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Reliability Analysis of Some Units of a Liquefied Natural Gas Plant: A Case Study

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ABSTRACT

This research demonstrated the reliability analysis of some units of a Liquified Natural Gas Plant. In the study, unit plants of reboiler, stripper, cooling, compressor, acid dehydrated, heat transfer fluid, expander, and liquefaction were examine in terms of reliability and unreliability for a period of eight years. The results obtained revealed decrease in reliability value of unit plant with increase in period of utilization, whereas unreliability and cost increased with increase in the period of utilization of each unit plant. The research findings show that high cost of unreliability was obtained on heat transfer fluid unit plant, whereas, the most reliable unit plant was the acid dehydrated unit. The study revealed that all the unit plants considered maintained high performance within the period under investigation. The function parameters evaluated in this research work include, mean time between failure, total mean time between failure, failure rate, total failure rate, failure per year, total failure rate, failure per year, total failure per year, corrective time per failure, total corrective time per year, time lost per year, total lost time per year, time lost from unreliability, gross margin, total gross margin, and breakdown maintenance cost for all the unit plant. The result obtained from the research work revealed that the reliability value is within the range of 36.84 to 81.90% whereas unreliability value is within the range of 18.10 to 69.88% for the various plant units sampled. The failure rate obtained revealed 4.57x10 for reboiler, 6.00x10 for stripper, 1.14x10 for cooling, 2.28x10 for compressor, 7.13x10 for Acid Dehydration, 1.30x10 for Heat Transfer, 6.85x10 for Expander and 4.57x10 for Liquefaction respectively. Finally, the study is found useful in monitoring, and predicting some units of liquefied natural gas plant in term of failure.

Key words: Reliability, analysis, units, liquefied natural gas plant, a case study

1. INTRODUCTION

The present research is based on the concept of reliability analysis on some units of liquefied natural gas (LNG) operating system for optimum production with low operational cost as well as reliability, unreliability and availability of the different unit components. Studies on the reliability concepts have been carried out by various research groups in chemical, mechanical, electrical, civil processes etc. [1] The significance of the concept is to establish and identify areas within the plant that are prone to abnormal influence on the system as well as area of worst case in terms of disasters [2].

The LNG process plant is a highly complex plant with diverse equipment control schemes and operating procedures [3]. When process failure occurs, it influences the man-hour loss, production profit, cost of unreliability etc [4]. If the system failure leads to leakage for a chemical section of the LNG plant, there is tendency of releasing major hazardous constituents to the environment, and the process can lead to explosion, fire outbreak as well as release of toxic constituents [5].

The review to understand the LNG process operation mechanism to reduce cost, increase profit, reduce risk and improve production is necessary on this research work [6[. Review on the failure cases will be identified, the man-hours losses, maintenance cost, mean time between failure, failure rate, reliability, and unreliability will be discussed and lessons from them will help to improve the operational system of LNG plant [7]. This research work will be used in developing measures for improvement in terms of prevention as well as mitigating strategies for controlling the LNG process plant failure. Leakage of hydrocarbon in LNG plant will influence the environment greatly since its constituent is highly flammable as well as very toxic in composition [8-10].

Research was conducted to analyze the risks associated with failure, which revealed that major cause was explosion and fire outbreak resulting to casualties such as environmental damage and loss of properties. In their research, they further outlined the significance of prevention and mitigation [11]. Energy today is the driving force of industry for sustainable development as well as social economic development of any given nation. It is revealed that for the recent years energy consumption has increased rapidly with the aid of natural gas [12]. It is also observed that as production increases, failures are also being recorded in the LNG plant when machines are not properly serviced or maintained. Most of the plant reactors are subjected to high energy utilization, high pressure system prone to flammable, toxic and hazardous characteristics; there is tendency of leakage, rupture which leads to corrosion of the reactor or plant. The corrosion incident in the plant can cause malfunction of the plant [13]. Leakage of LNG plant may result in serious accidents that can lead to man hour loss, production down time, profit reduction on production, increase in risk, fire outbreak, and loss in terms of economic value, heavy casualties, exposition and reputational issues [14]. The application of the reliability techniques and tools concepts can be established to enable the researcher outline the significance of reliability, unreliability of LNG plant. Reliability of the event was determined by diagnosing the degree of failures of unit component, which will be used in the formulation and determination of functional parameters in the various LNG plant units. The research work will propose the best method for improving the performance of some units of the LNG plants and to reduce leakages. It is observed that the regular failure experienced in the plants is low pressure due to leakage along the flow lines [15]. The potential risk factors of LNG plant in terms of leakage will be identified and finding the possible control measures and risk management of the plant to reduce man hour loss, reduction in production, reduce risk, increased economic value of the plant operation will be applied in the work.

2. MATERIALS AND METHODS

The following methods were adopted in carrying out the research work on reliability analysis of some units of liquefied natural gas plants such as;

a) Identification of component failures
b) The cause of the component failure
c) Company policies in terms of maintainability
d) Operational conditions
e) Identification of other important constrains as discussed in this research work. The mathematical model developed on this research work was based on these factors highlighted above.

Reliability Approach Adopted

The following concepts were used in handling the analysis of Liquefied Natural Gas (LNG) component unit using reliability approach. The steps involved in the reliability approach adopted are as stated below:

a) Reliable information was obtained from the NLNG which is similar to failures experienced in other plants.
b) Data for formulation was obtained from NLNG, which was related to various failures as obtained from different unit plant failures.
c) Report from the maintenance teams reveals the various root cause of failure of each unit component.
d) Oral interview was conducted to determine the root cause of the various unit plant failures.
e) The policy in term of maintainability was examine to determine the man hour lost as a result of delay before carrying out maintenance on failed plant unit.
f) Reliability concept of Monte Carlo techniques was applied in this research work.

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g) Application of life cycle cost analysis was considered in the research work.
h) Improvement of the study by considering the application of statistical techniques.
i) Recommendation of the best practice to improve maintainability, reliability, availability, unreliability following all full understanding of the root work leading to unit plant failure.

Reliability Models

The study was carried out by developing a mathematical model considering the number of failure of each unit plant and for 5 years period of studies. The following parameters was considered such as Mean Time Between Failure (MTBF)[1], Total Mean Time Between Failure (TMTBF)[1], Mean Time to Failure (MTTF)[1], Mean Time to Repair (MTTR)[1], Mean Corrective Maintenance Time (MCMT)[1], Mean Time Between Maintenance (MTBM)[1], Mean Active Maintenance Time (MAMT)[1], Failure Rate, Total Failure Rate, Failure per year, total failure per year, total lost time per year, time lost from unreliability, cross margin, total gross margin, scrap disposal cost per incident, breakdown maintenance cost, total breakdown maintenance cost, total lost cost availability, reliability and unreliability.

Evaluation of Mean Time between Failures (E^1_{MTBF})

The evaluation of mean time between failures is denoted by E^1_{TMBF} therefore

$$E^1{}_{MTBF} = \frac{S^1}{N^1} \tag{1}$$

Where S^1 is the study interval in years and N^1 is the number of failures over the year under investigation.

