Development of a Failure Prediction Model for Heat Exchanger Tube

By

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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

January 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.

(MOHD FIKRAM BIN MAT YAZID)

ABSTRACT

Heat exchanger is crucial equipment in plant maintenance work that must run efficiently. Failure to operate it efficiently will effect in loss profit for the plant. In a worse case scenario when maintenance was not done as prepared for unexpected failure of the heat exchanger could occur. For planning in maintenance work, it is necessary to predict the equipment failure so that maintenance department could prepare for shutdown schedule. Related to this problem, this project was using Weibull model to predict failure using data of heat exchanger PE-2-E-400 at Ethylene Polyethylene (M) Sdn Bhd (EPEMSB). For modeling, the input data to the Weibull model was a set of industrial inspection data of the heat exchanger tube thickness covering a period of fourteen years. The measurements were made in regions of the heat exchanger where corrosion/erosion was the major cause of failure. Weibull model was used to predict the thickness of the tube related with time. By predicting the thickness of the tube and using maximum failure risk that lies on minimum allowable thickness given by the heat exchanger manufacturer, prediction was undertaken. The model was used to compare between actual data and predicted data by calculate the error percentage.

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CHAPTER 1
INTRODUCTION

1.1 Background of Studies

Ethylene Polyethylene M Sdn Bhd located in Kerteh, Terengganu is one of PETRONAS subsidiaries. The main product of this plant is polyethylene. This plant is running twenty-four hours per day. Many types of equipment in this plant including rotating and static equipments had failed within the expected failure time given by the manufacture but some of them have potential to fail out of the time range.

Situation where this equipment fails to run due to unexpected failure will create problem to maintenance departments that since they have major responsibility to these equipment. Most of the equipment failure will cause to temporary shutdown to all the operation in plant. And for some cases, unexpected failure will cause higher cost of maintenance due to lack of spare parts, buying replacement parts in short time or buying parts with low quantity. This unexpected failure will disturb the schedule of preventive maintenance and reactive maintenance. Preventive maintenance represent the primary mean to prevent breakdown and defect while reactive maintenance means maintenance work doing when plant shutdown[1]. By starting to predict failure it can reduce the necessity of the reactive maintenance activities and simplify the planning of the preventive maintenance.

In order to keep smooth operatios, it is important that to know or predict failure of some equipment in plants. As stated by Roberto Manta (2005) says a good preventive maintenance program may be discriminated by observing the number of unscheduled downtimes and breakdowns occurring, clearly indicating that the whole system is not running as it should (p. 280).

This study focused on prediction heat exchanger tube failure in EPEMSB plant. Heat exchanger PE-2-E-400 and PE-2-E-401 was placed in train 1 and 2 where polymerization process was performed. Heat exchanger functioned to cool the product to the required temperature. When this equipment was failed, all operation in train 1 and 2 were required to shutdown because reactor in train 1 and 2 could not resist temperature that exceeding its requirement. And also time required to repair this equipment was about 3 weeks if preparation was made. Therefore, it is necessary to predict failure of this heat exchanger so that preparation can be done.

1.2 Problem Statement

Heat exchanger failure predictions become very important to EPEMSB plant since it could affect the economical aspect of the company. When the heat exchanger failed, operations will shutdown and maintenance work was required. The repairing of the equipment when it was involved the tube replacement requires a long time. In order to have good maintenance plans, failure prediction is required. This was addressed in the study

1.3 Objectives of Study

Objective of this study is to predict heat exchanger tube failure using Weibull model and corrosion rate. The output of the model is the time when the tube thickness reaches minimum allowable thickness or maximum failure risk.

1.4 Scope of Study

The scope of study covers on the thickness analysis of heat exchanger tube, due to the corrosion. Data and condition of the tube thickness was provided by EPEMSB. For Weibull analysis, WinSmith Weibull software was used. Validation of the project was based on EPEMSB data.

CHAPTER 2

LITERATURE REVIEW

2.1 Heat Exchanger in Petrochemical Industry

Heat exchangers are used in this industry both for cooling and heating large scale processes. The type and size of heat exchanger used depending on the type of fluid, temperature, density, viscosity, pressures, chemical composition and other thermodynamic properties[2].

In many petrochemical processes there is waste of energy or a heat stream being exhausted, heat exchangers can be used to recover this heat and put it to use by heating a different stream in the process. This practice saves a lot of money in industry as the heat supplied to other streams from the heat exchangers would otherwise come from an external source which is more expensive and more harmful to the environment.

In polymerization process heat exchanger is used to reduce heat of chemical process reaction in reactor[2]. Major chemical process will happen in reactor that produces high thermal activity. In order to continue process to other equipment, product need to flow in lower temperate that is suitable to other equipment function. To do that, product must flow in the heat exchanger where the temperature will decrease to the required temperature needed by the process.

Flow of the product into the exchanger is either in parallel or countercurrent exchange[3]. In parallel-flow heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In counter-flow heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is most efficient, in that it can transfer the most heat.

2.2 Reason of Equipment Failure

When the heat transfer surfaces have been coated by films of scale or carbon[2] it will affect the cooling process. The heating surfaces may have been reduced due to choked passages for the cooling medium in the heat exchanger. The cooling medium itself may be too hot probably due to a fault in another machine like the cooling tower[4] where the heat can be taken away at the atmosphere.

The flow of coolant can sometimes be the reason[2] When the cooling pump fails, or the driving belt snaps there will be a lack of coolant flow. One must also find out whether the valves for coolant have been accidentally closed or not.

