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Abstract: Malaysia as the second-largest producer of crude palm oil has abundance of biomass residues from palm oil industries which can be converted to bio-chemicals to generate electricity. However, despite institutional arrangements of the biomass industry, there are several risks which may prone to reduce efficiency of biopower boiler especially empty fruit bunch as the fuel. Boiler is one of the primary equipment of power generation plants, in a significant role in converting biofuel to electricity. The main risk areas in biopower boiler are dearator, economizer, fuel preparation, and water cooling system. Available risk methodologies are not able to provide accurate results for a combination of risks. In this work, Bayesian network approach is introduced to determine and predict risk associated with biopower boiler. The predictive and diagnosis analyses of the Bayesian Network were performed to find the casual links which cause the failure and make a prediction of the control measures to reduce the rate of mistakes. Results revealed that dearator showed a significant effect when the system operates beyond the limits of its design. In conclusion, Bayesian Networks appear to be an assist for decision makers to decide when and where to take preventive or mitigate measures.

1. Introduction

Renewable energy is one of the major contributors in fulfilling the world's energy demand. Biomass is one in all the renewable energy sources that are presently being exploited by the biomass industries. Malaysia produces a minimum of 168 million tonnes of biomass, as well as timber and palm waste, rice husks, coconut trunk fibers, municipal waste and sugar cane waste annually [1]. The biomass industries started using biomass wastes as fuel for energy sources due to the low rates of pollution and they can cut back the number of waste drop. Palm oil industries use the waste from processed palm fruits, namely mesocarp fibre, kernel shell and empty fruit bunch as fuel to get steam so as to burn the fuel and generate power [2].

As fossil energy assets falling-off and fuel costs rise, the improvement of biomass power in the world extends, bolstered by measures, for example, the Renewable Heat Impetus and the Renewables Obligation [2]. The quick advancement of this industry has a positive environmental effect at the same time, progressively, there are inquiries over the security of EFB biomass power generation frameworks. The best biopower generation frameworks are the result of a working partnership between planner, mechanical and building administrations engineer where all parts of structure, the board and task are painstakingly

considered and incorporated, with an accentuation on wellbeing and security. As of 2016, the biopower industry in Malaysia had reached maturity stage which resulted to setting up of Large-Scale biomass, biogas and small hydro plants. However, there is challenge in feedstock availability and pre-treatment for large scale power generation as the treatment cost would result in high feedstock cost than coal. There were 6-8 EFB biopower companies that the government planned to install them, but only 4 companies are available now due to the cost and safety of the biomass power plant [4,7].

Biomass power plant boiler is one of the primary equipment of fired fuel power plants. The main systems in a biopower boiler are dearator, economizer, water cooling system, and fuel preparation. These systems if they could not work properly in the boiler system, it would cause the plant a high economic lost. A risk-based inspection is a kind of pursuit of security and economy of unified system management idea and technique that can effectively estimate equipment risk and reduce the operational cost [2,3]. However, there are several serious risks and health and safety hazards related to EFB biopower boiler that cannot be ignored. As EFB contain around 67% moisture, it requires high intensity of drying to use as fuel in the boilers. Furthermore, the high alkali content of EFB such as K and Na play an important role for organic fertilizers or bioethanol production but not suitable for combustion as it will cause slagging and fouling in the boiler that resulted in plant shutdown and economic losses[4]. EFB needs such care and preparation to be used as fuel, unprocessed EFB could cause the boiler to be too wet and unable to produce steam.

The risk estimation presumably is the most crucial part of the entire procedure of accessing hazards/unsafe situations in the work, and especially in the industries and plants, where the working conditions are sometimes unstable. Usually risk are considered as a quantity, which can be estimated and expressed by a mathematical relation, under the help of real accident's data. Apart from the fact that the calculated risk value is averaged over time and is determined by the parameters considered while others are left disregarded, there are many further uncertainties which can drive the calculated risk value with at least an order of magnitude up- or downwards such as non-identified risks, model simplifications, and inaccurate or missing data [5]. Potential work accidents can happen as consequences of blast boiler system. Equipment in the plant can cause unsafe conditions for workers and the probability of danger arising resulting in disability and even death. Critical failure of degradation of plant equipment during its operation is detrimental in terms of cost, safety and environmental effects. Therefore, continuous attention should be provided to improve available risk assessment methodologies. Also, it is important to develop new risk assessment technique that can provide more information and flexibility to the industry for better risk management than the available techniques.

