KMUTNB Int J Appl Sci Technol, Vol. 10, No. 1, pp. 61–70, 2017

Research Article

Reliability Analysis for Refinery Plants

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Received: 22 April 2016; Accepted: 22 June 2016; Published online: 30 January 2017

Abstract

One of the main problems in compiling Preventive Maintenance (PM) plans for large-scale industries consisting of many subunits in the production system is the criterion used in the selection of machines and equipment to be maintained. The criteria most used are the failure frequency of each machine and equipment and the maintenance cycle time specified in the manual, as preventive maintenance is considered to be mainly time-based. In some cases, Failure Mode and Effect Analysis (FMEA) technique is applied in the selection of machines and equipment by considering individual and independent machines in the subsystems. The overall mechanisms of the machines and equipment were not considered, which may affect the production capacity. Therefore, this research applies reliability engineering techniques to find the overall reliability of machines and equipment in the production system of oil refinery models and determine the machine in the subsystem that affects that overall reliability. This in turn causes optimal preventive maintenance planning for machines and equipment in order to achieve the maximum efficiency for the oil refinery process. This research begins by studying the procedures of oil refinery models, then creating a reliability block diagram of the subsystems to find the reliability of the machines and equipment within each subsystem. Afterwards, the overall reliability of the production system will be determined, which leads to arranging the reliability of machines and equipment in the subsystems in ascending order. This develops into the preventive maintenance planning process so that the refinery process achieves its maximum efficiency.

Keywords: Refinery plants, Reliability engineering, Maintenance

1 Introduction

From 2008 to 2011, there were failures found on instrumental and mechanical equipment in an oil refinery model in Rayong province. The failure frequency of equipment was as high as 33 times, which cost about 26,214,092 baht. At present, the method chosen by Maintenance Engineers is to group the types of failure that occur to each machine and determine the maintenance cycle time as stated in the manual. Apart from the aforementioned, Failure Mode and Effect Analysis (FMEA) technique for oil refinery models is also applied in the selection of machines in order to create preventive maintenance plans. Preventive maintenance is based on time. For instance, the maintenance cycle time is determined in relation to both the production

Please cite this article as: I. Nakamanuruck, V. Rungreunganun, and S. Talabgaew, "Reliability analysis for refinery plants," *KMUTNB Int J Appl Sci Technol*, vol. 10, no. 1, pp. 61–70, Jan.–Mar. 2017.

quality and schedule [1]. The production quality can be found from the control chart, in which shows that the machine may have deteriorated whenever the median of the system shifts. The main purpose of this research is to use FMEA to find out which types of failure modes cause the failure of the machines or the stop of the production, and the median of the production process to shift. Every type of failure would affect the quality of the end product. The total preventive cost would then be estimated to see which types of failure modes cause the highest expense. Similarly, FMEA is also used to analyze the abnormality of the Computer Numerical Control (CNC) machine [2] or the centrifugal pump by using the following parameters: probability of occurrence (O), severity (S), and capability in detecting errors (D). The severity of the damage occurred would then be rearranged according to the significance, which would be used to improve the preventive maintenance plan and establish it as a standard [3], [4].

Moreover, Reliability Engineering is also applied to the machines in the production process by considering individual equipment. One of the cases is applying the Mixed Integer Programming method to identify the maximum profit that can be benefited from the maintenance of the machines in the Hydroalkaline (HAD) petrochemical plant, by specifying the target function to be maximum profit [5]. The income from the production process will be calculated from the reliability of the system, which is derived from the Reliability Block Diagram (RBD) of the petrochemical process. After that Louita [6], the optimal cycle time for the maintenance of the complex electricity system would be found. The concept is that the failure of equipment has a domino effect, since this type of system operates as a multi-state function. So in this case the maintenance plan for individual equipment should not be applied. Thus the failure rate model is developed from the probability of the occurrence of failure and the estimation of the amount of times that failure is expected to occur. The cost of failure and cost of prevention would then be used to calculate the expense rate. Another case is Ghosh [7], which considers the expenses that follow the failure of a compressor pump or blade. The expenses include production opportunity loss, repairing or replacing of machines' cost, planned maintenance costs, and so on. On the other hand, by considering the benefits that would occur if this equipment had high reliability and could operate continuously, it would generate production profit for the factory. Weibull and exponential functions would be applied to find the failure rate of the machines, while [8] uses the Monte Carlo method to simulate a random number of times in which the parts of the wind power plants would fail. A mathematics equation showing the inverse relationship between the reliability value and the life cycle of equipment, called the Proportional Age Set Back (PAS) model, was created. The deterioration of the blades occurring from the unstable environment was studied by creating a reliability model using the probability of the wind speed and the statistic of the deterioration rate of blades occurring in the past.