Most common factor of heat exchanger failure is tube failure due to loss of wall thickness that may affect leakage and reducing in efficiency of the heat exchanger[5. Through readings and research, there is several type of corrosion that will lead to tube failure:

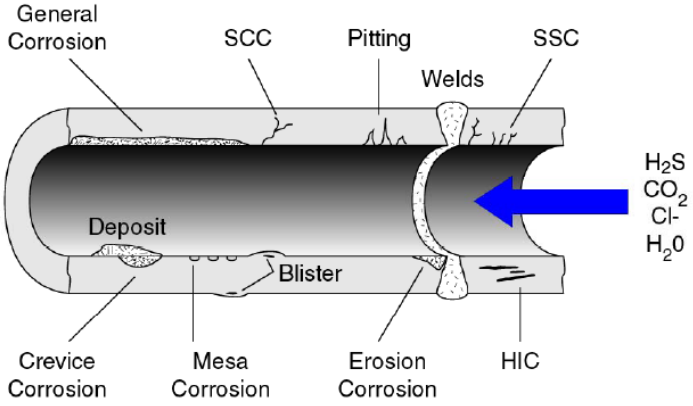


Figure 2.1: Type of corrosion at tube heat exchanger

- General Corrosion

Uniform corrosion is generally use by the rusting of steel. General corrosion is predictable. The life of components can be estimated based on simple test results. Allowance for general corrosion is relatively simple

Figure 2.2: Showing corrosion at tube surface

- Pitting Corrosion

Pitting is a localized form of corrosive attack. Pitting corrosion can be recognized by the looking at the surface where holes or pits on the metal surface. Pitting can cause failure due to perforation while the total corrosion, as measured by weight loss. The rate of penetration may be 10 to 100 times than general corrosion. Sometime pits may be small and difficult to detect. In some cases pits may be covered due to general corrosion. Pitting may take some time to initiate and develop to an easily viewable size.

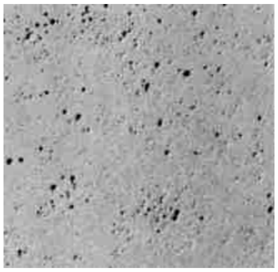


Figure 2.3: Pitting at tube surface

- Crevice corrosion

It always occurs at spaces between two metal surfaces or between metals and nonmetal surfaces. This differential aeration between the crevice (microenvironment) and the external surface (bulk environment) gives the crevice an anodic character. This can contribute to a highly corrosive condition in the crevice. Some examples of crevices are listed below:

1. Washers
2. Threaded joints
3. Role tube ends
4. Deposits

- Surface Corrosion Cracking

Stress corrosion cracking is an insidious type of failure as it can occur without an externally applied load or at loads significantly below yield stress. Thus, catastrophic failure can occur without significant deformation or obvious deterioration of the component. Pitting is commonly associated with stress corrosion cracking phenomena.

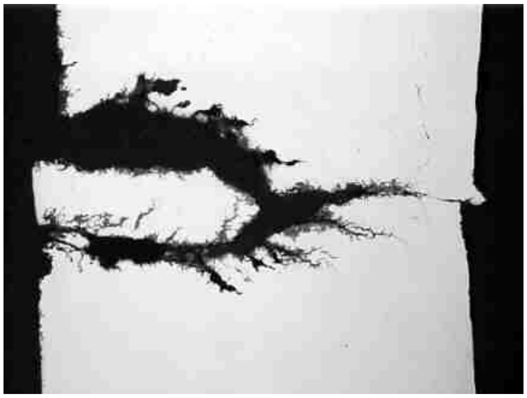


Figure 2.4: Surface Corrosion Cracking

- Mesa Corrosion

Corrosion experienced in service involving exposure of carbon or low alloy steels to flow wet carbon dioxide conditions at different temperature. Iron carbonate surface scale will often form in this type of that can protected low corrosion rate. However, under the surface shear forces produced by flowing media[17], this scale can become damaged metal to corrosion. Corrosion attack produces mesa-like features by corroding away the active regions and leaving the passive regions relatively free of corrosion that will effect the surface profile reminiscent of the mesas produced in rock by wind and water erosion.

Figure 2.5: Surface that experienced Mesa Corrosion

- Erosion Corrosion

Corrosion of a metal which is caused or accelerated by the relative motion of the environment and the metal surface[18]. It is characterized by surface features with a directional pattern which are a direct result of the flowing product. Erosion corrosion is most occuring in soft alloys (i.e. copper, aluminum and lead alloys)

Figure 2.6: Inner surface having Erosion Corrosion

- Deposit Corrosion

A condition often indicated ultrasonically by some areas showing at near original specification, and adjacent areas of high wall loss. It is more prevalent at the bottom of horizontal lines, on lower floors, and where flow rates are slowest[17].

Figure 2.7: Deposit at inner surface of tube

- Hydrogen Induced Cracking (HIC)

Brittle mechanical fracture caused by penetration and diffusion of atomic hydrogen into the crystal structure of an alloy and also referred to as hydrogen embrittlement[19]. This can occur during elevated-temperature thermal treatments and in service during electroplating, contact with maintenance chemicals, corrosion reactions, cathodic protection, and operating in high-pressure hydrogen.