Evaluation of Total Mean Time between Failures (E^1_{TMTBF})

The evaluation of total mean time between failures is denoted by E^1_{TMBF} and the mathematical expression is given as

$$E^1{}_{TMTBF} = \left(\frac{1}{E^1{}_{MTBF}}\right) + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Tunit\,B} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Tunit\,C} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Tunit\,D} x\,(AHPY) \tag{2}$$

Where AHPY represent annual hours per year

The equation (2) can be found useful in the expression of the evaluation of total failures per year (ETFPY)[1] which is denoted by (ET)[1] Therefore the evaluation of total failures per year (ETFPY) for the plant unit failure of the NLNG plant can be expressed as

$$(ET)^1 = \frac{Evaluation of\ Annual\ Hour\ per\,Year}{Evaluation of\ Total\ Failures\,per\,Year} = (ETFPY)^1$$

$$\frac{(EOAHPY)^1}{(EOTFPY)^1} \tag{3}$$

Evaluation of Failure Rate (EOFR)[1]

The evaluation of the failure rate of the NLNG plant studied can be determined using the mathematical formula stated below

$$(EOFR)^1 = \frac{1}{E^1{}_{MTBF}} = \frac{1}{S^1/N^1} = \frac{N^1}{S^1} \tag{4}$$

For various units of the plant we have

$$(EOFR)^1 = \left(\frac{1}{E^1{}_{MTBF}}\right) = \left(\frac{N^1}{S^1}\right)_{Tunit} \tag{5}$$

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Evaluation of Total Failure Rate (EOTFR)[1]

The evaluation of the total failure rate of the units can be expressed mathematical as:

$$(EOFR)^1 = (EOFR)^1{}_{Tunit\,A} + (EOFR)^1{}_{Tunit\,B} + (EOFR)^1{}_{Tunit\,C} + (EOFR)^1{}_{Tunit\,D} \quad (6)$$

The Model for Train Unit Plant Functional Parameters Failure

There is need to evaluate the lost from unreliability per year of the train unit plant failure on the various groups of the liquefied natural gas plant.

Evaluation of Failures per Year (EOFPY)[1]

The mathematical expression for the evaluation of failures per year of each train unit plant can be expressed as;

$(EOFPY)^1$ = (evaluation of failure rate for each unit plant) x (annual hour per year) (7)

Therefore

$$(EOFPY)^1 = \left(\frac{N^1}{S^1}\right)(EOAHPY)^1 \quad (8)$$

$$(EOFPY)^1 = (EOFR)^1 \ (EOAHP) \quad (9)$$

$$(EOFPY)^1 = \left(\frac{1}{E_{MTBF}}\right)(EOAHPY) \quad (10)$$

Evaluation of Total Failure Per Year (EOTFPY)[1]

The mathematical concept for the evaluation of total failure per year (E)TFPY)[1] can be expressed as:

$$(EOTFPY)^1 = \sum (EOFPY)^1{}_{unitA} + \sum (EOFPY)^1{}_{unitB} + \sum (EOFPY)^1{}_{unitC} + \sum (EOFPY)^1{}_{unitD} \quad (11)$$

where $(EOTFPY)^1$ is evaluation of total failure per year, (EOTFPY) is Summation of evaluation of total failure per year for components of group A.

Evaluation of Total Corrective Time Per Failure (EOTCTPF)[1]

The mathematical expression for the evaluation of total corrective time per failure (EOTCTPF) of the NLNG unit plant failures is given as

$$(EOCTF)^1 \ \frac{\begin{array}{c}(EOCTPF)^1{}_{unitA}\ (EOFPY)^1{}_{unitA} + (EOCTF)^1{}_{unitB}\ (EOCTF)^1{}_{unitB} + \\ (EOCTF)^1{}_{unitC}\ (EOCTF)^1{}_{unitC} + (EOCTF)^1{}_{unitD}\ (EOCTF)^1{}_{unitD}\end{array}}{(EOTFPY)^1} \quad (12)$$

$$(EOTCTPF)^1 = \frac{\left(\begin{array}{l}Evaluation of\ corrective time\ per\ failure of\ each unit\\ plant\ x\ evaluation of\ \ per\ year of\ each unit\ plant\end{array}\right)}{(Evaluation of\ total\ failure per\ year)} \quad (13)$$

Evaluation of Lost Time Per Year (EOLTPY)[1]

In the evaluation of lost time per year $(EOLTPY)^1$ of each unit plant in terms of mathematical concept can be written as

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$$(EOLTPY)1 = \begin{pmatrix} Evaluation of \ failures of \\ each unit \ plant \end{pmatrix} x \begin{pmatrix} Evaluation of \ correctie time \\ fialure \ for each unit \ plant \end{pmatrix} \quad (14)$$

Evaluation of Total Lost Time Per Year (EOTLTPY)

The concept of evaluation of total lost time per year in the NLNG unit plant can be determined using the mathematical expression of the summation of each unit plant of evaluation of lost time per year as shown below in equation (3.15)

$$(EOTLTPY)^1 = (EOLTPY)^1{}_{unit\,A} + (EOLTPY)^1{}_{unit\,B} + (EOLTPY)^1{}_{unit\,C} + (EOLTPY)^1{}_{unit\,D} \quad (15)$$

Evaluation of Time Lost from Unreliability

a. Gross Margin Evaluation (GME)¹

The gross margin evaluation $(GME)^1$ of each unit in the NLNG unit plant was determined using the mathematical expression stated below

$$(GME^1) = \begin{pmatrix} Evaluation of \ lost \ time \\ per \ year \end{pmatrix} x \begin{pmatrix} Evaluation of \ gross \\ margin \ x \ hour \end{pmatrix} \quad (16)$$

Hence

$(GME)^1 = (EOLTPY)^1$(evaluation of lost gross margin of \$ x per hour) (17)

b. Evaluation of Total Gross Margin (EOTGM)¹

The mathematical evaluation for the total gross margin of the NLNG unit plant is calculated using the mathematical expression stated below

$$(EOTGM)^1 = \left[(EOLTPY)^1 (EOLGM \ at \$ \ x \ per \ hours)\right]_{unitA} + \left[(EOLTPY)^1 (EOLGM \ at \$ \ per \ hours)\right]_{unitB} + (EOLTPY)^1 (EOLGM \ at \$ \ per \ hour)\ \Big]_{unitC} + (EOLTPY)^1 (EOLGM \ at \$ \ per \ hour)\ \Big]_{unitD} \quad (18)$$

c. Evaluation of Scrap Disposal Cost Per Incident (EOSDCPI)¹

In the evaluation scrap disposal cost per incident $(EOSDCPI)^1$, the mathematical approach stated below can be found useful, thus

$$(EOSDCPI)^1 = \begin{bmatrix} Evaluation of \ failure \\ per \ year \ (EOFPY)^1 \\ for each unit \ plant \end{bmatrix} \begin{bmatrix} Evaluation of \ Scrap \\ disposal \ cost \ of \ \$ \ per \\ incident \end{bmatrix} \quad (19)$$

