World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:5, No:12, 2011

Development of a RAM Simulation Model for Acid Gas Removal System

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***Abstract*—**A reliability, availability and maintainability (RAM) model has been built for acid gas removal plant for system analysis that will play an important role in any process modifications, if required, for achieving its optimum performance. Due to the complexity of the plant, the model was based on a Reliability Block Diagram (RBD) with a Monte Carlo simulation engine. The model has been validated against actual plant data as well as local expert opinions, resulting in an acceptable simulation model. The results from the model showed that the operation and maintenance can be further improved, resulting in reduction of the annual production loss.

***Keywords*—**Acid gas removal plant, RAM model, Reliability block diagram

I. Introduction

ACID gas removal plant is one of the important sub-systems in gas processing plant where its main function is to remove the acid gases from the natural gas. The acid gases (CO_2, N_2, H_2S) can account between 1% to 99% of overall composition of the natural gas [1] and specifically for CO_2 , its removal is critical due to its contribution to global warming [2]. In addition, if more than 3% of CO_2 composition is found in the natural gas, it is unmarketable [2]. Furthermore, CO_2 also causes corrosion to the pipeline because it can react with water vapor to form a carbonic acid [2]. Another acid gas is sulfuric acid, H_2S which is much more reactive and is easier to remove.

Natural gases with high CO_2 concentrations are encountered in diverse areas including South China Sea, Gulf of Thailand, Central European Pannonian basin, Australian Cooper-Eromanga basin, Colombian Putumayo basin, Ibleo platform, Sicily, Taranaki basin, New Zealand and North Sea South Viking Graben [3]. The composition of CO_2 can reach as high as 80% in certain natural gas wells such as wells at the LaBarge reservoir in western Wyoming and the Natuna production field in Indonesia [4]. Besides, purged gas from a gas-reinjected enhanced oil recovery well can contain as much as 90% CO_2 [5].

Given the current CO_2 content in the natural gas, gas processing plant operators need to ensure high operational availability of acid gas removal plants so that production demand is satisfied. In order to achieve the high availability target, it is imperative to know which equipment is critical and understand how changes in maintenance strategy would influence plant's availability. Reliability, availability and maintainability (RAM) simulation modeling is one of most useful tools that can be used to provide insight by identifying exactly those pieces of equipments that are critical for the plant's availability. Using RAM simulation model, different maintenance strategies and their influence on reliability and maintainability can be tested for the overall plant performance.

In addition, if the CO_2 content were to increase in the future, the plant operator may need to revise the process layout. For example, the influence of various adjustments in process layout (i.e. equipment redundancy) can be studied. The output of RAM model is a quantified indication of results from any new proposed strategy, either in maintenance or in process layout, so that production demand can still be achieved and profitable.

This paper will present a RAM model for acid gas removal plant using a Reliability Block Diagram (RBD) with a Monte Carlo simulation engine. The objectives of RAM simulation model are:

- To assess equipment criticality in term of reliability and maintainability and their contributions to the system availability, so that appropriate improvement actions can be taken.
- To identify opportunities and options to optimize plant availability, and quantify the consequence of such option in term of cost / benefits.
- To assess the impact of running the acid gas removal operation with feed gas having high level of CO_2 content and evaluate options to mitigate that impact.

The model input was taken from actual plant data and was validated against local expert opinions, resulting in a satisfactory simulation model. The results from the model showed that the operation and maintenance can be further improved, and that in doing so, the annual production loss could be reduced further.

II. Technical Background

A. RAM Modeling

RAM modeling is considered to be one of the two most significant areas for profitability improvement [6]. RAM modeling can simulate the configuration, operation, failure, repair and maintenance of equipment. The inputs to RAM modeling will include the physical components and maintenance schedules in a system and the outputs can determine how productive the system can be over the plant life. RAM studies will generate sufficient data to make decisions for possible system changes that may increase system efficiency and hence, project profits.