2. Methodology

Figure 1 summarises the steps to develop a Bayesian Network risk assessment model. The details of each step are described as follows:
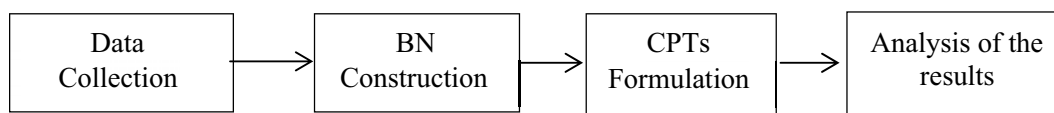

Figure 1. Flow diagram for risk assessment model.

2.1. Data collection
The scope of risk analysis in this present paper is limited to fuel preparation, water cooling system, deaerator, and economizer. In data collection stage, the parameters that reflect the causality scenario were determined. Literature search or biopower boiler historical data is utilized throughout the understanding of the scenario.

2.2. Development of Bayesian Network model
The first step in constructing the BN is the development of the graphical representation to express the cause and effect relationships between the variables. This is important as it provides a straightforward means of analyzing and communicating causal assumptions that are not easily expressed using standard mathematical notation. In this study, a commercial software package namely Hugin Expert was used to construct the BN model. Software Hugin Expert allows interactive creation of the network, maintenance of knowledge bases and integrates new evidence, efficient algorithm to support the implementation of Bayesian probability calculations, thus making a complete probabilistic model [6].

2.3. Formulation of CPTs and prior probabilities
The next step was to specify the possible states and define the conditional probability tables (CPTs) value. The data for prior probabilities and conditional probability tables were gathered from existing literatures. Prior to performing the analysis, the probability values in every column of CPTs were normalized to become 1. Probability values of the marginal and conditional were required to be nonzero in which each condition of CPT is in the range of 0 to 1. The information was collected from existing literatures for onshore pipeline incidents.

2.4. Bayesian Network analyses
Two types of analyses were carried out namely prediction analysis and diagnosis analysis. In the prediction analysis, the model will be updated whenever new knowledge or evidence is available. Meanwhile for the diagnostic analysis, the accidental path will be discovered and the posterior probability will be calculated. Based on the results obtained, a countermeasure to reduce the risk of the important factors should be taken to reduce the effect of the risks.

3. Results and discussion

3.1 Proposed Bayesian Network model
The information was collected based on available literature. Referring to the available data in existing literature, the main areas that bipower boiler risk can occur are fuel preparation, water cooling system, deaerator, and economizer. The possible risks for each category is summarised in Table 1. The developed Bayesian network the relationships of the potential risks at many points along the life cycle of the boiler is shown in Figure 2. This life cycle provides an organization with the capability to integrate risk factors into programs, standards, procedures, and process using a disciplined approach.

In the fuel preparation, evaluation of environmental and occupational health impacts needs an understanding of the properties and characteristics of the fuel, moreover as thought of fuel process, handling and storage. After the fuel is fed to the boiler, deaerators commonly used to remove oxygen and different gases from the water that feeds into boilers that generate steam. Deaerators are helpful as they take away the gases that attach to the metallic parts of the steam system which may cause corrosion by forming oxides, or rust.