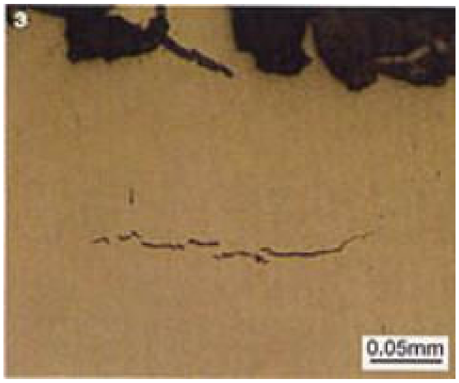
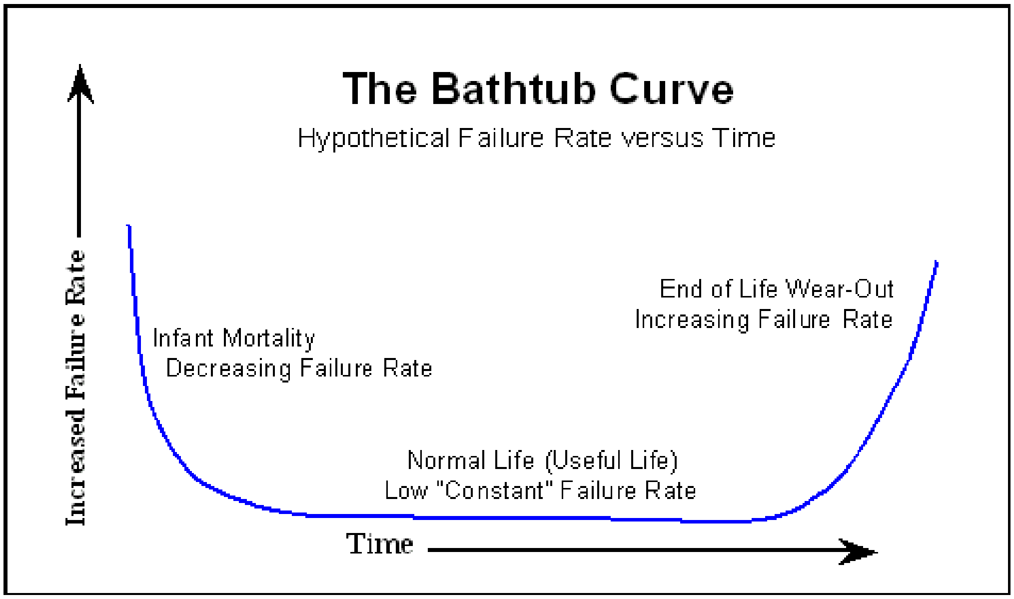


Figure 2.8: HIC at tube surface

2.3 Failure rate

The bath-tub curve is composed of three distinct regions[5]: the decreasing hazard rate region (infant mortality), constant hazard rate region (useful life) and the increasing hazard rate region (wear out). The most widely used mathematical model for describing the failure behavior of tube exchanger over time is the Weibull distribution function.



Source from (info@accoladeeng.com)

Figure 2.9: Bathtub Curve

This bathtub curve does not representing the failure rate of single item but describe the relative failure rate of entire products. It is said that some unit will fail in early stage of performing or in infant mortality region, some will fail during normal life where they have constant failure rate and some may fail during end of life or in wear-out region.

Infant mortality is highly undesirable [14] and always cause by defect and blunders: material defect, errors in assembly and lack of knowledge in running the equipment. This region happened does not mean that failure will occur when after certain time period but a time when the failure rate is decreasing at early stage of performance and it may last for years.

Failure in normal life is occurs at random time and consider as relatively in constant failure rate. In fact there is no constant failure rate in real products. Relatively constant failure rate happen considered as random cases “stress exceeding strength” [14].

In wear-out region, all material, product or equipment is through the wear-out process when they run for a long time. Theoretically, wear-out time calculated is shorter than the operational wear-out time. With some equipment, failure in wear-out is normal and replacement can be done.

2.3.1 Weibull Distribution Function

Weibull analysis is an engineering tool for analyzing life-data. The Weibull analysis quantification technique is the tool of choice for reliability engineers around the world (Abernethy 1996). In practice it is found that the relationship can usually be described by the following three parameter distribution known as the Weibull distribution named after Professor Waloddi Weibull:

$$R(t) = \exp(-x/\alpha)^{\beta} \qquad (1)$$

In the general Weibull case the reliability function requires two parameters (β, α) [7] .They do have meanings in the same way as does failure rate. They are parameters which allow us to compute Reliability and MTBF.

2.3.2 Parameters Estimating

There are several ways to estimating the value Weibull parameters. Most common method that used to determine its value by plotting the linear graph after modified the Weibull equation. It is necessary to obtain the value of these parameters since they will determine the behavior of product that been investigated. Equation (1) can be adjusted into linear equation as below to obtain equation (2):

$$F(x) = 1 - e^{-\left(\frac{x}{\alpha}\right)^{\beta}}$$

$$1 - F(x) = e^{-\left(\frac{x}{\alpha}\right)^{\beta}}$$

$$\ln(1 - F(x)) = -\left(\frac{x}{\alpha}\right)^{\beta}$$

$$\ln\left(\frac{1}{1 - F(x)}\right) = \left(\frac{x}{\alpha}\right)^{\beta}$$

$$\ln\left[\ln\left(\frac{1}{1 - F(x)}\right)\right] = \beta \ln\left(\frac{x}{\alpha}\right)$$

$$\ln\left[\ln\left(\frac{1}{1 - F(x)}\right)\right] = \beta \ln x - \beta \ln \alpha \qquad (2)$$

Where $\beta =$ shape parameter and

$\alpha =$ Characteristic life

With derived the equation of $\ln\left[\ln\left(\frac{1}{1 - F(x)}\right)\right] = \beta \ln(x) - \beta \ln \alpha$ from equation (1) we can form the linear equation by comparing with general formula of linear equation, Y = mX + b where:

$$Y = mX + b;$$

$$Y = \ln\left[\ln\left(\frac{1}{1-F(x)}\right)\right]$$

$$m = \beta \qquad (3)$$

$$X = \ln(x) \qquad (4)$$

$$b = -\beta \ln \alpha \qquad (5)$$

where β that can get directly from slope of the graph after we plotting the graph and α value can calculate from equation (5) as below:

$$-\beta \ln \alpha = b$$

$$\ln \alpha = \frac{-b}{\beta} \qquad (6)$$

$$\alpha = e^{-\left(\frac{b}{\beta}\right)}$$

And b is the value of Y interception in the linear graph. In this study, β is the shape parameter that related to bathtub curve and its value will determine the shape of the curve. When Beta < 1, infant mortality characterized by a declining instantaneous failure rate with time, Beta = 1, chance failures have a constant instantaneous failure rate with time, and Beta > 1, wear out failures characterized by increasing instantaneous failure rate with time.

2.4 Case Study

2.4.1 Heat Exchanger Detail

In EPEMSB plant at Area 2 Train 1 and 2 (PE-2-E-400/401), the heat exchangers was placed more than 20.00 meter height from the ground level, and possibility for corrosion on out side diameter of the tube may not be ruled out due to two phase corrosion and pitting on cooling water side. Process department has also mentioned the decrease of heat transfer efficiency[13].