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The following definitions were adopted in this study:

- Equipment failure is the termination of the ability of an item to perform a required function (i.e. zero suction for pumps and leaks for static equipment).
- System failure is the inability of the system to produce the product within the product specification (i.e. system fails to remove a specified level of CO_2 content)
- Reliability is defined to be the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions.
- Maintainability is the probability that a system will be restored to operational effectiveness within a given period of time when the maintenance action is performed in accordance with prescribed procedures. In this particular case, maintainability is considered operational maintainability as the analysis includes administrative time and logistic time in addition to the actual repair times.
- Availability is defined as the probability that a component or system is performing its required function at a given point in time or over a stated period of time when operated and maintained in a prescribed manner.

B. Reliability Block Diagram

A reliability block diagram (RBD) is a graphical analysis technique that shows how component reliability contributes to the success or failure of a complex system. RBD explains how the components are related reliability-wise. For people who are not familiar with the modeling technique, an RBD is simple to understand since it shows the physical assets in the system. Figure 1 shows an example of RBD.

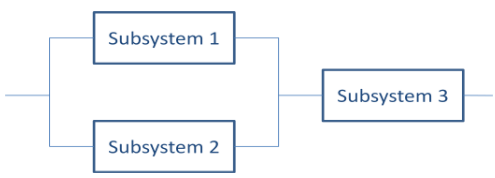

Fig. 1 An example of RBD

A RBD is drawn as a series of blocks connected in series or parallel configuration. Each block represents a component of the system with a failure rate. For series configuration, any failure along a series path causes the entire series path to fail. In other words, series connections represent logic "and" of components. By contrast, parallel configuration is redundant, meaning that all of the parallel paths must fail for the parallel system to fail. Parallel connections represent logic "or". For system that has series and parallel configuration, the connections represent voting logic.

In this study, RBD is analyzed using a Monte Carlo simulation engine that works in a probabilistic ways by randomly drawing the time to failure (TTF) and time to repair (TTR) from stochastic distributions. It uses many simulations in one run and subjects the system to typical events in each simulation. With Monte Carlo simulation it is, therefore, possible to calculate time-dependent availability.

III. Research Framework

The modeling approach is as shown in Figure 2. The study was executed by building a RBD model using Block-Sim 6 software from ReliaSoft. The distribution functions of failure frequencies and repair times for all equipment were determined by statistical analyses of the failure data and maintenance data, respectively, and fitted into Weibull++ software also from ReliaSoft. Once the model was filled with the quantitative data, the model was run and the results and outcomes of the simulation model was validated by maintenance engineers, plant managers and plant engineers using their tacit knowledge of the process and its failures.