d. Evaluation of Breakdown Maintenance Cost of Unreliability (EOBMCOU)¹

It is necessary to evaluate the breakdown maintenance cost of unreliability using the mathematical expression stated below

$$(EOBMCOU)^1 = \frac{[Evaluation of \ gross \ margin][evaluation of \ scrap \ disposal \ cost]}{[Evaluation of \ total \ breakdown \ maintenance \ cost]} \quad (20)$$

e. Evaluation of Total Breakdown Maintenance Cost (EOTBMC)¹ of Unreliability

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The evaluation of total breakdown maintenance cost (EOTBMC)[1] of the NLNG unit plant was evaluated using the mathematical model expression as shown below

$$\left(EOTBMC\right)^{1} = \left(EOBMC\right)^{1}{}_{unitA} + \left(EOBMC\right)^{1}{}_{unitB} \left(EOBMC\right)^{1}{}_{unitC} + \left(EOBMC\right)^{1}{}_{unitD} \qquad (21)$$

f. Evaluation of Total Lost Cost (EOTLC)[1]

The evaluation of the total lost cost of the NLNG unit plant investigated can be resolved using the mathematical expression stated below

$$\left(EOTLC\right)^{1}{}_{TunitA} = \left(EOGMC\right)^{1}{}_{TunitA} + \left(EOGMC\right)^{1}{}_{TunitB} + \left(EOGMC\right)^{1}{}_{TunitC} + \left(EOGMC\right)^{1}{}_{TunitD} \qquad (22)$$

Where T represent the various train in liquefied Natural gas Plant operation

Process Plant Determination Variables, Reliability, Unreliability and Availability

Evaluation of Reliability Model of liquefied Natural Gas Plant Process

The evaluation of the reliability of liquefied natural gas plant can be achieved by recalling the mathematical equation or formula as stated below

$$R^{1} = \left(\frac{1}{M_{TBF}}\right)t \qquad (23)$$

Considering the various trains in the LNG plant in this case, the reliability can be evaluated by considering the summation of each failure of the train unit. Therefore, equation (23) can be written as

$$R^{1} = \left(\frac{1}{M_{TBF}}\right)_{TunitA} + \left(\frac{1}{M_{TBF}}\right)_{TunitB} + \left(\frac{1}{M_{TBF}}\right)_{TunitC} + \left(\frac{1}{M_{TBF}}\right)_{TunitD} \qquad (24)$$

Evaluation of Unreliability Model of Liquefied Natural gas Plant Process

In the evaluation of unreliability of the liquefied natural gas plant process can be estimated by recalling the mathematical expression stated below

$$U_{R} = 1 - e^{-\left(\frac{1}{M_{TBF}}\right)t} \qquad (25)$$

Where U^{R} represent unreliability, t is time

Evaluation of Availability Model of Liquefied Natural Gas Plant Process

The availability model for the evaluation of the liquefied natural gas plant process can be achieved by recalling the mathematical expression shown below

$$A^{V} = \frac{E^{1}{}_{MTBF} - EOLTPY}{E^{1}{}_{MTBF}} \qquad (26)$$

Identification of Different Plant Unit Train 1-6 and Others

The liquefied natural gas process plant is made up of various unit train, normal 1-6 having the following units: Reboiler unit, Stripper unit, Cooling unit, Compressor unit, Acid dehydration unit, Heat transfer fluid unit, Expander unit and Liquefication unit. The various train units are important components or session in the liquefied natural gas plant.

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Sampling

Oral interview was carried out to ascertain the nature in terms of a built plant of the Nigerian Liquefied Natural Gas Plant as well as various literatures was considered. The causes of the failures were not revealed and data was gathered by random sampling within the vicinity. Names of those interviewed were not taken for security reasons and the data obtained from the sampling covers the period of 7 years experience of event. The rough information gathered was formulated into mathematical models, tool and technique to enable the research proceed to the next level.

Identification of Root Cause (IORC)

In this research work, it was difficult to have access to the Nigerian liquefied natural gas plant located at Bonny Island, on that issues concerning root cause was not identified but the researcher adopted the various root cause analysis from various literatures as proposed by greater researchers.

Description of the Event for Data Collection

The event of data collection covers 1st May, 2011 to 31st May, 2018 in terms of plant unit report; but the data information of various failures covers 2011 to 2018. Because of random sampling on this research average value were considered to represent the whole data for each train unit failure for 7 years period. The data collected is inclusive of shutdown periods for plant.

Mean Team between Failure (E^1MTBF) Model

The evaluation of mean time between failures is denoted by E^1MTBF

$$E^1MTBF = \frac{S^1}{N^1} = S^1 \quad (27)$$

Where S^1 is the study interval in years and N^1 is the number of failures over the year under investigation.

Total Mean Time between Failures (TMTBF) Model

The evaluation of Total Mean Time between failures is denoted by E^1_{TMTBF} and the mathematical expression is given as

$$\left(E^1{}_{TMTBF}\right) = \left(\frac{1}{E^1{}_{MTBF}}\right)_{Reb} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Sti} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Con} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Com}$$
$$+\left(\frac{1}{E^1{}_{MTBF}}\right)_{Aci} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Hea} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Exp} + \left(\frac{1}{E^1{}_{MTBF}}\right)_{Liq} \quad (28)$$
$$x \ \left(Annual\ hours\ per\ year\right)$$

Failure Rate $(EOFR)^1$ Model

The evaluation of failures rate of the NLNG plant studied can be determined using the mathematical formula stated below

$$\left((EOFR)^1\right) = \frac{1}{E^1{}_{MTBF}} = \frac{1}{\frac{S^1}{N^1}} = \frac{N^1}{S^1} \quad (30)$$

For various units of the plant we have

$$(EOFR)^1 = \left(\frac{1}{E^1{}_{MTBF}}\right) = \left(\frac{N^1}{S^1}\right)_{Tunit} \quad (31)$$

Total Failure Rate $(EOTFR)^1$ Model

The evaluation of total failure rate of the units can be expressed mathematical as

$$(EOTFR)^1 = (EOFR)^1{}_{Reb} + (EOFR)^1{}_{Str} + (EOFR)^1{}_{Con} + (EOFR)^1{}_{Com} + (EOFR)^1{}_{Aci}$$
$$+(EOFR)^1{}_{Hea} + (EOFR)^1{}_{Exp} + (EOFR)^1{}_{Liq} \quad (32)$$

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Failures Per Year (EOFPY)¹ Model

The mathematical expression for the evaluation of failures per years of each unit of plant can be expressed as

(EOFPY)¹ = (Evaluation of failure rate for each unit plant x (Annual hours hour year) (32a)