As aforementioned, Failure Mode and Effect Analysis (FMEA) and Reliability Engineering can both be chosen as the methods for the machines and equipment selection in order to make a maintenance plan. In both cases, the equipment is still considered individual and not as the overall system. This may affect the efficiency of the production process. Thus, in this research, the reliability engineering technique is applied to find the overall reliability of the machines and equipment in the production system of the oil refinery model. The machines and equipment in the subsystems that affect the overall reliability would be analyzed, which then lead to the appropriate preventive maintenance planning for machines and equipment so that the oil refinery process will achieve its maximum efficiency.

2 Procedure

The research procedure can be divided into four steps. The first is to study the refinery system of the refinery model; second is to create a reliability block diagram of the subsystems in the oil refinery process; third is to construct reliability equations of the subsystems in the oil refinery process and fourth is to find the reliability value of subsystems and the overall system.

2.1 *Study the refinery system of the oil refinery model*

The refinery system of the oil refinery model can be separated into 16 major units, by using the Equivalent Distillation Capacity (EDC) as the unit of measure. It is calculated by using the method developed by

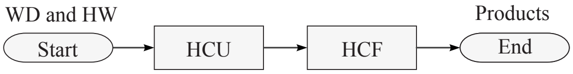

Figure 1: Hydrocracker Unit (HCU) and Hydrocracker Fractionator Unit (HCF) linked in series.

Solomon Associates, in which this company uses the EDC value to display the complex level of the oil refinery procedure. It is more suitable than the previous unit of measure used in oil refinery industries, Barrel. This research emphasizes on the procedure that is most significant in the oil refinery process by analyzing the EDC values. From the oil refinery plant, there are 16 main sections but the Hydrocracker Unit (HCU) and Hydrocracker Fractionator Unit (HCF) have the highest EDC, and they are connected in series, as shown in Figure 1.

Figure 1 shows that the raw materials used in HCU are Waxy Distillate (WD) and Hydrowax (HW). The function of this unit is to convert heavy vacuum gas oil received from the High Vacuum Unit (HVU) into light vacuum gas oil by using hydrogen (H_2) as the reactant to eliminate sulfur (S) and nitrogen (N_2). The reaction process will create hydrogen sulfide (H_2S), ammonia (NH_3) and is an exothermic reaction, so hydrogen (H_2) at low temperature must be fed into the reactor in order to control the temperature of the overall system. The HCU flowchart can be found in Figure 2. As for HCF, the main goal is to convert the crude oil from HCU by fractional distillation at different temperatures. The products achieved include Liquefied Petroleum Gas (LPG), light naphtha, heavy naphtha, kerosene, gas oils, and hydrowax. Hydrowax would be sent back to the HCU to improve the quality as the level of sulfur (S) and nitrogen (N_2) is still above the standard. The HCF flowchart is shown in Figure 3.

From Figures 2 and 3, the functional flowcharts of HCU and HCF can be created. HCU is separated into 10 (ten) sections which include feed, fresh gas, recycle gas, reactor, Hot High Pressure Separator (HHPS), Cool High Pressure Separator (CHPS), Hot Low Pressure Separator (HLPS), make up water, Cool Low Pressure Separator (CLPS), and ADIP absorption. On the other hand, HCF is separated into 3 (three) sections: the fractionator feed, hydrocracker main fractionators, and side strippers. The functional flowchart of HCU and HCF is shown in Figure 4 and 5, respectively.

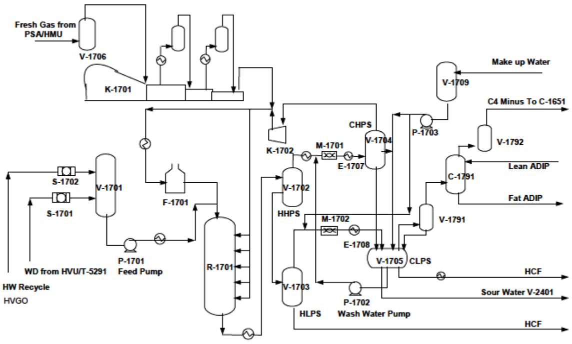

Figure 2: Hydrocracker Unit (HCU) flowchart.