Tubes (original) were supplied by M/S. Benteler, Germany in normalized condition and confirm to the Chemical composition, mechanical properties, hardness (from 64 to 75 HRB ≤85 HRB), hydraulic test (1500 PSI) as per ASTM A 334gr1 .Outer diameter and thickness of original supplied tubes were 25.4mmX 2.23mm respectively

Figure 2.10: PE-2-E-400 Heat Exchanger in EPEMSB

Original tube material and size were supplied as per specification. Tube design calculation provide the minimum thickness of tube having tube side design pressure of 319 psi is 0.97 mm and the corrosion was from cooling water side under the deposits .Bottom part of the tube of the vertical exchanger was having more corrosion than top one because of tendency of precipitation of cooling water chemical on tube surface rather than dispersion in the water. Cooling water chemical should have property to disperse the chemical even at low flow area as well as at 110 ^{o}C (which is reached during the starting of the operation).

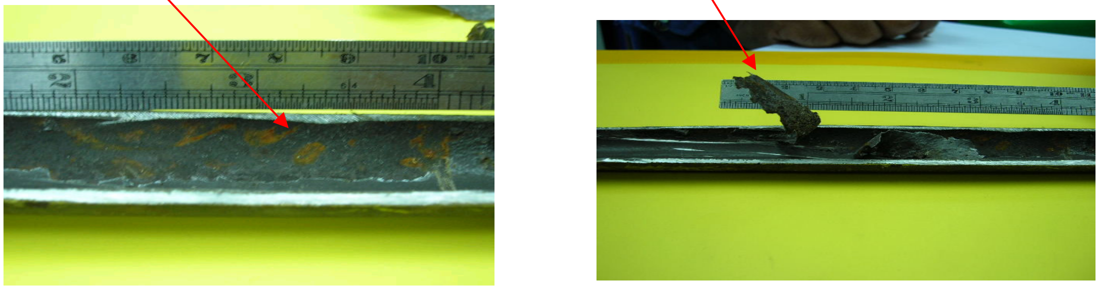
2.4.2 Findings on Heat Exchanger

a) **PE-2-E-401 (Downstream gas cooler**):

For downstream gas cooler, wall thinning process or corrosion was reported on the outer diameter of the tube at the cooling water side and no thinning process or corrosion was reported on inside of tubes. Thin layer of deposit (light blackish in colour) was observed throughout the length of the pulled out tube. And also corrosion was noticed under the baffle plate. Cooling water deposit on the tube was analyzed by the cooling water treatment vendor and get the result of component in the deposit(P2O5 30.1%, CaO 27.1%, Fe2O3 24.4%, Ignition loss 10.3%, Acid Insoluble Residual 5%, ZnO 1.1% ,Zinc was detected at minimal level) ,where scale formation was noticed.

b) **PE-2-E-400 (Upstream gas cooler**):

A thin layer (varies from 30 to 70 micron) of polymer black in color is found through out the length of cut section of tube



Oxidation mark reddish colour (underneath the coating)

Flake (thin film) of polymer after pulling out about 30 to 70 µ

Figure 2.11: Showing failure on tubes

Figure 2.12: Tube sheet having deep pitting

Thin layer of deposit (light blackish in color) was observed throughout the length of the tube. Deep pitting corrosion was found just above the bottom tube sheet having a length of about 200mm. Corrosion was noticed under the baffle plate. No appreciable corrosion was observed on other area.

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 Planning

Initially, the project was about researching and understanding on the basic concept of failure. It was the most important thing in a plant process. A thorough literature review has been done through reference books, internet and journals for further understanding. Actual thicknesses data based on study/reviewed analysis on the thickness reading have been done by collecting data from EPEMSB plant. This was to:

- Investigated the current condition of the heat exchanger tube.
- Modeled weibull using all the information gathered.

3.2 Procedure Identification

Methodology of this project can best be explained by the diagram below. Basically it consists of the planned sequence of work for two semesters of this project. Analyzing, Modeling and Performance Analysis of the whole system were done in the second semester.

In order to achieve the objectives of the project, the procedures were identified and planned accordingly. Figure shows the project work flow involved for overall of this project. Thus, one of the important steps that need to be taken was debugging at every step in this procedures. This involves correction, which was done to meet the specification of each step. Besides that, all procedures were needed to be well-planned in details and systematic to avoid problem in the following procedures. Each procedure was performed to follow step by step in order to make the process flow become smooth.

3.2.1 Methodology

a) Understand and analyzing the problem requirements

In order to achieved the objective of this project, clear understanding about the objective and problem was very important. First consideration in this project was understood the problem when heat exchanger failed to run. To solve this problem, clear view of objective is needed. The main objective of this project was to predict heat exchanger tube failure due to the thickness of the tube. Once the problem statement and the objectives was defined clearly then moved to the next step.

b) Literature Review

Research through internet and other reading material such as books and journals is important when gathered information to run this project. Through literature, there were few factors that lead to heat exchanger failure. As discussed in Chapter 2, some factor come from external factor (flow rate of coolant, heat absorb from cooling tower at atmosphere and other additional equipment like pump and motor not running at high performance) and most internal factor was tube failure. Common factor that will lead to tube failure was corrosion.

c) Analyzing the Research Findings

After gathered all the information about literature and data from EPEMSB, data was extracted to get data that related to this project. EPEMSB plant has been provided data from year 1991 till 2006 about heat exchanger tube thickness and full report of heat exchanger tube thickness in 2005. Report from year 2005 and initial year (1991) of tube thickness was foundation to predict the tube thickness. In year 1991, thickness was derived from tolerance of manufacturer to get the maximum and minimum thickness.