Water cooling system is commonly heat rejection system that rejects waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Cooling towers may either use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature, the water used must cleaned from wastes or it may cause pipeline blockage. After the water cooled, it goes through the economizer where it recovers a portion of this heat for pre-heating the feed water and/or combustion air. Risks can mostly occur at these areas which will reduce the boipoer boiler efficiency. These risks may eventually result in an operator making improper decisions.
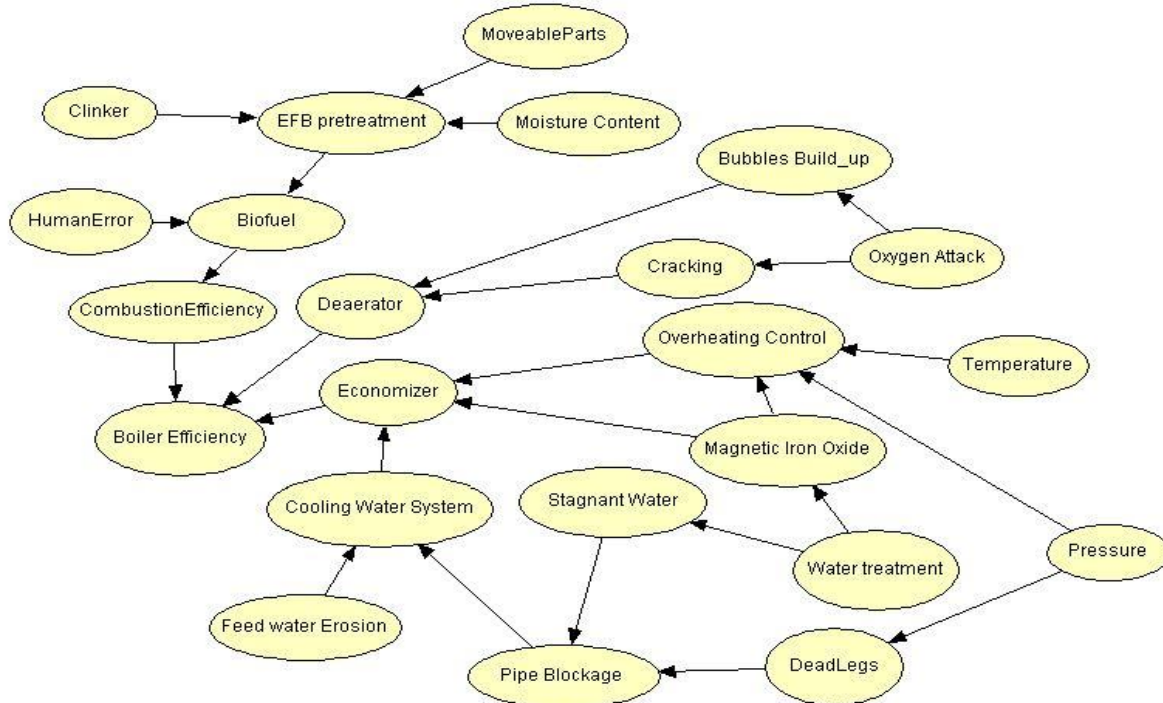
Figure 2. BN model of risk due to different areas.

3.2. Prior probabilities generation

The variables and states of activities on biopower boiler that will lead to reduce efficiency of the combustion tabulated as in Table 1. In this paper, the probability data were extracted from different literature sources rather than from a specific boiler. These data sources were gathered base on the experience from different biopower boiler operations in order to generate the prior probabilities and conditional probability tables.

Table 1. Parameters and the data sources for probability distributions.

Parameter	States	Probability data sources	Parameter	States	Probability data sources
Moisture content	High, Low	[7,8]	Temperature and pressure	High, Low	[12-14]
Movable parts	Yes, No	[8]	Overheating control	Good, Poor	[7-12]
Clinker	Yes, No	[9]	Magnetic iron oxide	Good, Poor	[5,13]
EFB pretreatment	Good, Poor	[7-9]	Stagnant water	High, Low	[15]
Biofuel	Good, Poor	[9.10]	Pipe blockage	Yes, No	[8,13]
Human error	Good, Poor	[11]	Feed water erosion	High, Low	[16]
Combustion efficiency	Good, Poor	[9-12]	Water cooling system	Good, Poor	[14-16]
Oxygen attack	High, Low	[10]	Dead legs	Good, Poor	[15]
Bubbles build up	Yes, No	[12]	Economizer	Good, Poor	[13,14]
Cracking	Good, Poor	[11,12]	Boiler efficiency	Good, Poor	[8-16]
Dearator	Good, Poor	[10-12]	Water treatment	Good, Poor	[15,16]

3.3. Bayesian Network analyses

The prior probabilities from the data sources listed in Table 1 were utilized to determine the probability of biopower boiler risks. The prediction of the boiler efficiency is as depicted in Figure 3. From the results obtained, the highest risk found was from deaerator with 68% contributions which include oxygen attack (71%), cracking (74%), and bubbles build up (71%) will lead to boiler failure. The rule of deaerator is that the gas solubility in a solution decreases because the temperature of the solution rises and approaches the saturation temperature. The deaerator system must make sure that oxygen level are not too high or too low because the use of biomass fuel, EFB, is really risky. It takes so much effort to extinguish burning EFB fibers inside the furnace.