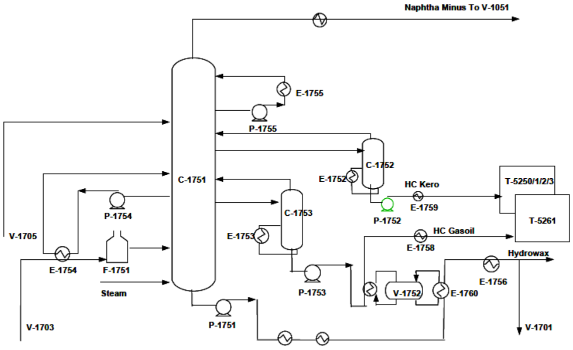

Figure 3: Hydrocracker Fractionator Unit (HCF) flowchart.

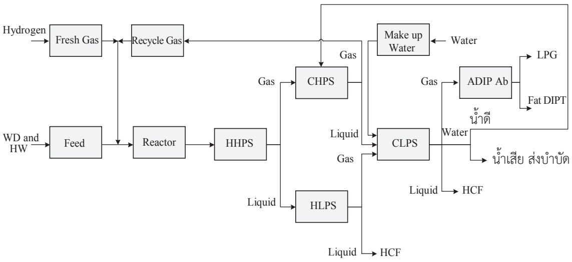

Figure 4: Hydrocracker Unit (HCU) functional flowchart.

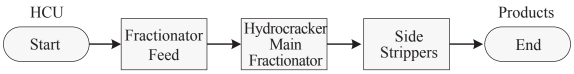

Figure 5: Hydrocracker Fractionator flowchart (HCF) functional flowchart.

2.2 *Create a reliability block diagram of the subsystems in the oil refinery process*

From the procedures of the Hydrocracker Unit (HCU) and Hydrocracker Fractionator Unit (HCF), the reliability value of both systems can be found by changing the flowchart and functional flowchart to Reliability Block Diagram (RBD). However, for complex system that operates continuously and each individual part affects the process of the following step, which is called as Multi State function, the significance of the equipment is not specific to only one part, but rather specific to the overall connection of the system that has continuous effects [9], [10]. If any section is damaged, the HCU and HCF systems would not be able to operate, leading to a loss in revenue. Thus, maintenance of this equipment is necessary and definitely brings forth additional expenses, called the maintenance cost. From Figure 1, it can be seen that HCU and HCF are linked in series, so the reliability can be found as Equation (1).

$$R_S = R_{HCU} \times R_{HCF} \tag{1}$$

Equation (1) shows the reliability of the system (R_S) is obtained from the product of the reliability of HCU (R_{HCU}) and reliability of HCF (R_{HCF}). The reliability value of HCU and HCF can be estimated from RBD, in which RBD is a diagram to describe the relationship of the equipment in the system. The systems can be connected in series, parallel or stand by modes for complexity systems [11].This research focuses only on the main equipment as it is significant and necessary to the production process. The RBD of HCU and HCF can be seen in Figures 6 and 7, respectively.

2.3 *Construct reliability equations of the subsystems in the oil refinery process*

The reliability of the overall system can be found by first finding the reliability of the 2 subsystems: the Hydrocracker Unit (HCU) and Hydrocracker Fractionator Unit (HCF) which are linked in series as aforementioned in 2.2. Further details to find the reliability of the two subsystems are shown in Figures 6 and 7, in which each system is linked in series within itself. As per theory, systems connected in series require all components to function. Thus, the reliability equations of HCU and HCF can be found as Equations (2) and (3) respectively.

$$R_{HCU} = \begin{matrix} R_{Feed} \times R_{FreshGas} \times R_{\mathrm{Re}cycleGas} \times R_{\mathrm{Re}actor} \times R_{HHPS} \\ \times R_{CHPS} \times R_{MakeUpWater} \times R_{HLPS} \times R_{CLPS} \times R_{ADIPab} \end{matrix} \tag{2}$$

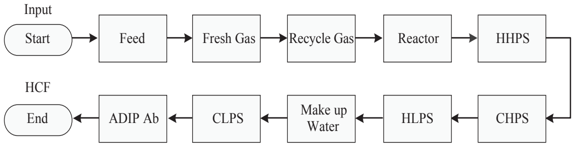

Figure 6: Reliability block diagram of Hydrocracker Unit (HCU).