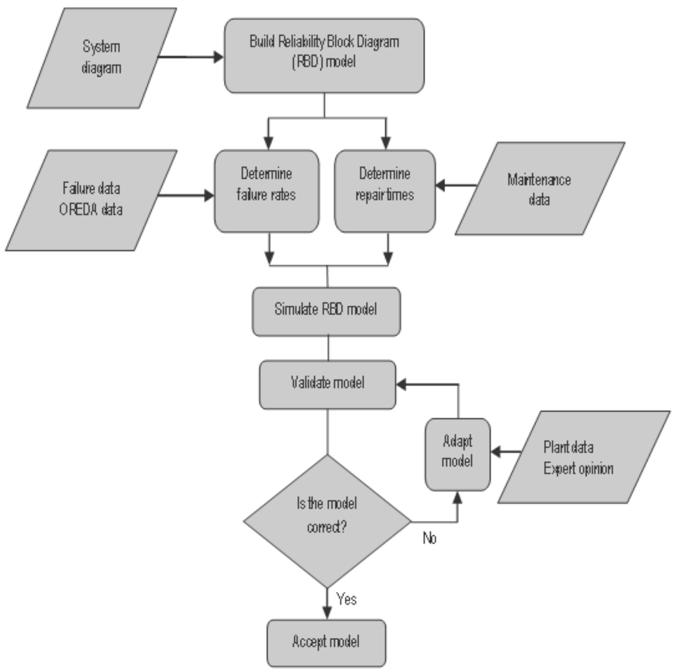

Fig. 2 Modeling approach

IV. Building RAM Model

The study is focused on the acid gas removal plant to understand the impact on the availability of the current process layout should there be an increase of CO_2 level in the feed gas in the future. The data measuring the uptime and downtime of various pieces of equipment in AGRU was taken from the performance data, manual maintenance records as well as the maintenance system. The performance data and maintenance data was used to calculate the MTBF and MTTR for pumps and then trend test will be checked to whether the failure exhibits homogeneous Poisson process (HPP) or non-homogeneous Poisson process (NHPP). If the failure exhibit HPP, then the lifetime distribution can be determined, else, the failure follows the Power law. Figure 3 shows the steps needed to determine the time to failure model [7].

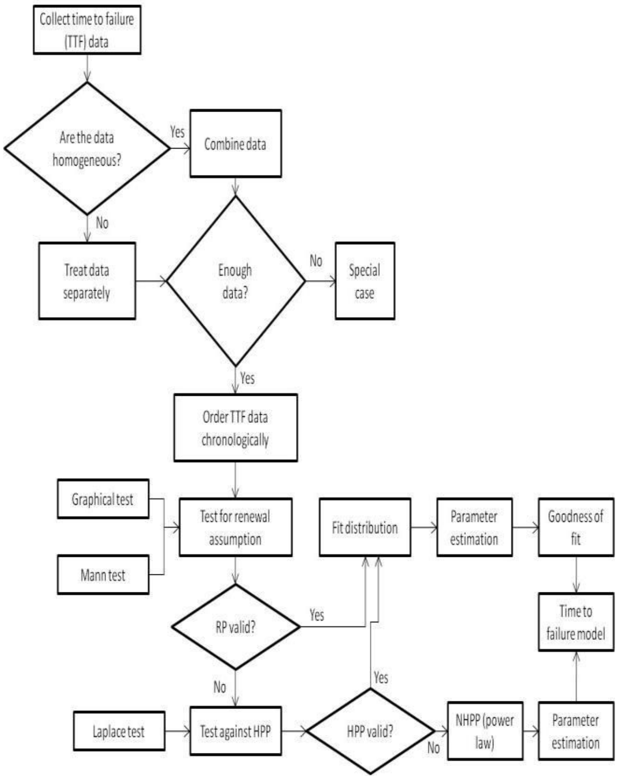

Fig. 3 Steps to determine the time to failure model

V. Results And Discussions

A. Reliability Models for Equipment

Based on the performance data and maintenance data, the results show that most pumps have constant failure rates (i.e. follows the exponential distribution). Two pumps in Plant 3 were found to be the most unreliable equipment and have the highest downtime; therefore, some improvement efforts should be prioritized for these two pumps. Table 1 shows the examples of failure rate of pumps for different plants. Since the behavior of the rotating equipment exhibit random failure mode, the occurrence of next failure cannot be accurately predicted. This result will aid maintenance to strategize the maintenance plan as well as spare parts planning for instance with random failure mode the plant should focus on predictive maintenance rather than time based preventive maintenance.

TABLE I
EXAMPLES OF PUMP FAILURE RATES

Plant	Pump Name	Failure rate (Failure/hr)
Plant 1	PA1	0.0008
	PB1	0.0012
	PC1	6.16×10^{-5}
Plant 2	PA2	4.60×10^{-4}
	PB2	1.99×10^{-4}
	PC2	5.6×10^{-5}
Plant 3	PA3	0.0009
	PB3	1.29×10^{-4}
	PC3	5.62×10^{-5}

B. RAM Model

Figure 4 is the typical result from BlockSim 6 simulation software showing the probable occurrence of failures for each of the equipment as well as the resultant system failure within the period of simulation. The failures are randomly selected from distribution which is the basis of Monte Carlo simulation method. This means that the result will be different for each runs but with enough sampling, it will converge to analytical solution.