Therefore

$$(EOFPy)^1 = \left(\frac{N_1}{S_1}\right)(EOAHPy)^1 \quad (33)$$

$$(EOFPy)^1 = (EOFR)^1 \, (EOAHPy)^1 \quad (34)$$

Total Failure Per Year (EOTFPY)¹ Model

The mathematical concept for the evaluation of total failure per year (EOTFPY) can be expressed as

$$(EOTFPy)^1 = \sum(EOFPy)_{Reb} + \sum(EOFPy) + \sum(EOFPy)_{Coo} + \sum(EOFPy)_{Com} + \sum(EOFPy)_{Aci} + \sum(EOFPy)_{Hea} + \sum(EOFPy)_{Liq} \quad (35)$$

Total Corrective Time per Failure (EOTCTPF)¹ Model

The mathematical expression for the evaluation of total corrective time per failure (EOTCTPF) of the NLNG unit plant failures is given as

$$(EOCTF) = (EOCTPF)^1{}_{Reb} \; x(EOFPy)_{Reb} + (EOCTFy)_{Str} \; x(EOFPy)_{Str} + (EOCTPF)_{Coo} \, x(EOFPy)_{Coo} + (EOCTF)_{Com} \; x(EOFPy)_{Com} + (EOCTPF)_{Aci} \; x(EOFPy)_{Aci} + (EOCTPF)_{Hea} \; x(EOFPy)_{Hea} + (EOCTPF)_{Exp} \; x(EOFPy)_{Exp} + (EOCTPF)_{Liq} \; x(EOFPy)_{Liq} \quad (36)$$

$$(EOTCTPF)^1 = \frac{\left(\begin{array}{l} Evaluation of\ corrective time\ per\ failure \\ of\ each unit\ plant\, x\ Evaluation per\ year \\ of\ each\ plantnit \end{array}\right)}{Evaluation of\ total\ failure per\ year} \quad (37)$$

Lost Time Per Year (EOLTPY)¹ Model

In the evaluation of lost time per year (EOLTPY)¹ of each unit plant in terms of mathematical concept can be written as

$$(EOLTPy)^1 = \left(\begin{array}{l} Evaluation of\ \ failure \\ of\ each\ unit\ plant \end{array}\right) x \left(\begin{array}{l} Evaluation of\ corrective time\ failure \\ for each unit\ plant \end{array}\right) \quad (38)$$

To determine the evaluation of lost time per year of component futures can be expressed as

$$(EOLTPy)^1 = \left(\begin{array}{l} Evaluation of\ \ failure \\ of\ each\ unit\ plant \end{array}\right) x \left(\begin{array}{l} Evaluation of\ corrective time\ failure \\ for each unit\ plant \end{array}\right) \quad (39)$$

Total Lost Time per Year (EOTLTPY) Model

The concept of evaluation of total lost time per year in the NLNG unit plant can be determined using the mathematical expression of the summation of each unit plant of evaluation of lost time per year as shown below

$$(EOTLTPy)^1 = (EOLTPy)^1{}_{Reb} + (EOLTPy)^1{}_{Str} + (EOLTPy)^1{}_{Coo} + (EOLTPy)^1{}_{Com} + (EOLTPy)^1{}_{Aci} + (EOLTPy)^1{}_{Hea} + (EOLTPy)^1{}_{Exp} + (EOLTPy)^1{}_{Liq} \quad (40)$$

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Time Lost from Unreliability Model

Gross Margin Evaluation (GME)[1]

The gross margin evaluation (MGME)[1] of each unit in the NLNG unit plant was determined using the mathematical expression stated below

$$(GME)^1 = \begin{pmatrix} Evaluation of \ lost time \\ per \ year \end{pmatrix} x \begin{pmatrix} Evaluation of \ gross margin \\ in hour \end{pmatrix} \quad (41)$$

Total Gross Margin (EOTGM) Model

The mathematical evaluation of the total gross margin of the NLNG unit plant is calculated using the mathematical expression stated below

$$(EOTGM)_T = (GME)_{\mathrm{Re}b} + (GME)_{Str} + (GME)_{Coo} + (GME)_{Com} + (GME)_{Aci} + (GME)_{Hea} \ (GME)_{Exp} + (GME)_{Liq} \quad (42)$$

Time Lost from Unreliability Model

In the evaluation of scrap disposal cost per incident (EOSDCPI), the mathematical expression is stated below

$$(ECOSDPCI) = \begin{pmatrix} Evaluation of \ failure per \ year \\ (EOFPy)^1 \ for each unit \ plant \end{pmatrix} \begin{pmatrix} Evaluation of \ scrap disposal \\ \mathrm{cost}\$ \ per incident \end{pmatrix} \quad (43)$$

Breakdown Maintenance Cost of Unreliability (EOBMCOU)[1] Model

It is necessary to evaluate the breakdown maintenance cost of unreliability using the mathematical expression stated below

$$\frac{(EOBMCOU)^1 = (Evaluation of \ gross margin)(Evaluation of \ scrap disposal \mathrm{cost})}{(Evaluation of \ total breakdown maintenance cost)} \quad (44)$$

Total Breakdown Maintenance Cost (EOTBMC) of Unreliability Model

The evaluation of total breakdown maintenance cost (EOTBMC)[1] of the NLNG unit plant is calculated using the mathematical model expression given below

$$(EOTBMC)^1 = (EOBMC)^1{}_{\mathrm{Re}b} + (EOBMC)^1{}_{Str} + (EOBMC)^1{}_{Coo} + (EOBMC)^1{}_{Com} + (EOBMC)^1{}_{Hea} + (EOBMC)^1{}_{Aci} + (EOBMC)^1{}_{Exp} + (EOBMC)^1{}_{Liq} \quad (45)$$

Evaluation of Total Lost Cost (EOTLC)[1]

The evaluation of the total lost cost of the NLNG unit plant investigated can be resolved using the mathematical expression stated below

$$(EOTLC)^1 = (EOGMC)^1{}_{\mathrm{Re}b} + (EOGMC)^1{}_{Str} + (EOGMC)^1{}_{Coo} + (EOGMC)^1{}_{Com} + (EOGMC)^1{}_{Hea} + (EOGMC)^1{}_{Aci} + (EOGMC)^1{}_{Exp} + (EOGMC)^1{}_{Liq} \quad (46)$$

Process Plant Determination Variables, Reliability, Unreliability and Availability

Reliability Model of Liquefied Natural Gas Plant Process

The evaluation of the reliability of liquefied natural gas plant can be achieved by recalling the mathematical equation on formula S[1] stated below

$$R^1 = \left(\frac{1}{M_{TBF}}\right)^t \quad (47)$$

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Considering the various trains in the NLNG plant in this case, the reliability can be evaluated by considering the summation of each failure of the train unit. Therefore, equation (22) can be written as

$$R^1 = \left(\frac{1}{M_{TBF}}\right)_{Reb} + \left(\frac{1}{M_{TBF}}\right)_{Str} + \left(\frac{1}{M_{TBF}}\right)_{Coo} + \left(\frac{1}{M_{TBF}}\right)_{Com} + \left(\frac{1}{M_{TBF}}\right)_{Aci} + \left(\frac{1}{M_{TBF}}\right)_{Hea} + \left(\frac{1}{M_{TBF}}\right)_{Exp} + \left(\frac{1}{M_{TBF}}\right)_{Liq} \tag{48}$$

Unreliability Model of Liquefied Natural gas Plant Process

In the evaluation of Unreliability of the liquefied natural gas plant process can be estimated by recalling the mathematical expression below

$$U_R = 1 - e^{-\left(\frac{1}{M_{TBF}}\right)t} \tag{49}$$

3. RESULTS AND DISCUSSION

Reliability and Unreliability of Reboiler Units

The result of reliability and unreliability of the reboiler unit was examined on the influence of time as presented in Figure 1.