The second highest error of 38% contribution was from economizer system which consist of water cooling system (38%), overheating control (44%), and magnetic iron oxide (31%) caused boiler malfunction via water supplying to produce steam. The potential economizer relies on the prevailing stack temperature, the quantity of make-up water required, and also the hours of operation. Economizer needs a good monitoring system to notice the problem if it occurs. Maintenance is highly needed for economizer to make sure pipes are not blocked or boiler reach overheated level.

Finally, EFB pretreatment activities contributing to 37%, which include moisture content (30%), moveable parts (39%), clinker (15%), and human error (20%) are associated with boiler failure. Operational errors occur when testing the quality of the fuel, if the quality is outside of or beyond the parameters of its design, the boiler will not be able to burn and produce steam. For example, when utilizing EFB as fuel, the high moisture content of EFB affects strongly the combustion process such as lowering the flame temperature and/or the boiler efficiency. Unprocessed EFB is presented as very wet whole empty fruit bunches each weighing several kilograms while treated EFB is a fibrous material with fiber length of 10-20 cm and reduced moisture content of 30-50%.
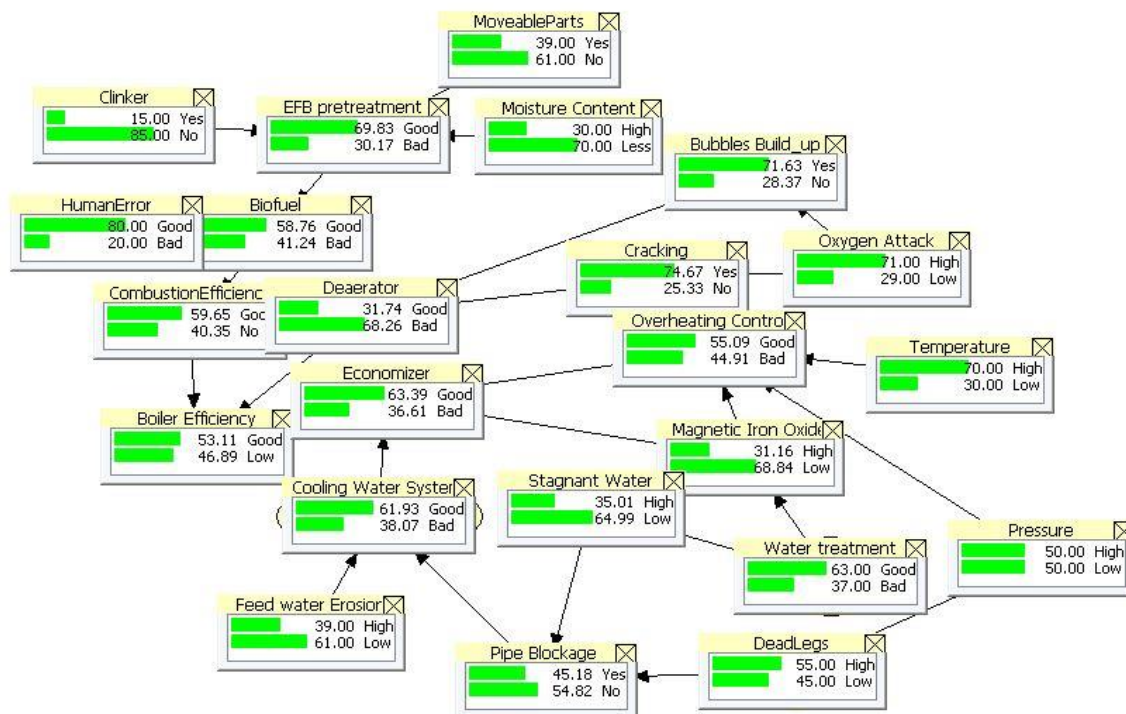

Figure 3. BN model with monitoring window.