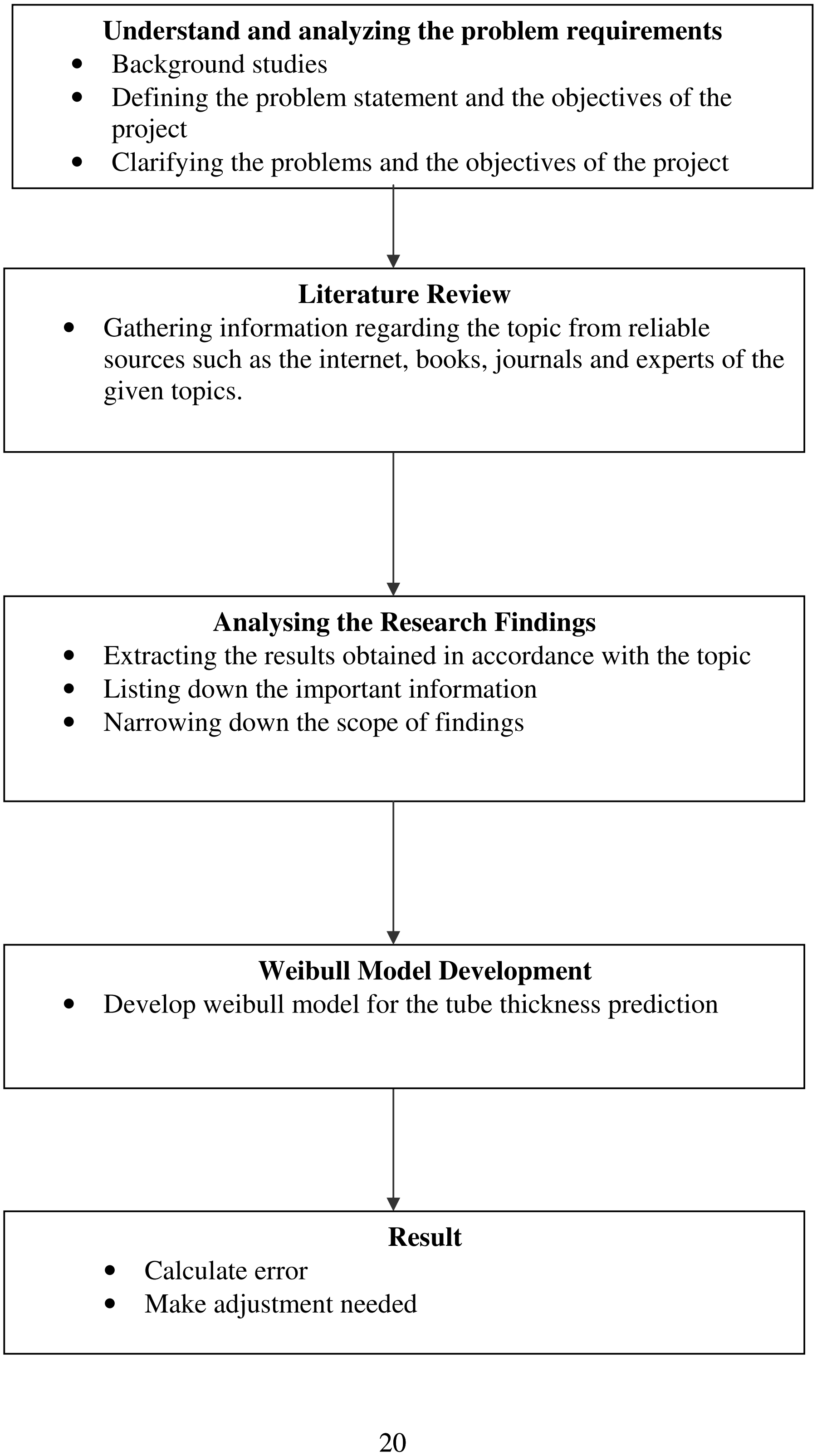
d) Corrosion Model Development

Corrosion model was developed using Weibull cumulative distribution function (CDF) .Data from year 1991 and 2005 was plotted using Weibull WinSmith software. Graph percentage occurrence of CDF versus thickness was performed. Value for percentage occurrence of CDF was calculated based on maximum and minimum thickness of tube derived from year 1991. By using this graph, value of α and β was obtained. ETA or (α) value is characteristic thickness of total tube thickness in that year. By assuming that corrosion rate is uniform varies with time (years), ETA prediction could be done.

e) Result

To check whether value of ETA predicted was reliable to the system, comparison was done between ETA value of actual data and ETA value of predicted data to calculate the error. Next, after the ETA predicted was confirmed that reliable to the system, then linear regression of scatter ETA predicted value was performed to get the time when ETA value reach the maximum failure risk or minimum allowable thickness.

To get clear view of the methodology of this project, below is the simplified methodology using flow chart.



Understand and analyzing the problem requirements

- Background studies
- Defining the problem statement and the objectives of the project
- Clarifying the problems and the objectives of the project

Literature Review

- Gathering information regarding the topic from reliable sources such as the internet, books, journals and experts of the given topics.

Analysing the Research Findings

- Extracting the results obtained in accordance with the topic
- Listing down the important information
- Narrowing down the scope of findings

Weibull Model Development

- Develop weibull model for the tube thickness prediction

Result

- Calculate error
- Make adjustment needed

3.3 Tool/Equipment Required

Tool and equipment (more to software) that being used for this project are as follows:

- Weibull WinSmith

  This software provides easiest way to calculate the value of Weibull parameters. By just put in the input value and selected the appropriate function of Weibull (two parameters), it automatically plotted and calculated the value of α and β

- Microsoft Excel

  This software has been used during performing the linear regression method to predict time of failure. Graph ETA versus years was performed. From the trend line of the graph, time of failure was estimated.

CHAPTER 4

RESULTS & DISCUSSIONS

Based on simulation using Weibull Winsmith software and linear projection using Microsoft Excel, estimated time for tube thickness will fail was obtained. First, ETA value for year 1991 and 2005 was obtained by plotting using Weibull WinSmith software. After ETA value was obtained then decreasing thickness per year was calculated using ETA value for year 1991 and 2005.