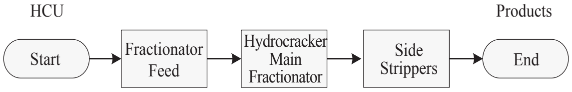

Figure 7: Reliability block diagram of Hydrocracker Fractionator Unit (HCF).

Figure 8: Parts linked in series.

$$R_{HCF} = R_{FractionatorFeed} \times R_{Hydrocrac\,\mathrm{kerM}\,F} \times R_{SideStrippers} \tag{3}$$

The reliability equations of HCU and HCF consist of multiple operating functions, where each operating function has its own individual reliability value. This individual reliability value can be obtained from that of the main equipment in each operating function. Each operating function consists of the equipment listed in Table 1 and 2. The reliability of the operating function can be found similarly by creating the RBD of each one, which will be discussed in the following step.

2.4 *Find reliability value of subsystems and overall system in the oil refinery process*

After reliability block diagrams of the subsystems have been created, the reliability of each subsystem will be determined from the type of the block diagram. From studies, it shows that the subsystems in the HCU and HCF are either linked in series, parallel, or a mixture between the two with reserve equipment on standby.

- Series: is the system that consists of parts or machines that are arranged in order, one part or one machine at a time. The operation of systems linked in series can only function when every part or machine is working. If any part is damaged, it would affect the entire system and the system would not be able to function at all [12], as shown in Figure 8.

Table 1: Equipment ID and Reliability variables of the equipment in the Hydrocracker Unit

System	No.	ID Equipment	Name of Equipment	Reliability
Feed	1	S-1701A	Reactor Fresh Feed Filter (A)	$R_{S-1701A}$
	2	S-1701B	Reactor Fresh Feed Filter (B)	$R_{S-1701B}$
	3	S-1702A	Reactor Recycle Feed Filter (A)	$R_{S-1702A}$
	4	S-1702B	Reactor Recycle Feed Filter (B)	$R_{S-1702B}$
	5	V-1701	Reactor Feed Surge Vessel	R_{V-1701}
	6	P-1701	Reactor Feed Pump	R_{P-1701}
Fresh Gas	1	V-1706	F.G. Compressor 1ST Stage Suction Vessel	R_{V-1706}
	2	K-1701A	Fresh Gas Compressor (A)	$R_{K-1701A}$
	3	K-1701B	Fresh Gas Compressor (B)	$R_{K-1701B}$
	4	K-1701S	Fresh Gas Compressor (S)	$R_{K-1701S}$
Recycle Gas	1	K-1702	Recycle Gas Compressor	R_{K-1702}
	2	F-1701	Recycle Gas Furnace	R_{F-1701}
Reactor	1	R-1701	HCU Reactor	R_{R-1701}
Hot High Pressure Separator	1	V-1702	Hot HP Separator	R_{V-1702}
Cool High Pressure Separator	1	M-1701	Static Mixer-Hot HP Vapor/Wash Water	R_{M-1701}
	2	E-1707	Air/Hot HP Vapour	R_{E-1707}
	3	V-1704	Cold HP Separator	R_{V-1704}
Hot Low Pressure Separator	1	V-1702	Hot HP Separator	R_{V-1702}
Make up Water	1	V-1709	Wash Water Surge Vessel	R_{V-1709}
	2	P-1703A	Wash Water Make Up Pump (A)	$R_{P-1703A}$
	3	P-1703B	Wash Water Make Up Pump (B)	$R_{P-1703B}$
Cool Low Pressure Separator	1	M-1702	Static Mixer-Hot LP Vapor/ Wash Water	R_{M-1702}
	2	E-1708	Air/Hot LP Vapour	R_{E-1708}
	3	V-1705	Cold LP Separator	R_{V-1705}
	4	P-1702A	Wash Water Recycle Pump (A)	$R_{P-1702A}$
	5	P-1702B	Wash Water Recycle Pump (B)	$R_{P-1702B}$
ADIP Absorption	1	V-1791	HCU Feed Gas KO Vessel	R_{V-1791}
	2	C-1791	HCU Adip Absorber	R_{C-1791}
	3	V-1792	HCU Treated Gas KO Vessel	R_{V-1792}

Table 2: Equipment ID and Reliability variables of the equipment in the Hydrocracker Fractionator Unit