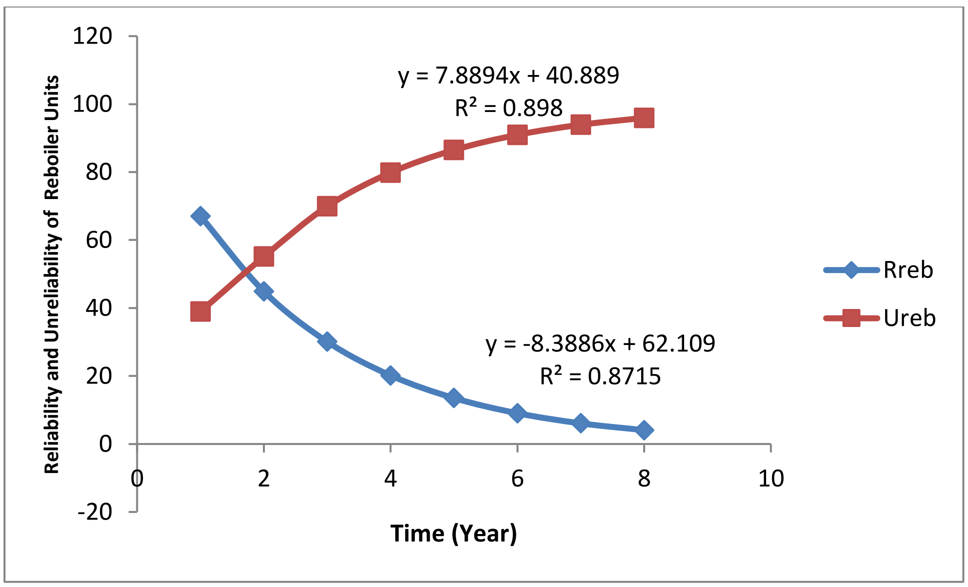

Figure 1: Graph of Reliability and Unreliability of Reboiler Units versus Time

The Figure 1 showcases the relationship between reliability and unreliability of the reboiler unit upon the influence of time on a liquefied natural gas plant operation. Increase in unreliability was observed with increase on reliability upon the influence of time due to continuous failure experienced on the reboiler unit components. The variation in the reliability and unreliability of the reboiler unit components on the liquefied natural gas plant can be attributed to the variation to the period of exposure, component utilization hour, quantity of product used, manpower installation approaches applied during maintenance, repair technique etc. The equation of the curve was established y = 7.8894x + 40,889 with the square root of the best fit as $R^2 = 0.898$ for unreliability of the reboiler component. The equation of the curve obtained revealed that the slope and the intercept as 40.889 and 7.8894 for the concept of unreliability for the reliability case, the equation of the curve is give as y = 8.3886x + 62.109 with the square root of the best fit given as $R^2 = 0.8715$ as well as the value of slope and intercept given as 62.109 and -8.3586 as presented in Figure 1.

Reliability and Unreliability of Stripper Unit

The result of reliability and unreliability of the Stripper Unit was examined on the influence of time as presented in Figure 2.

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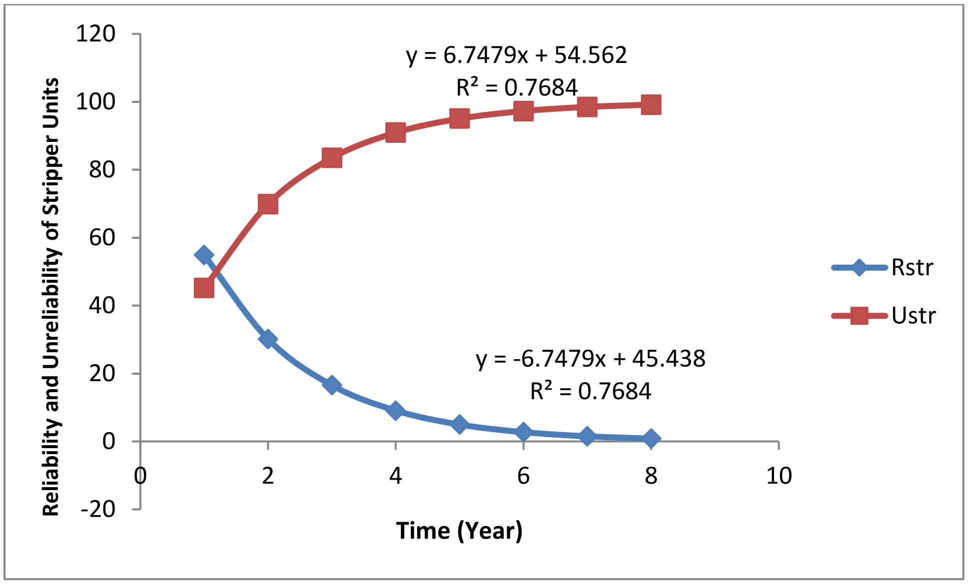

Figure 2: Graph of Reliability and Unreliability of Stripper Unit versus Time

The graph of reliability and unreliability of stripper unit of the liquefied natural gas plant upon the influence of time is shown in Figure 2. It is observed that an increase in unreliability and decrease on reliability of the stripper unit occurs as a result of content failure of the unit components. The failures can be attributed ageing nature of the facilities and component unit on the striper plant. The variation in the unreliability and reliability of the stripper unit can be attributed to the variation in time, aging of the plant unit and other environmental factors. The equation of the curve established is given as $y = 6.7479x + 54.562$ with the square root of the best fit given as $R^2 = 0.7684$ for unreliability of the stripper unit whereas for the reliability of the stripper unit, the equation of the curve is given as $y = 6.7479x + 45.438$ with the square root of $R^2 = 0.7684$ as shown in Figure 2. The behaviour in terms of reliability and unreliability of the stripper unit of the liquefied natural gas plant unit considered can be view on constant failure of various components that made up the stripper unit resulting to the aging characteristics of the unit component materials used in installation and repair when failure occurs.

Reliability and Unreliability of Cooling Unit

The result of reliability and unreliability of the Cooling Unit was examined on the influence of time as presented in Figure 3.