3.4. Diagnosis analysis

The diagnostic analysis in Bayesian network inference was adopted to calculate the posterior probabilities of basic events which can be used to find the weak links exist in the human error of oil and gas pipelines. The posterior probability distribution of each risk factor in case of an accident. In this initialized situation, the nodes were characterized by their prior probabilities as presented in Figure 3. Suppose it observed that boiler efficiency is in state Poor and P(Boiler Failure =Poor)=1 was entered into the model. This entered evidence increase the belief in all of the possible causes based on diagnostic inference. This will result in 76% probability due to deaerator, 45% due to economizer and 61% due to combustion efficiency. Figure 4 shows the results of the revised posterior probability for each risk factor area. It can be observed that the occurrence probability due to deaerator, economizer, and combustion efficiency increase to approximately 76%, 45% and 61% respectively.

Overall the most influence factors are from bad decision making and poor communication in the organisational. From the analysis, the practical fault diagnosis and checking should then focus on the probability of these suspected factors to control the risk of boiler failure. Therefore, the posterior probabilities can provide new evidential information for fault diagnosis in real time. By performing this analysis, the posterior joint probability of all variables/parents given the accident occurrence are helpful for safety evaluation.
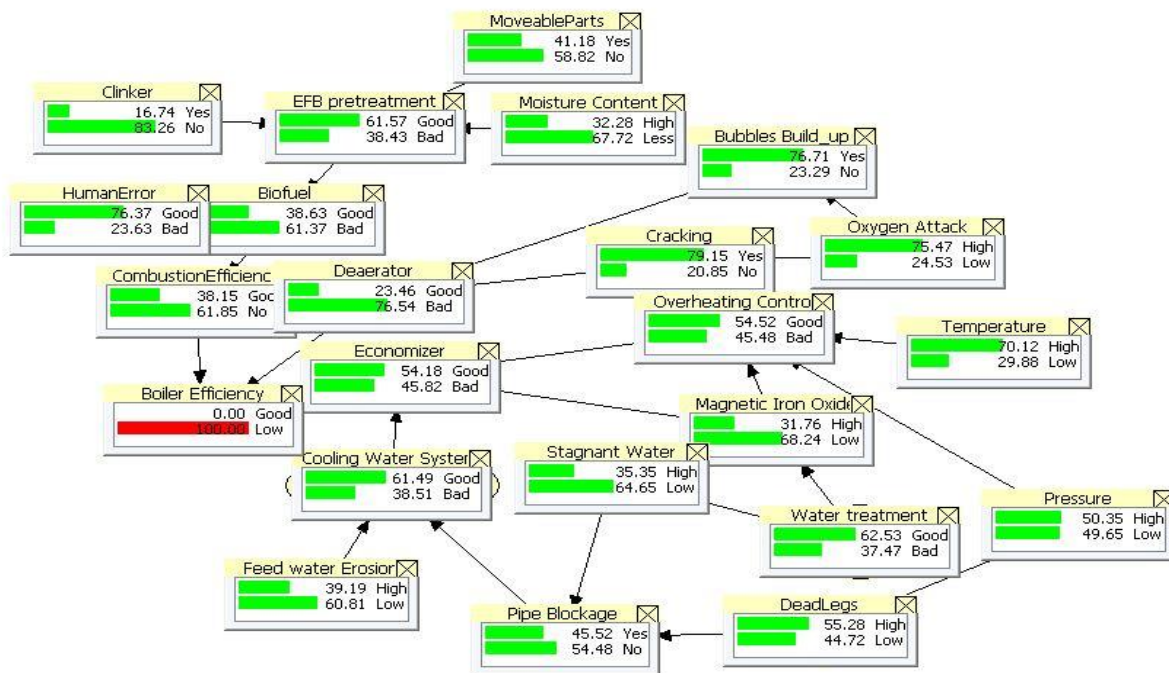

Figure 4. BN model for diagnosis analysis.

3.5. Predictive analysis

Evidence propagation was conducted to predict the probability distribution of the framework outcome and other relevant variables under the combination of changes in the assumption of certain variables. The aim of the analysis was to predict the probability distribution of the occurrence of boiler failure factors before an accident occurs. In this section, the propagation of evidence examines several different scenarios and combinations of events taking place (i.e. 100% probability). To check the proposed Bayesian network model, the percentage of biopower boiler risk areas in terms of bad response to change, no alarms prioritized

and bad quality of data were considered. As a result, the probability of boiler failure is increases up to approximately 54% as shown in Figure 5.