System	No.	ID Equipment	Name of Equipment	Reliability
Fractionator Feed	1	E-1754A	HLPS Feed/Hydrowax Exchanger (A)	$R_{E-1754A}$
	2	E-1754B	HLPS Feed/Hydrowax Exchanger (B)	$R_{E-1754B}$
	3	F-1751	HCF Furnace	R_{F-1751}
Hydrocracker Main Fractionator	1	C-1751	Main Fractionator	R_{C-1751}
	2	P-1755A	HCFTCR Pump (A)	$R_{P-1755A}$
	3	P-1755B	HCFTCR Pump (B)	$R_{P-1755B}$
	4	E-1755	HCF-TCR Air Cooler	R_{E-1755}
Side Strippers	1	C-1753	Gasoil Stripper	R_{C-1753}
	2	E-1753	Gasoil/Hydrowax Exchanger	R_{E-1753}
	3	P-1753A	Gasoil Pump (A)	$R_{P-1753A}$
	4	P-1753B	Gasoil Pump (B)	$R_{P-1753B}$
	5	E-1758A	Air/Gasoil (A)	$R_{E-1758A}$
	6	E-1758B	Air/Gasoil (B)	$R_{E-1758B}$
	7	C-1752	Kero Stripper	R_{C-1752}
	8	E-1752	Kero/Hydrowax Exchanger	R_{E-1752}
	9	P-1752A	Kero Pump (A)	$R_{P-1752A}$
	10	P-1752B	Kero Pump (B)	$R_{P-1752B}$
	11	E-1759A	Kero Run Down Air Cooler (A)	$R_{E-1759A}$
	12	E-1759B	Kero Run Down Air Cooler (B)	$R_{E-1759B}$
	13	P-1751A	Hydrowax Pump (A)	$R_{P-1751A}$
	14	P-1751B	Hydrowax Pump (B)	$R_{P-1751B}$
	15	E-1760	Ip Bfw/Hydrowax Exchanger	R_{E-1760}
	16	E-1756A	Air/Hydrowax (A)	$R_{E-1756A}$
	17	E-1756B	Air/Hydrowax (B)	$R_{E-1756B}$

The reliability of R_s system can be calculated from the following Equation (4)

$$R_S = P(x_1)\times P(x_2 / x_1)\times ...\times P(x_n / x_1 x_2 ..x_{n-1}) \tag{4}$$

Where P(x_j/x_i) is the conditional reliability that part x_j can function only when part x_i is functioning. However, the probability of functioning or malfunctioning of each individual part is independent of each other; thus the reliability of the system would become Equation (5) and (6)

$$R_S = P(x_1)\times P(x_2)\times ...\times P(x_n) \tag{5}$$

$$R_S = R_1 .R_2 ...R_n \tag{6}$$

- Parallel: in calculating the reliability of the system linked in parallel, such as the production line, the value can be improved by increasing the amount of parts or machines linking the original system in parallel. This type of system will fail only when all the parts fail simultaneously. If there is one part that cannot function, the system would still be able to operate. This is the advantage of this type of system [12], as shown in Figure 9.

If the probability of the failure part is P_f or F_S, so P_f or F_S can be found as Equation (7) and (8).

$$P_f = P(\overline{x}_1 .\overline{x}_2 ...\overline{x}_n) \tag{7}$$

Where $P(\overline{x}) = 1 - P(x)$

$$P(\overline{x}) = 1 - \left[1 - P(x_1)\right].\left[1 - P(x_2)\right]...\left[1 - P(x_n)\right] \tag{8}$$

When $P(\overline{x})$ is the failure or the probability of failure for each part. Thus, the reliability of the system linked in parallel can be calculated from the Equation (9).

$$R_s = 1 - \left[(1 - R_1)(1 - R_2)...(1 - R_n)\right] \tag{9}$$

- Stand by: this system was designed to have parts on standby. Whenever any parts are damaged, the parts on standby would function in its place. Figure 10 shows the Two Parallel Elements model of the standby system [13].

From Figure 10, the system is linked in parallel, where the two parts that are linked in parallel have the same functions, thus one of them can be placed on standby mode at a time. For instance, if Part A is damaged, the switch will automatically change to link to Part B to continue the operation of the system. The system may fail in three cases:

- *Case 1*: Part A functions, Part B malfunctions, Switch is damage, System failure (Type 2)
- *Case 2*: Part A malfunctions, Part B functions, Switch is damage, System failure (Type 1)
- *Case 3*: Part A malfunctions, Part B malfunctions, System failure

Where q_S is the probability that the system failure is Type 1, and q'_S is the probability that the system failure is Type 2. The unreliability of the system can be written as Equation (10).

$$Q = p_a q_b q'_s + q_a p_b q_s + q_a q_b \tag{10}$$

Where $R_S = 1 - Q$

And the Three Element Voting Redundancy model [13] of the standby system is shown in Figure 11.

From Figure 11 the standby system is linked in parallel, where the parts that are linked in parallel have the same functions, so that system can be put on standby mode. For example, Part D can only function when Part A and Part B function. However, when either

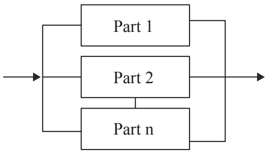

Figure 9: Parts linked in parallel.

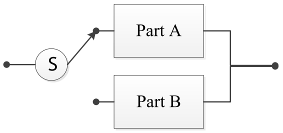

Figure 10: Two Parallel Elements model of the standby system [13].

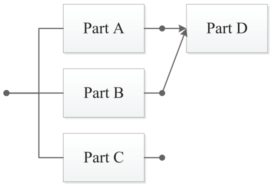

Figure 11: Three Element Voting Redundancy model of the standby system [13].

Part A or B fails, the system will change automatically to Part C which is the standby part, to function in its place so that the operation can continue. The damaged parts can also be repaired at this point to prepare for the next case of failure. The reliability of this standby system can be calculated in two cases [13].

1. There is no chance for the switch to fail, as shown in Equation (11) and (12).

$$R_S = P\left(AB \cup AC \cup BC\right) \tag{11}$$

$$R_S = \begin{array}{l} P(A)P(B) + P(A)P(C) + P(B)P(C) \\ -2P(A)P(B)P(C) \end{array} \tag{12}$$

2. There is a chance that the switch would fail, as shown in Equation (13) and (14).

$$R_S = P(AB \cup AC \cup BC) \times (R_{Switching}) \tag{13}$$

$$R_S = P(A)P(B) + \begin{bmatrix} P(A)P(C) + P(B)P(C) \\ -2P(A)P(B)P(C) \end{bmatrix} \times (1 - Q_{Switching}) \tag{14}$$

Where $Q_{switching}$ is the probability of the switch failure

From the aforementioned theories and from the inspection of the equipment in the oil refinery plant of case study, in which the inspection follows the rotation of employee shifts (t=12 hours). Thus, the failure rate would be constant, which means that it does not depend on working hours but rather on the load of the equipment [15]. For Stand By systems, there will be no chance for the switch to fail. One example to find the reliability of the feed system is demonstrated as follows; the operation of the feed system is subsystems 1, 2 and 3 linked in series and set on standby. For the standby systems, the equipment that acts as the standby part as well as the switch must not be damaged, as shown in Figure 12.

Figure 12 shows the operations of the feed system, which is the procedure to decontaminate any contamination that came with the 2 raw materials: Waxy distillate (WD) and Hydrowax (HW) before they enter the system. The instruments used are S-1701 A/B and S-1702 A/B. The materials would flow to rest in instrument V-1701 before being pumped into the following section by P-1701, as according to the manual. The failure rate collected from 2008 until 2011 are listed in Table 3.

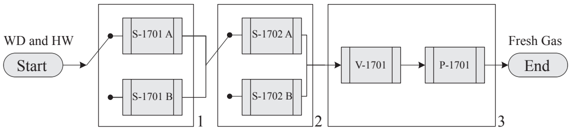

Figure 12: Reliability block diagram of feed system.

Table 3: Equipment ID and statistic of the Failure Rate of the feed system

No.	**ID Equipment**	**Name Equipment**	**λ (Failure Rate) (times/hr).**
1	S-1701A	Reactor Fresh Feed Filter (A)	0.00031
2	S-1701B	Reactor Fresh Feed Filter (B)	0.00003
3	S-1702A	Reactor Recycle Feed Filter (A)	0.00006
4	S-1702B	Reactor Recycle Feed Filter (B)	0.00009
5	V-1701	Reactor Feed Surge Vessel	0.00000
6	P-1701	Reactor Feed Pump	0.00003

From Figure 12 and statistic of failure rate (λ) in Table 3, the reliability of the feed system can be calculated as Equation (15).

$$\mathrm{R}_{\mathrm{Feed}} = R_{Subsystem1} \times R_{Subsystem2} \times R_{Subsystem3} \tag{15}$$

Where

$$R_{Subsystem1} = \left[1 - (1 - R_{S-1701A})(1 - R_{S-1701B})\right]$$

$$R_{Subsystem2} = \left[1 - (1 - R_{S-1702A})(1 - R_{S-1702B})\right]$$

$$R_{Subsystem1} = R_{V-1701} \times R_{P-1701}$$

Substitute $R_{subsystem1}$, $R_{subsystem2}$ and $R_{subsystem3}$ into the above equation, thus the reliability of the feed system can be found to be Equation (16).

$$R_{Feed} = \begin{array}{l} \left[1 - (1 - R_{S-1701A})(1 - R_{S-1701B})\right] \times \\ \left[1 - (1 - R_{S-1702A})(1 - R_{S-1702B})\right] \times \\ \left[R_{V-1701} \times R_{P-1701}\right] \end{array} \tag{16}$$

In this paper, it is assumed that the reliability equation follows the exponential model which is Equation (17) [14].

$$R(\mathrm{t}) = \mathrm{e}^{-\lambda t} \tag{17}$$

Where; λ is failure rate (time/hr.) = $1/MTTF$
$MTTF$ is Mean Time to Failure
t is time required for each operator to inspect the equipment (t =12 hr.)

Table 4: Reliability equation of Hydrocracker Unit (HCU) system

System	Reliability Equation of System		
Feed	$R_{Feed} = \left[1-(1-R_{S-1701A})(1-R_{S-1701B})\right] \times \left[1-(1-R_{S-1702A})(1-R_{S-1702B})\right] \times \left[R_{V-1701} \times R_{P-1701}\right]$		
Fresh Gas	$R_{FreshGas} = R_{V-1706} \times \left[R_{K-1701A}R_{K-1701B} + R_{K-1701A}R_{K-1701S} + R_{K-1701B}R_{K-1701S} - (2R_{K-1701A}R_{K-1701B}R_{K-1701S})\right]$		
Recycle Gas	$R_{RecycleGas} = R_{K-1702} \times R_{F-1701}$	Make up Water	$R_{MakeUpWater} = R_{V-1709} \times \left[1-(1-R_{P-1703A})(1-R_{P-1703B})\right]$
Hot High Pressure Separator	$R_{HHPS} = R_{V-1702}$	ADIP Absorption	$R_{ADIPab} = R_{V-1791} \times R_{C-1791} \times R_{V-1792}$
Hot Low Pressure Separator	$R_{HLPS} = R_{V-1703}$	Reactor	$R_{Reactor} = R_{R-1701}$
Cool Low Pressure Separator	$R_{CLPS} = \left[R_{M-1702} \times R_{E-1708} \times R_{V-1705}\right] \times \left[1-(1-R_{P-1702A})(1-R_{P-1702B})\right]$		
Cool High Pressure Separator	$R_{CHPS} = R_{M-1701} \times R_{E-1707} \times R_{V-1704}$		

Table 5: Reliability equation of Hydrocracker Fractionator Unit (HCF) system

System	Reliability Equation of System
Fractionator Feed	$R_{FractionatorFeed} = \left[1-(1-R_{E-1754A})(1-R_{E-1754B})\right] \times R_{F-1751}$
Hydrocracker Main Fractionator	$R_{Hydrocrac\,\mathrm{kerM}F} = R_{C-1751} \times R_{E-1755} \times \left[1-(1-R_{P-1755A})(1-R_{P-1755B})\right]$
Side Strippers	$R_{SideStrippers} = \begin{matrix} \left[R_{C-1753} \times R_{E-1753}\right] \times \left[1-(1-R_{P-1753A})(1-R_{P-1753B})\right] \times \left[1-(1-R_{E-1758A})(1-R_{E-1758B})\right] \times \\ \left[R_{C-1752} \times R_{E-1752}\right] \times \left[1-(1-R_{P-1752A})(1-R_{P-1752B})\right] \times \left[1-(1-R_{E-1759A})(1-R_{E-1759B})\right] \times \\ \left[1-(1-R_{P-1751A})(1-R_{P-1751B})\right] \times R_{E-1760} \times \left[1-(1-R_{E-1756A})(1-R_{E-1756B})\right] \end{matrix}$

Thus, the reliability of the feed system is calculated to be 0.99963. The calculations to find the reliability values of the other systems are shown in Tables 4 and 5.

3 Results

From the statistic of the failure rate of the subsystems for 4 years, the reliability of the system can be calculated as listed in Table 6.