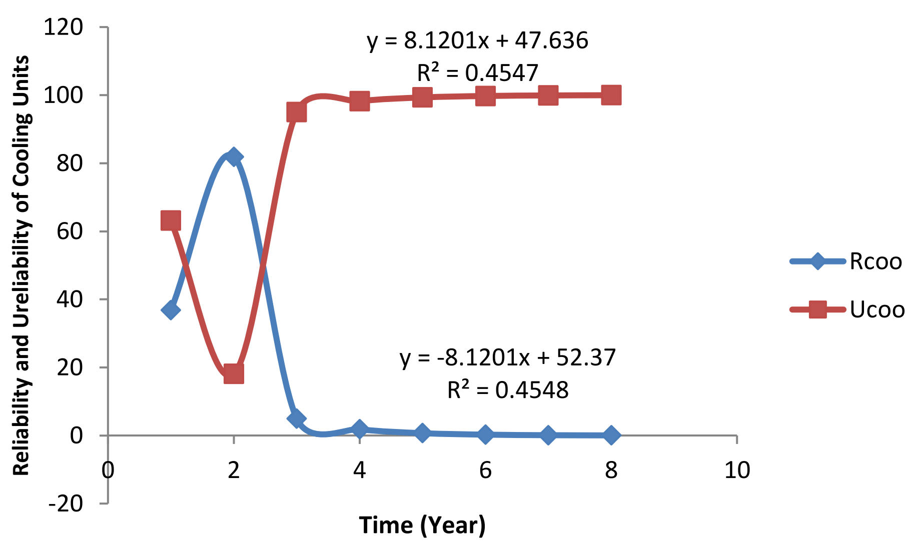

Figure 3: Graph of Reliability and Unreliability of Cooling Unit versus Time

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From Figure 3 it is seen that the relationship between reliability and unreliability upon the influence of time on the cooling unit of the liquefied natural gas plant was studies. The results obtained revealed initial decrease in unreliability before sudden increase was observed and a constant value as well as obtained. The equation of the curve is given as y = 8.120x + 47.636 with the square root of the best fit given as $R^2 = 0.4547$. Similarly, considering the state of the reliability of the cooling unit, it is observed at an increase was observed for a period of years before sudden decrease was experienced until a constant value of reliability was achieved as presented in Figure 3. The equation of the curve of reliability of the cooling unit is given a y = 81.201x + 52.37 with the square root of the best fit for the cooling unit is given as $R^2 = 0.4548$. The variation in the reliability and unreliability value of the various components used in the repair or maintainability of the cooling unit can be attributed to various factors such as production time, installation fault operational hour of the cooling unit system, environmental factors.

Reliability and Unreliability of Compressor Unit

The result of reliability and unreliability of the Compressor Unit was examined on the influence of time as presented in Figure 4.

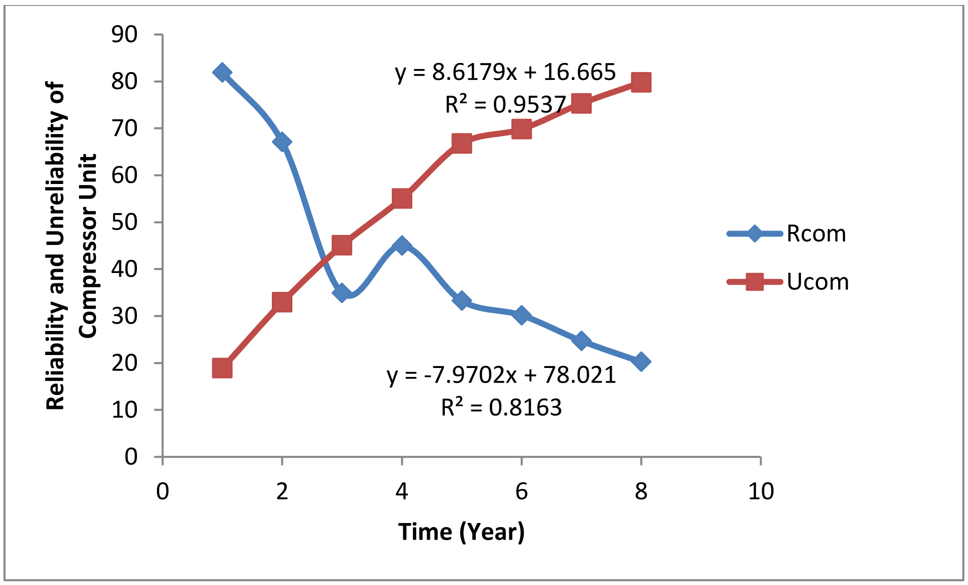

Figure 4: Graph of Reliability and Unreliability of Compressor Unit versus Time

The behaviour of the reliability and unreliability of compressor unit of liquefied natural gas plant is shown in Figure 4. The results obtained revealed increase in unreliability of the cooling unit components upon the influence of periods of exposure and utilization by the plant unit as well as the failure can be attributed to the aging of components installation error, quality of component material. The equation of the curve for cooling unit of the liquefied natural gas plant is given as y = 8.6179x + 16.665 with square root of best fit for the cooling unit is given as R2 = 0.9537 for the cooling unit of unreliability for reliability the equation of the curve for the cooling unit is given as y = 7.9702x + 78.021 with the square root of the best fit for the cooling unit given as R2 = 0.8163. The result presented in Figure 4 demonstrates decrease in reliability with increase in time. The decrease in reliability can be attributed to lump component sampled as well as constant failure of these components in the cooling unit. Other important factors to be considered included the aging of component materials in the cooling unit, the manner and nature of maintenance, the type of materials used during repair and quality of the manpower used in terms of experienced.

Reliability and Unreliability of Acid Dehydrated Unit

The result of reliability and unreliability of the Acid Dehydrated Unit was examined on the influence of time as presented in Figure 5.

The characteristics of the behaviour of the acid dehydrated unit of the liquefied natural gas plant was examined in terms of reliability and unreliability upon the influence of time as presented in Figure 5. Result obtained demonstrates an increase in unreliability of the component materials on the acid dehydrated unit in terms of failure characteristics upon the influence of period of utilization and exposure of the various components for operational usage. The variation in the unreliability value of the acid dehydrated unit of liquefied natural gas plant can be attributed to variation on time of operational usage and other factors such as quality of materials used during repairs, experience of manpower used for the service of repair, identification of the root cause of

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the failure before replacement of the faulty items in the acid dehydrated unit plant. The equation of the curve obtained for the acid dehydrated unit plant of the liquefied natural gas plant is given as y = 5.2337x + 66.26 with the square root of the best fit for the acid dehydrate unit is given as R^2 = 0.6764 for unreliability. For reliability the equation of the curve is given as y = 5.2337x + 33.74 with the square root of the best fit for the acid dehydrated unit is given as R^2 = 0.6764 as presented in Figure 5. The variation in the reliability valve of the acid dehydrate unit plant components can be attributed to variation in the constant failure of the various utilization by the plant, aging of the materials used for repair, manpower experience etc.