According to Bayesian logic, the only method to measure a situation with an undefined outcome is through defining its probability. Bayes' theorem can provide a scientific method that could be used to calculate, given events in prior trials, the probability of a target occurrence in future trials. Hence this Bayesian model predictive-analysis is another example of Bayesian logic which can be used to predict future events for decision making.
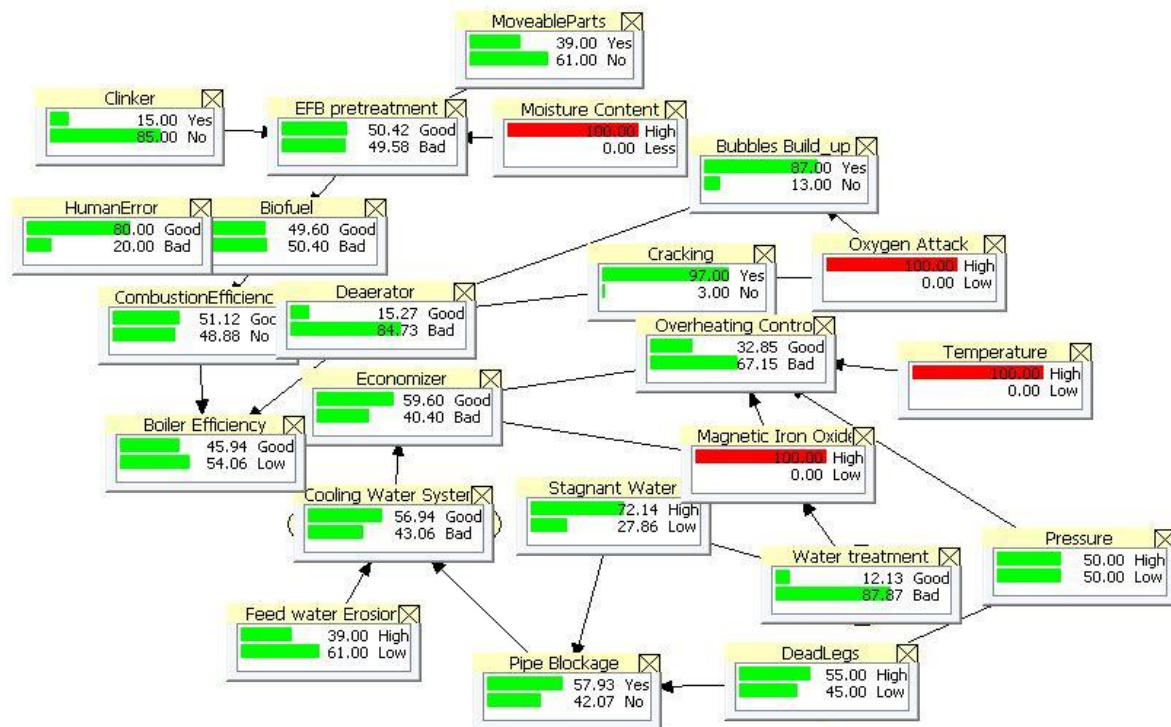

Figure 5. BN model for predictive analysis.

4. Conclusion

In this study, a quantitative risk analysis approach due to EFB biopower boiler is constructed using Bayesian network. The proposed model is constructed according to a cause and effect relationship. Two types of analysis were carried out to explore the advantage of the proposed approach. Through forward prediction analysis, the probability of boiler failure occurrence can be calculated based on the evidence occurred. Meanwhile, through diagnostic analysis, the critical risk factors that may lead to failure occurrence were determined. From the results obtained, the proposed Bayesian network inference techniques can be applied to provide valuable understandings to the prevention of accidents and safety improvement. The counter measure could be suggested based on the results in order to reduce the risk of boiler failure. In general, this work is mainly based on collection of different existing data sources and the accuracy of the biopower boiler failure prediction could be further improved with more relevant failure data. As Bayesian Network is able to integrate various type of data, expert judgment together with real data from a specific case study should be utilised for future works.

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