Table 6: Reliability of Hydrocracker Unit (HCU) and Hydrocracker Fractionator Unit (HCF) subsystems

Systems	Subsystems	Reliability
Hydrocracker Unit (HCU)	Feed	0.99963
	Fresh Gas	0.99998
	Recycle Gas	0.99963
	Reactor	0.99926
	Hot High Pressure Separator	1.00000
	Cool High Pressure Separator	1.00000
	Hot Low Pressure Separator	1.00000
	Make up Water	1.00000
	Cool Low Pressure Separator	0.99993
	ADIP Absorption	0.99926
Hydrocracker Fractionator Unit (HCF)	Fractionator Feed	0.99817
	Hydrocracker Main Fractionator	0.99963
	Side Strippers	0.99890

From Tables 1 and 2, the reliability of each equipment is estimated by using Equation (9) and the reliability of Hydrocracker Unit (HCU) in Equation (2) and Hydrocracker Fractionator Unit (HCF) in Equation (3) can be estimated by substituting the reliability values from Tables 4 and 5. The reliability values of HCU and HCF systems were found to be equal to 0.99769 and 0.99670 respectively, as shown in Table 6. These values would then be substituted into Equation (1) to find the reliability of the main system to be 0.99449.

4 Discussion

The Failure Mode and Effect Analysis (FMEA) technique is applied to consider the failure characteristics or the cause that leads to Potential Failure Mode, which occurs from designs, productions, or services. The effects due to potential failures would then be analyzed, and would lead to the specification of Preventive Maintenance plans, as researched by Pandey [1] and Rungsa [2]. However, the application of FMEA technique alone is not suitable with the characteristics of refinery plants. The usage of system reliability increases the control in maintenance for the entire plant since every machine and equipment in the refinery process must operate simultaneously in order for the system to operate.

As for finding the overall reliability of the system, previously only the Reliability Block Diagram was used for the subsystems, as researched by Goel [5]. However, in this research, the reliability block diagram for subsystems in real operating conditions were considered, which consists of the system being connected in standby mode. This mode is fairly complicated, and is more suitable for real operating conditions. The reliability and unreliability values of the system can be seen in Table 7, arranged in order from least to greatest.

Table 7: Reliability and unreliability values in ascending order

Subsystem	Reliability	Unreliability
Fractionator Feed	0.99817	0.00183
Side Strippers	0.99890	0.00110
Reactor	0.99926	0.00074
ADIP Absorption	0.99926	0.00074
Feed	0.99963	0.00037
Recycle Gas	0.99963	0.00037
Hydrocracker Main Fractionator	0.99963	0.00037
Cool Low Pressure Separator	0.99993	0.00007
Fresh Gas	0.99998	0.00002
Hot High Pressure Separator	1.00000	0.00000
Cool High Pressure Separator	1.00000	0.00000
Hot Low Pressure Separator	1.00000	0.00000
Make up Water	1.00000	0.00000

From Table 7, the reliability and unreliability values of the fractionator feed, side strippers, reactor, ADIP absorption, feed, recycle gas, hydrocracker main fractionator, Cool Low Pressure Separator (CLPS), fresh gas, Hot High Pressure Separator (HHPS), Cool High Pressure Separator (CHPS), Hot Low Pressure Separator (HLPS) and make up water subsystems are shown in ascending order, respectively. These values show that preventive maintenance as stated in the manual may not be suitable as there is still deterioration in the instruments, which creates higher expenses for corrective maintenance. Thus, the improvement of the instruments should be considered sequentially, to improve the preventive maintenance plan to have higher efficiency.

5 Conclusions

From the analysis to find the reliability of the oil refinery model in Rayong province, in which the systems are chosen by using the equivalent distillation capacity as the criterion, the research models chosen are Hydrocracker Unit (HCU) and Hydrocracker Fractionator Unit (HCF). The statistic used in this study is collected from 2008 to 2011, which includes the failure rate of the equipment in the system to find the reliability of the instruments and system. This creates the reliability of Hydrocracker Unit (HCU) and Hydrocracker Fractionator Unit (HCF) to be 0.99769 and 0.99670, respectively. This in turn causes the reliability of the main system to be equal to 0.99449. Thus, this will help lead to an improvement of preventive maintenance plans of model plants in the future.

Acknowledgments

This research was supported by Thailand Research Fund (TRF). This support is gratefully acknowledged.

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