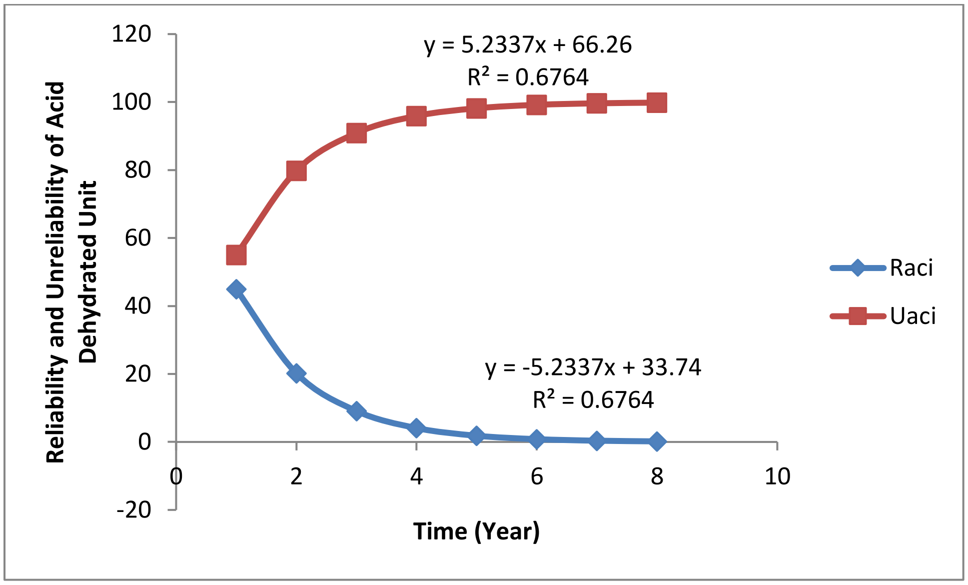

Figure 5: Graph of Reliability and Unreliability of Acid Dehydrated Unit versus Time

Reliability and Unreliability of Heat Transfer Fluid Unit

The result of reliability and unreliability of the Heat Transfer Fluid Unit was examined on the influence of time as presented in Figure 6.

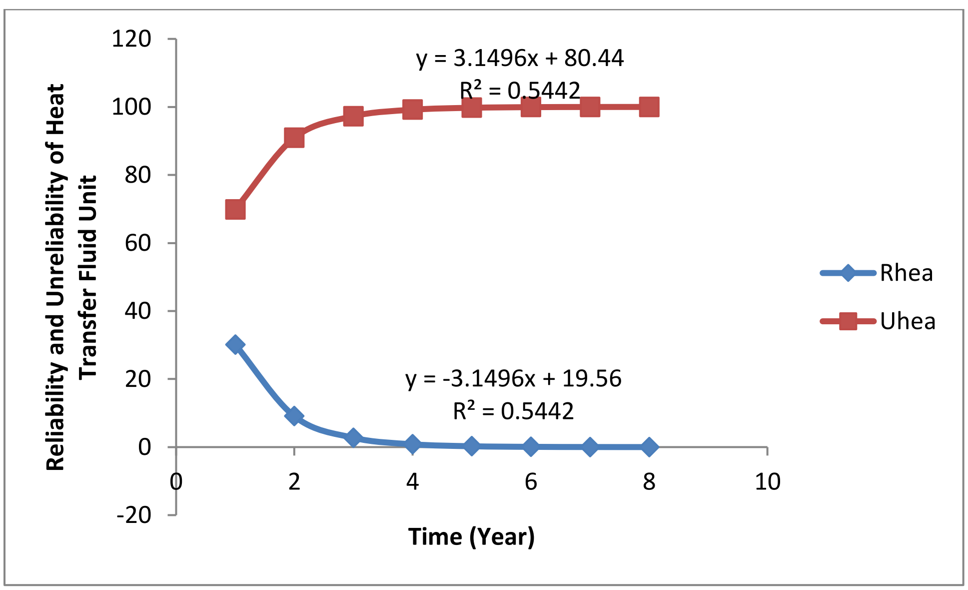

Figure 6: Graph of Reliability and Unreliability of Heat Transfer Fluid Unit versus Time

The heat transfer fluid unit of the liquefied natural gas plant was studied in terms of reliability and unreliability and results obtained is shown in Figure 6 upon the influence of time. The results obtained for unreliability revealed an increase in unreliability of the heat transfer fluid unit component failure upon the influence of time. The equation of the curve obtained is given as y = 3.1496x + 8044 with the square root of the best fit given as R^2 = 0.5442 whereas for reliability the equation of the curve is given as y =

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3.1496x + 19.56 with the square root of the best fit given as R^2 = 0.5442. The variation in the characteristics of reliability and unreliability value of the components in the heat transfer fluid unit plant can be attributed to the variation in constant failure of the components, the aging of the components used during repairs experience of the manpower used for maintainability and other contributing factors, which include lack of identification of the root cause of the event. Decrease in reliability value was observed with increase in time of utilization of plant component materials.

Reliability and Unreliability of Expander Unit

The result of reliability and unreliability of the Heat Transfer Fluid Unit was examined on the influence of time as presented in Figure 7.

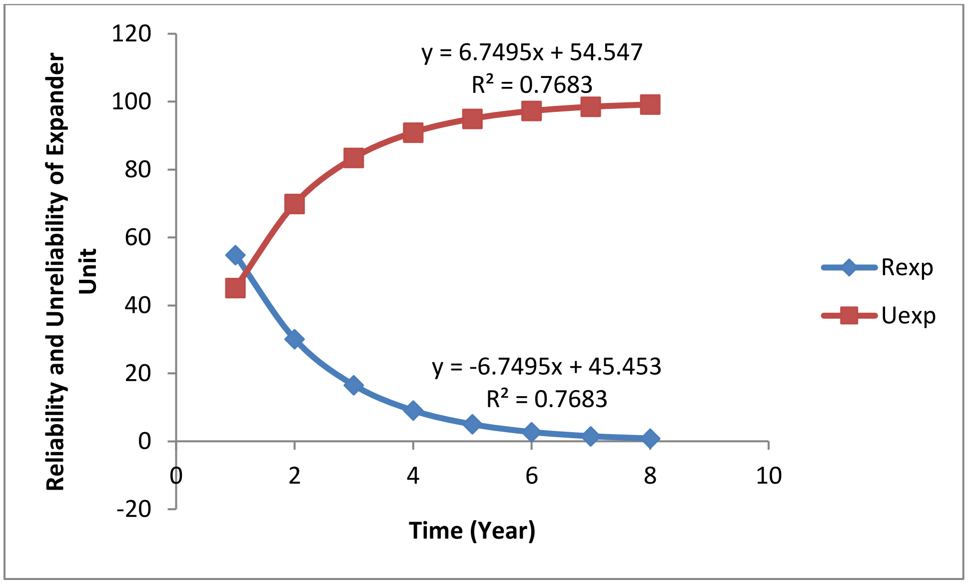

Figure 7: Graph of Reliability and Unreliability of Expander Unit versus Time

From Figure 7, it is seen that the reliability and unreliability characteristics of expander unit plant of the liquefied natural gas plant components was examined upon the influence of failures which was attributed to time utilization by the plant. Increase in unreliability was experienced with increase in time utilization of the plant unit. The equation of the curve for expander unit is given as y = 6.7495x + 54.547 with the square root of the best fit given as R^2 = 0.7683 whereas for the reliability, the equation of the curve was given as y = 6.7495x + 45.453 with square root of the best fit given as R^2 = 0.7683. The variation in the reliability and unreliability characteristics of the components used in the repair of the expander unit can be attributed to the variation in the constant failure of repair parts component experience of the manpower used, the quality of the component materials used for replacement and other environmental factor.