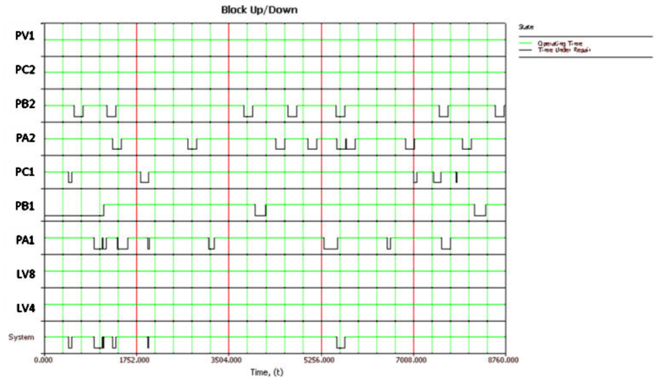

Fig. 4 Typical result from BlockSim 6 software

C. Validation of the Simulated Model

The model was validated by comparing the model results with the actual plant performance data. The results of the model validation are tabulated in Table 2 showing the error between the actual data and the simulated result. The model deemed acceptable as the results comparison shows errors of less than 1%.

TABLE II
VALIDATION RESULTS

Availability	Plant 1	Plant 2	Plant 3
Error (Actual – Simulation)	0.35%	-0.10%	0.08%

D. "What-if" Analysis

Figure 5 shows the example of "what-if" analysis. Assuming that with the current CO_2 content, by running 2-out-of 3 pumps, the availability is 98.35%. However, if CO_2 content increases and maintain running 2-out-of 3 pumps, the availability will drop to 89.19%. Thus, to improve the availability, the proper maintenance strategy should be put in place so that the MTTR will be less than 120 hours, thus achieving 94.89% availability. To further improve, the pump reliability should be improved by having MTBF more than 3 months, thus achieving 98.50%.

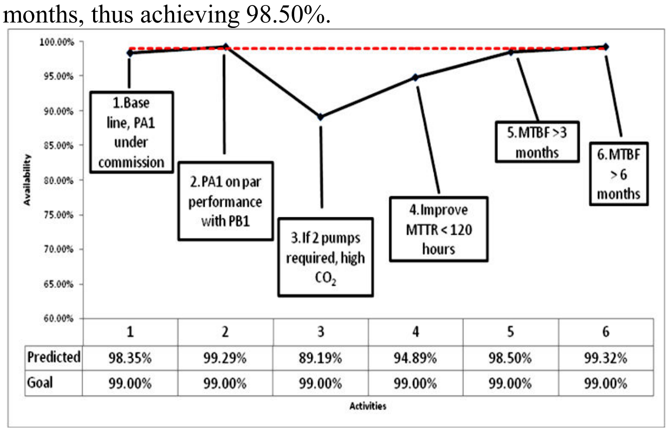

Fig. 5 The "what-if" scenario

VI. Conclusions And Recommendations

RAM model is seen to be a useful tool to improve the plant's availability for existing and operational plants. When the goal is to improve overall availability, this means the reliability must also be improved through increasing MTBF as well as improving the maintainability through reducing MTTR. To understand how much improvements need to be made to MTBF and/or MTTR in order to achieve the plant target availability, RAM model can used to do the "what-if" scenario. Thus, the model can contribute to finding the optimal solutions in term of the optimal number and type of planned maintenance actions. The model can be further expanded to include the maintenance cost factor as well as spare part management that would also contribute to optimizing plant performance.

Acknowledgment

The authors wish to thank Universiti Teknologi PETRONAS and the reviewers for their critical review and constructive suggestions to improve the quality and readability of this paper.

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