To predict thickness of tube in certain years, value of decreasing thickness per year multiplied by the age of the year. This approach was used by Barringer & Associate Inc.[20] to determine the thickness in their studies.

And using actual data given by EPEMSB plant, ETA value for each available year was obtained through the same procedure to calculate predicted ETA. This was to check the reliability of the model whether it is acceptable or not by comparing ETA value of actual ETA value and predicted ETA value and calculated the error percentage.

After error percentage had been identified, value of ETA predicted was plotted in scatter graph and trend line was performed. Using minimum allowable thickness as limit for the maximum risk, time for heat exchanger tube failure was determined when trend line of ETA value crossing the minimum allowable thickness[21].

4.1 Finding on Failure Data

Table 1 shows the thickness data from a periodic inspection program in EPEMSB plant. Data was taken from a tube cross section over a period of time reflecting the age/use of the tube at different locations in measurement plane[13]. This data shows small variations within each year.

Table 4.1: Thickness of tube in different location

Years	Thickness(mm)		
	Row1	Row 2	Row 3
1992	2.12	2.11	2.11
1993	2.09	2.10	2.09
1995	2.06	2.08	2.08
1997	1.98	2.03	2.04
2000	1.88	1.93	1.94
2003	1.80	1.88	1.89
2006	1.67	1.81	1.84

In table 4.1, Row 1 represented the thickness of all tube in that row. Same thing that applied to Row 2 and Row 3. This approach used to simplify the calculation when predicting the value of ETA because it is difficult to get the full thickness datasheet of heat exchanger tube bundle due to large number of tubes.

Table 4.2: Wall thickness reported in 2005

Total Tube	Percentage Loss	Thickness(mm)
28	0.20	1.69
26	0.29	1.50
30	0.36	1.35
2	0.46	1.13

Table 4.2 showing the tube thickness provided by EPEMSB plant. This plant had been providing full record for tube inspection in 2005. This data was used as main time-prediction together with data in year 1991(year zero) by assuming that corrosion rate was uniform.

The rule-of-thumb practice in this facility is[9]:

1. Begin heat exchanger tubing inspection at turnarounds when the wall thickness has been reduced 1/3 and
2. Consider the heat exchanger for retubing when tube wall thickness has been reduced to ½ of the original wall thickness

The minimum allowed wall thickness for this service (with environmental concerns and conditions) was 0.96 mm[21]. Starting wall thickness for the heat exchanger were not recorded when the heat exchanger was placed into service 14 years ago. Wall thickness for year zero were derived from the manufacturing tolerances assuming the minimum wall thickness was 1.93 mm and the maximum wall thickness was 2.29mm[20].

Data for wall thickness in year 2005 and year zero was plotted using Weibull WinSmith software where they automatically calculated the value of the α (characteristic thickness) and β (shape parameters).

4.2 Results on Weibull WinSmith

Wall thickness data for year 2005 and year 1991(year zero) was plotted as in Figure 4.1. Dash line represented the rule of thumb practice value when the tube thickness has reduced thickness by 1/3 or almost 66.67% of the tube thickness.

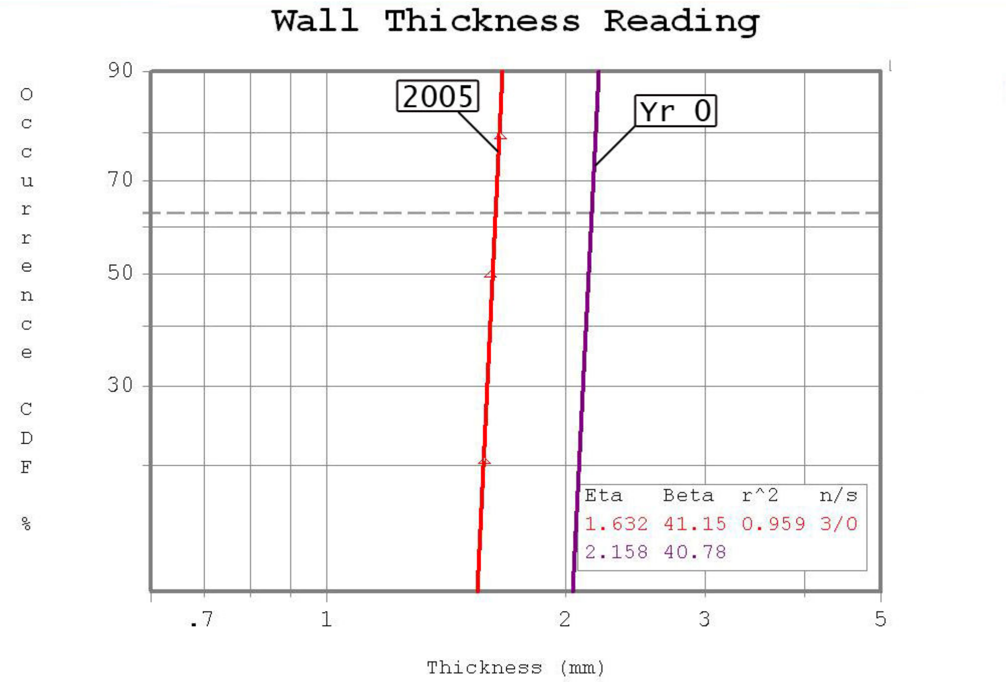


Figure 4.1: Wall thickness reading of Year 2005 and Year 0

A set of data as shown in Figure 4.1 with the large number of data input all the same values. This suggests the use of the "Inspection" option for analysis[10]. The inspection option regresses the trend line through the top point in the data stacks. The coefficient of determinations r^2 says this straight line explained 95.9% of scatter in the data.

From the figure Figure 4.1, value of Beta and Eta were calculated

Eta = α (characteristic thickness) represent the variation of thickness inspect in that year

Beta = β (shape parameter of weibull curve)

For component Weibull plots of single failure modes, the Weibull line slopes, Beta have physical significance[8]:

1) Beta < 1, infant mortality characterized by a declining instantaneous failure rate with time,
2) Beta = 1, chance failures have a constant instantaneous failure rate with time, and
3) Beta > 1, wear out failures characterized by increasing instantaneous failure rate with time.

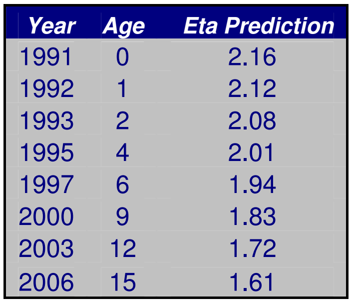
That mean data obtain from EPEMSB plant were increasing failure rate with respect to time ($\beta = 41.15$) Notice that the line slope (Beta) for year 0 was about the same as year 2005 (year 14). Look at the Eta values for the lines where for year 1991(Eta = 2.158) and year 2005 (Eta= 1.632)[20]

$$\begin{aligned}(2.158 - 1.632)/14 &= 0.526/14 \\ &= 0.03757 \text{ mm per year}\end{aligned}$$

for the characteristic wall thickness which says at year 20 to expect the characteristic wall thickness was forecast to be Eta = (2.158 – 0.03757x20) = (2.158 – 0.7514) = 1.4066 mm with line slope (β) is 41.15 (assuming corrosion mechanisms remain unchanged)

Thus, to predict the thickness of tube in a given year, that approach was applied using Year 2005 and Year 0 as based. Table 4.3 shows the value of Eta predicted by using method above.

Table 4.3: Value of Eta (α) predicted



Year	Age	Eta Prediction
1991	0	2.16
1992	1	2.12
1993	2	2.08
1995	4	2.01
1997	6	1.94
2000	9	1.83
2003	12	1.72
2006	15	1.61

For example in Year 2003, (year 12) to calculate the value of Eta;

$$Eta(\alpha_{predicted12}) = Eta(\alpha_{year0}) - \left[\left(\frac{Eta(\alpha_{year0}) - Eta(\alpha_{year14})}{14}\right)x12\right]$$

$$= 2.158 - \left(\frac{2.158 - 1.632}{14}x12\right)$$

$$= 1.72 \text{ mm}$$

Years that predicted in table 4.3 were based on actual data available that provided by the EPEMSB. By predicting thickness at those years, error had been calculated by comparing the predicted data and the actual data.

In order to compare predicted data and actual data, actual data in Table 4.1 also was plotted using Weibull WinSmith software. By obtain the ETA (characteristic thickness) of the tube in actual data; comparison was made by calculate the error.

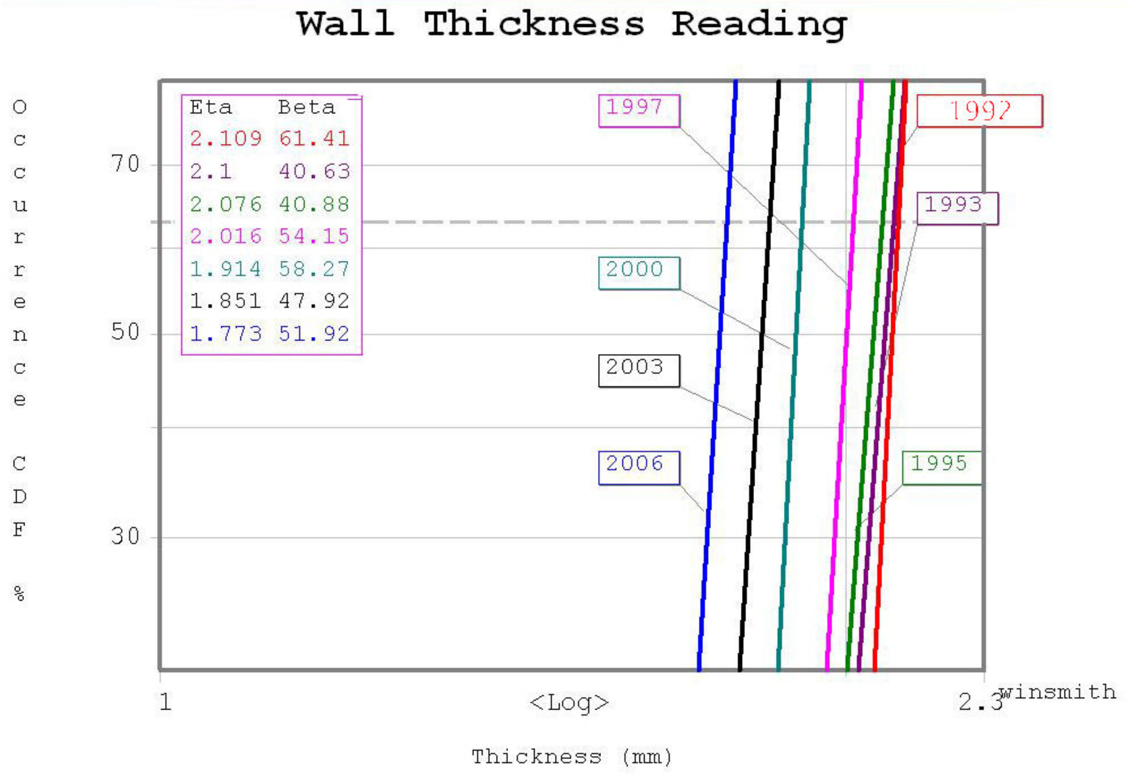


Figure 4.2: Wall thickness reading of Actual Data

From figure 4.2, Beta value was slightly same between others that could conclude that corrosion rate was uniform and Eta value decreased as it shows the characteristic thickness of the tube. Beta value for year 1992 was the highest between all data show that high thinning rate due to plant running at lower performance.