Reliability and Unreliability of Liquefaction Unit

The result of reliability and unreliability of the Liquefaction Unit was examined on the influence of time as presented in Figure 8.

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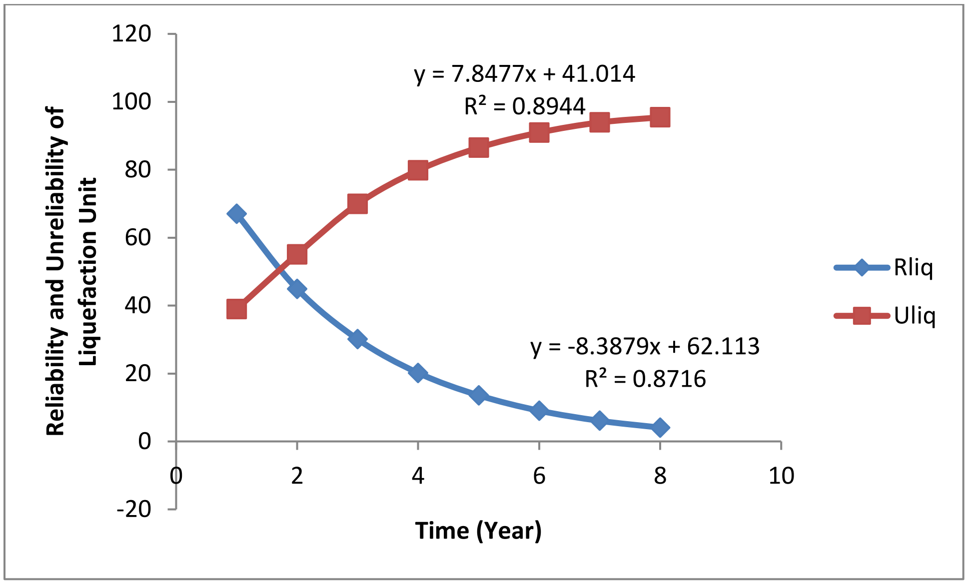

Figure 8: Graph of Reliability and Unreliability of Liquefaction Unit versus Time

Figure 8 demonstrates the relationship between reliability and unreliability of liquefraction unit component failures upon time utilization of the liquefied natural gas plant. The result presented in Figure 8 illustrates decrease in reliability value of the component due to constant failure experienced in the unit with the period under investigation. In the case of unreliability, increase is observed with increase in time as shown in Figure 8. The variation of the reliability and unreliability value of liquefraction unit components used for repair of faulty items can be attributed to the various component in the constant of time, period of component parts utilization of the plant maintainability concepts, and other contributing factors as mentioned in the various area of discussion. The equation of the curve for the liquefraction unit is given as y = 7.8477x + 41.014 with the square root of the best fit for the liquefraction unit is given as $R^2 = 0.8944$ for the unreliability whereas for the reliability the equation of the curve for the liquefraction unit is given as y = 8.3878x + 62.93 with the square root of the best fit given as $R^2 = 0.5716$ as presented in Figure 8.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Biagiola, S. & Solsona, J. (2006). State Estimation in Batch Processes Using a Nonlinear Observer. *Mathematical and Computer Modelling*, 44(4), 1009-1024.
2. Blanchard, B.S. & Fabrycky, W.J. (1998). System Engineering and Analysis, 3rd edition. Prentice Hall. *Intern national Series in Industrial and Systems Engineering*, 4(6), 73-78.
3. Chetouani, Y. (2008). Design of a Multi-Model Observe-Based Estimate for Fault Detection and Isolation (FDI) Strategy: Application to a chemical reactor. *Brazilian Journal of Chemical Engineering*, 25(4), 766-777.
4. Chukwure, L. & Ukpaka, C. P. (2020). Inhibitor Efficiency Relative to H_2SO_4 Medium of Metals Steel Corrosion: The Integration of Plant Extracts, *International Journal of Petroleum and Petrochemical Engineering*, 6(4), 13-20.
5. Yanbua, G., Xiaoli, M., Wang, D. & Meng, T. (2016). Comprehensive Risk Evaluation of Long Distance Oil and Gas Transportation Pipelines Using a Fuzzy Petri Net Model. *Journal of Natural Gas Science and Engineering*, 33(2), 18-29.
6. Hovland, G.E., Von-Hoff, T.P., Gallestey, E.A., Antonie, M., Farruggio, D. & Pace, A.D.B. (2005). Nonlinear Estimation Methods for Parameter Tracking in Power Plants. *Control Engineering Practice*, 13(1), 1341-1355.
7. Jamshidi, A., Yazdani-Chamzini, A., Yakhchali, S.H. & Khaleghi, S. (2013). Developing a New Fuzzy Influence

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

System for Pipeline Risk Assessment. *Journal of Loss Prevention in the Process Industries*, 26(1), 197-208.

8. Afamefune, K. A., Ukpaka, C, P & Nkoi, B. (2020). Reliability Analysis of Opukushi Seibou Oil Field Flowline to Mitigate Corrosion Failure. *Journal of New views in Engineering and Technology (JNET),* 2(4), 10-18.
9. Koteswara, R.G. & Kivan, Y. (2016). Analysis Accidents in Chemical Process Industries in the Mid 1998-2015. *International Journal of Chemical Technology Research*, 9(4), 177-191.
10. Lavasani, *S.M.,* Ramzali, B., Sabzalipour, F. & Akyuz, E. (2015). Utilization of Fuzzy Fault Tree Analysis (FFTA) for Quantified Risk Analysis of Leakage in Abandoned Oil and Natural Gas Well. *Ocean Engineering*, 108(2), 729-737.
11. Li, X., Chan, G. & Zhu, H. (2016). Quantitative Risk Analysis on Leakage Failure of Submarine Oil and Gas Pipelines Using Bayesian Network. *Process Safety and Environmental Protection*, 103(3), 163-173.
12. Lynda, A., Samanthala, H. & Christopher, S. W. (2015). Risk Management in the Extractive Industry: An Empirical Investigation of the Nigerian Oil and Gas Industry. Journal of Applied Business and Economics, 17(1), pp.86-99
13. Marjanovic, D., Sandoz, D. & Loveth, D. (2004). Statistical Process Monitoring of Industrial Batch Processes Presented at the World Batch Forum. *European Conference Mechei-en Belgium*, 19(6), 11-13.
14. McEvoy, T. & Wolthusen, S. (2010). A Formal Adversary Capability Model for SCADA Environment, Presented at the Fifth International Workshop on Critical Information and Infrastructure Security, 73-75.
15. Meel, A. & Seider, W.D. (2006). Dynamic Failure Assessment using Bayessian Theory. *Chemical Engineering Science*, .61(3), .36-56.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS