = 0.0254
ElseIf (frm1_1.opt4Temp.Value = True) And (frm1_1.optTemperate.Value = True) Then
rate = 0.127
ElseIf (frm1_1.opt4Temp.Value = True) And (frm1_1.optArid.Value = True) Then
rate = 0.0508
ElseIf (frm1_1.opt5temp.Value = True) And (frm1_1.optMarine.Value = True) Then
rate = 0.0508
```

```
ElseIf (frm1_1.opt5temp.Value = True) And (frm1_1.optTemperate.Value = True) Then
rate = 0.0254
ElseIf (frm1_1.opt5temp.Value = True) And (frm1_1.optArid.Value = True) Then
rate = 0
ElseIf (frm1_1.opt5temp.Value = True) And (frm1_1.optMarine.Value = True) Then
rate = 0
ElseIf (frm1_1.opt5temp.Value = True) And (frm1_1.optTemperate.Value = True) Then
rate = 0
ElseIf (frm1_1.opt5temp.Value = True) And (frm1_1.optArid.Value = True) Then
rate = 0
End If

If frm1_2.optYesSupport.Value = True Then
rateSupport = rate * 2
ElseIf frm1_2.optNoSupport.Value = True Then
rateSupport = rate * 1
End If

If frm1_2.optYesSoil.Value = True Then
rateSoil = rateSupport * 2
ElseIf frm1_2.optNoSoil.Value = True Then
rateSoil = rateSupport * 1
End If

If frm1_2.cboComplexity.Text = "Average" Then
rateComplex = rateSoil * 1
ElseIf frm1_2.cboComplexity.Text = "Below Average" Then
rateComplex = rateSoil * 0.75
ElseIf frm1_2.cboComplexity.Text = "Above Average" Then
rateComplex = rateSoil * 1.25
End If
```

```
Inspection = Val(frm1_3.txtCUI.Text)
If Inspection = 0 Then
rateInspection = rateComplex * 2
ElseIf Inspection > 1 Then
rateInspection = rateComplex * 1
End If

If frm1_4.opt1Equip.Value = True Then
rateInsulated = rateInspection * 1
ElseIf frm1_4.opt2Equip.Value = True Then
rateInsulated = rateInspection * 0.5
ElseIf frm1_4.opt3Equip.Value = True Then
rateInsulated = rateInspection * 0.25
End If

If frm1_4.cboCoating.Text = "None" Then
rateCoating = rateInsulated * 1.5
ElseIf frm1_4.cboCoating.Text = "Medium" Then
rateCoating = rateInsulated * 1.25
ElseIf frm1_4.cboCoating.Text = "High" Then
rateCoating = rateInsulated * 1
End If

picRate.Print Round(rateCoating, 4); "mmPY"

End Sub
```

(b) Programming Code for Stainless Steels CUI susceptibility Calculation

```
Private Sub cmdCompute_Click()
cmdNext.Enabled = True

Dim rate As Single, rateSupport As Single, rateSoil As Single, rateComplex As Single
Dim rateInspection As Single, rateInsulated As Single, rateCoating As Single
Dim rateChloride As Single, Inspection As Single, rateEffective As Single

picRate.Cls
If (frm2_1.opt1Temp.Value = True) And (frm2_1.opt1Envi.Value = True) Then
rate = 0
ElseIf (frm2_1.opt1Temp.Value = True) And (frm2_1.opt2Envi.Value = True) Then
rate = 0
ElseIf (frm2_1.opt1Temp.Value = True) And (frm2_1.opt3Envi.Value = True) Then
rate = 0
ElseIf (frm2_1.opt2Temp.Value = True) And (frm2_1.opt1Envi.Value = True) Then
rate = 0.127
ElseIf (frm2_1.opt2Temp.Value = True) And (frm2_1.opt2Envi.Value = True) Then
rate = 0.0762
ElseIf (frm2_1.opt2Temp.Value = True) And (frm2_1.opt3Envi.Value = True) Then
rate = 0.0254
ElseIf (frm2_1.opt3Temp.Value = True) And (frm2_1.opt1Envi.Value = True) Then
rate = 0.0508
ElseIf (frm2_1.opt3Temp.Value = True) And (frm2_1.opt2Envi.Value = True) Then
rate = 0.0254
ElseIf (frm2_1.opt3Temp.Value = True) And (frm2_1.opt3Envi.Value = True) Then
rate = 0
ElseIf (frm2_1.opt4Temp.Value = True) And (frm2_1.opt1Envi.Value = True) Then
rate = 0.0254
ElseIf (frm2_1.opt4Temp.Value = True) And (frm2_1.opt2Envi.Value = True) Then
rate = 0.127
ElseIf (frm2_1.opt4Temp.Value = True) And (frm2_1.opt3Envi.Value = True) Then
rate = 0.0508
End If
```

```
If frm2_2.optYesSupport.Value = True Then
rateSupport = rate * 2
ElseIf frm2_2.optNoSupport.Value = True Then
rateSupport = rate * 1
End If

If frm2_2.optYesSoil.Value = True Then
rateSoil = rateSupport * 2
ElseIf frm2_2.optNoSoil.Value = True Then
rateSoil = rateSupport * 1
End If

If frm2_2.cboComplexity.Text = "Average" Then
rateComplex = rateSoil * 1
ElseIf frm2_2.cboComplexity.Text = "Below Average" Then
rateComplex = rateSoil * 0.75
ElseIf frm2_2.cboComplexity.Text = "Above Average" Then
rateComplex = rateSoil * 1.25

Inspection = Val(FRM2_3.txtCUI.Text)
If Inspection = 0 Then
rateInspection = rateComplex * 2
ElseIf Inspection > 1 Then
rateInspection = rateComplex * 1
End If

End If
If frm2_4.opt1Equip.Value = True Then
rateInsulated = rateComplex * 1
ElseIf frm2_4.opt2Equip.Value = True Then
rateInsulated = rateComplex * 0.5
ElseIf frm2_4.opt3Equip.Value = True Then
rateInsulated = rateComplex * 0.25
End If
```

```
If frm2_4.cboCoating.Text = "None" Then
rateCoating = rateInsulated * 1.5
ElseIf frm2_4.cboCoating.Text = "Medium" Then
rateCoating = rateInsulated * 1.25
ElseIf frm2_4.cboCoating.Text = "High" Then
rateCoating = rateInsulated * 1
End If

If Frm2_5.opt1Equip.Value = True Then
rateChloride = rateCoating * 1.5
ElseIf Frm2_5.opt2Equip.Value = True Then
rateChloride = rateCoating * 1
End If

If Frm2_5.opt1Inspect.Value = True Then
rateEffective = rateChloride * 1
ElseIf Frm2_5.opt2Inspect.Value = True Then
rateEffective = rateChloride * 1.25
ElseIf Frm2_5.opt3Inspect.Value = True Then
rateEffective = rateChloride * 1.5
ElseIf Frm2_5.opt4Inspect.Value = True Then
rateEffective = rateChloride * 1.75
ElseIf Frm2_5.opt5Inspect.Value = True Then
rateEffective = rateChloride * 2
End If

picRate.Print Round(rateEffective, 4); "mmPY"
End Sub
```

(c) Basic Data Required for CUI for Carbon Steels

| VARIABLE | COMMENTS |
|---|---|
| Driver | The drivers for external corrosion under insulation. This can be the weather at a location. |
| Rate, in mmPY | Corrosion rate for external corrosion. Based on temperature and driver. |
| Date | Determine the time (in years). Default to date installed. Can change based on date of coating, time since last inspection. |
| Inspection Effectiveness | The effectiveness of the CUI inspection program. |
| Inspection Number | The number of CUI inspection. |
| Coating Quality | Related to the type of coating applied under insulation:<br>➢ None-no coating or primer only.<br>➢ Medium-single coat epoxy.<br>➢ High-multi coat epoxy or filled epoxy. |
| Complexity | The number of branches:<br>➢ Below average<br>➢ Average<br>➢ Above average |
| Insulation Condition | Determine weather insulation condition is good based on external visual inspection. Good insulation will show no sign of damage (i.e. punctured, torn or missing water proofing) or standing water (i.e. brown, green or black stains). |
| Pipe Support Penalty (Y/N) | If piping is supported directly on beams or other such configuration that does not allow for coating maintenance, external corrosion can be more severe. |
| Interface Penalty (Y/N) | If piping has interface where it enters either soil or water, this area is subject to increased corrosion. |

(d) Basic Data Required for CUI for Stainless Steels

| VARIABLE | COMMENTS |
|---|---|
| Driver | The drivers for external corrosion under insulation. This can be the weather at a location. |
| Rate, in mmPY | Corrosion rate for external corrosion. Based on temperature and driver. |
| Date | Determine the time (in years). Default to date installed. Can change based on date of coating, time since last inspection. |
| Inspection Effectiveness | The effectiveness of the CUI inspection program. |
| Inspection Number | The number of CUI inspection. |
| Coating Quality | Related to the type of coating applied under insulation:<br>➢ None-no coating or primer only.<br>➢ Medium-single coat epoxy.<br>➢ High-multi coat epoxy or filled epoxy. |
| Complexity | The number of branches:<br>➢ Below average<br>➢ Average<br>➢ Above average |
| Insulation Condition | Determine weather insulation condition is good based on external visual inspection. Good insulation will show no sign of damage (i.e. punctured, torn or missing water proofing) or standing water (i.e. brown, green or black stains). |
| Pipe Support Penalty (Y/N) | If piping is supported directly on beams or other such configuration that does not allow for coating maintenance, external corrosion can be more severe. |
| Interface Penalty (Y/N) | If piping has interface where it enters either soil or water, this area is subject to increased corrosion. |
| Is Insulation Cl “free”? (Y/N) | Determine if the insulation is Cl free. If unknown assume Cl is present. |

(e) Adjustments for Coatings

| Coating Quality | | |
|---|---|---|
| None | Medium | High |
| Date = Date installed | Date = Coating date + 5 | Date = Coating date + 15 |

(f) Adjustments for Complexity

| Below Average | Average | Above Average |
|---|---|---|
| Rate = Rate x 0.75 | Rate = Rate x 1 | Rate = Rate x 1.25 |

(g) Adjustments for Insulation Condition

| Below Average | Average | Above Average |
|---|---|---|
| Rate = Rate x 1 | Rate = Rate x 0.5 | Rate = Rate x 0.25 |

(h) Adjustments for Pipe Support Penalty

| Penalty Apply | Penalty Does Not Apply |
|---|---|
| Rate = Rate x 2.0 | Rate = Rate x 1.0 |

(i) Adjustments for Interface Penalty

| Penalty Apply | Penalty Does Not Apply |
|---|---|
| Rate = Rate x 2.0 | Rate = Rate x 1.0 |

(j) Adjustments for Chloride Free Insulation

| Chloride Free | Contain Chloride |
|---|---|
| Rate = Rate x 1.0 | Rate = Rate x 2.0 |