Table 4.4: Error calculated between two set of data

Year	Age	Eta Prediction	Eta Actual	% Error
1991	0	2.16	2.16	0
1992	1	2.12	2.11	0.59
1993	2	2.08	2.10	0.72
1995	4	2.01	2.08	3.10
1997	6	1.94	2.11	7.95
2000	9	1.83	1.94	5.73
2003	12	1.72	1.85	7.12
2006	15	1.61	1.77	9.22

Table 4.4 showing value between predicted thickness using weibull and actual data provided by EPEMSB plant. Percentages of error calculated show that small value of error was obtained and acceptable for studies. Value of error increased when time passes by might be due to not enough data input for actual data.

For further development of the model, large set of data should be provided to obtain accurate value of Weibull parameter (α and β) and to obtain minimal error as Weibull WinSmith software would bias the input value if the number of input not enough to plotted.

A method was described for finding the projected end of life using the characteristic wall thickness values and plotted the characteristic thickness values on a trend chart[9]. The trend chart included the critical wall thickness value determined from the Weibull plot. When the trend line of decreasing characteristic thickness values intersected with the critical minimum wall thickness, the maximum failure risk was reached which resulted in maximum failure. This technique helped predict end of life[21].

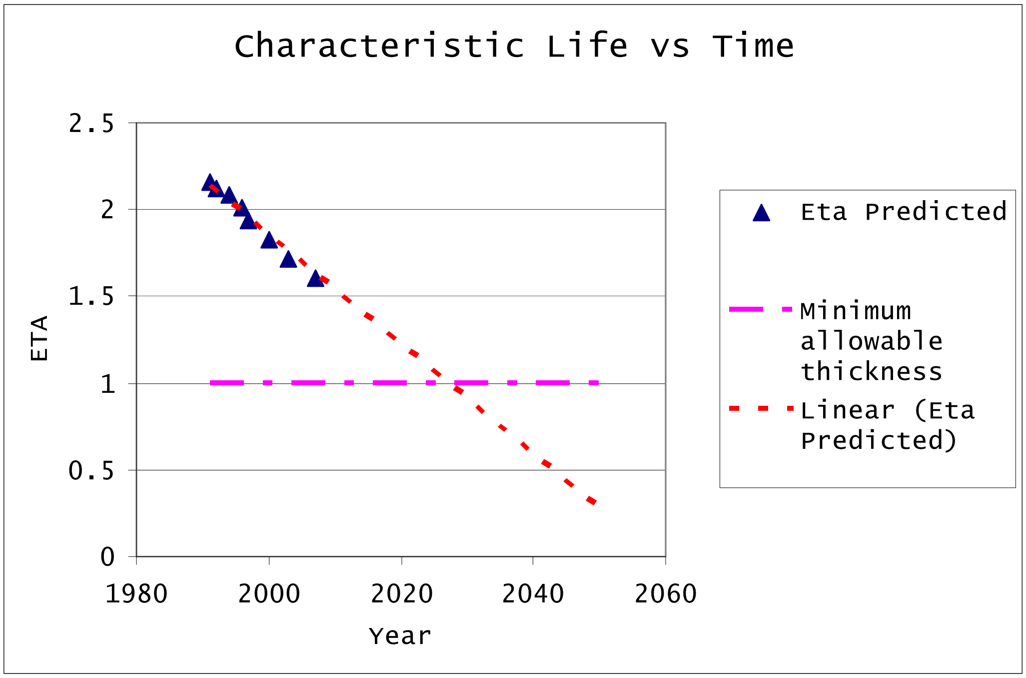


Figure 4.3: Characterictic Life (ETA) vs Time

Characteristic wall thickness values from Figure 4.3 provide a clearer signal for projecting the end of useful life as shown in Figure 4.2. The minimum line was established in Figure 4.3 by using the slope of wall thickness lines and passed the minimum wall thickness line through the maximum allowed failure, the minimum allowed value or Eta as 1 mm. This minimum value for Eta became the lower limit value for Figure 4.2. The regression trend line for Eta values versus time was projected from year 15 through the minimum Eta and they intersected at 2028 years

Error when estimating the end life of the tube heat exchanger as discussed before might be due to not enough data to be plot in the Weibull software. If not enough data input the Weibull, it would self-automate set the deviation of the trend line of the Weibull graph that wiould effect the value of Weibull parameters. In order to obtain accurate value of Weibull parameters, complete data should be represented before carried out studies using this software.

Beta values obtain from actual data fit the “bathtub curve” with little deviation due to data not presented in large set of data.

Table 4.5: Beta value

Year	*Beta*
1991	00.00
1992	61.41
1993	40.63
1995	40.88
1997	54.15
2000	58.27
2003	47.92
2006	51.92

At year one Beta = 61.41 show that increasing in failure rate at starting of the operation. This Beta located in the infant mortality due to lacked of experience handling heat exchanger. And then when year two and four, Beta showed constant value giving information that failure rate was constant. For years after that showing Beta value increase slightly showing that the failure rate was also increasing and moving to end of life wear out.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

The objective of this study to analyze historical data and predict the tube thickness failure was achieved. The time when the thickness had reached minimum allowable thickness has been identified using Eta vs Time graph. Eta value predicted give estimated failure time was about 2028. From the simulation, the time that tube would fail was recognized and maintenance department could plan on preparing for shutdown at appropriate time. Based on the final result, full inspection could be done in year 2026 to measure the tube thickness for shutdown preparation. Simulation using Weibull software could determine the value of Weibull parameter that used in predicting the tube thickness. Eta value of actual data was also varied with time to proof that the model is suitable to use. The existence of past failure data helped in predicting the tube thickness by calculated the error percentage between actual data and predicted data.

5.2 Recommendation

During this project, some findings related to this project have been discovered. Weibull WinSmith required more data to get accurate value for Weibull parameters. For further improvement, more failure data should be taken as sample to modeling failure prediction to get more accurate data. To get these data, inspection on heat exchanger or other equipment should be done annually and record should be made available for future predicting. Based on experience from this project, it is useful to use Weibull in determining or predicting failure.

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