Quality Analysis of Refused-Derived Fuel as Alternative Fuels in the Cement Industry and Its Evaluation on Production*

Kuntum Khoiro Ummatin, Qurrotin A. M. O. Arifianti, Aulia Hani, Yulis Annissa, *Department of Engineering Management, Universitas Internasional Semen Indonesia*

***Abstract*— Refused Derived Fuels (RDF) as an alternative fuel from municipal solid waste (MSW) is still required by the cement industry. Besides it has a high calorific value, RDF has a more economical price than coal. RDF production is also able to solve the problem of MSW and reduce CO_2 emissions. One of the cement industries in Indonesia has developed various alternative energy materials to reduce the use of coal, including rice husk, coconut fiber, and energy from MSW, which is processed into RDF.**

The purpose of this study is to investigate the RDF quality standard that is in accordance with the needs of the cement industry and evaluate the RDF production process. Quality Function Development (QFD) method is used to determine the parameters of RDF quality standards that are suitable for the cement industry.

The results of the QFD analysis show that there are six main characteristics in the RDF quality standard based on importance response, including RDF 3-5 cm, particulate 80 mg/Nm^3, humidity level ≤ 20%, mercury 5 mg/Nm^3, calorific value ≥ 2500 kcal/kg and low ash content. While the evaluation of the production process shows the number of RDF rejects quite high. The priority of process improvement with root cause analysis shows that it is necessary to conduct pre-production treatment of RDF on MSW material by drying, reduce impurities content through the screening process, and ensure the design of blades on the shredder in order to achieve the targeted size. The contribution of this research is for the development of alternative fuels RDF in the cement industry, especially in determining quality standards and procedures for optimal RDF results.

Keywords: Standard Quality, Refused-derived Fuels, QFD

I. INTRODUCTION

The cement industry usually requires coal as much as half of the cement produced [1]. One of the cement industries in Southeast Asia has a zero-waste program which processes waste around the factory. Municipal Solid Waste (MSW) would be processed into RDF as coal substitution in cement production. The other alternatives fuels that have been developed are rice husk and cocopeat. This policy is supporting the development of alternative fuel and solve the environmental problem at once.

Currently, MSW treatments in Indonesia are landfilling, burning, and dumping in unauthorized sites or into rivers. It cannot decrease the MSW totally, but it creates another problem, for example, pollution. The pollutant was known as CO_2, NOX, SO_2, etc.[2] Total of MSW in Indonesia in 2006 was 38,5 million tons/year which the most significant component is an organic waste (58%), plastic waste (14%), paper waste (9%), and wood waste (4%) [3].

The increasing population, followed by increasing the amount of MSW. It becomes a serious problem if there is no waste management program[4]. Waste to energy is a solution for MSW that will increase to approximately 2.2 tons per year in 2025**[5]. MSW is processed become SRF and refuse-derived fuel (RDF) products. That are suitable for cement works and power sectors** [6].

This research focuses on RDF production. There are two materials which contribute to the calorific value of RDF, high and low calorific value group. The high calorific value groups are paper waste and plastic waste (18600 Joule/gram). Inorganic materials such as fine glass and wet organic matter form a fraction that has a relatively low calorific value of 10,800 Joules/gram. Good quality RDF should have a high calorific value and low concentration of toxic compounds, namely heavy metals and chlorine[7]. The RDF production process includes the stages of sorting and enumeration. The process starts from moving the municipal waste dump with the excavator going to the hopper. Then this sorting process begins from the dried municipal waste to ballistic separator through a belt conveyor equipped with a magnetic separator to separate metal material from municipal waste. Finally, at the enumeration stage, municipal waste that has been sorted into the shredder machine would be chopped into smaller parts [8].

RDF produced from MSW treatment has calorific value to reach almost 3.500 kcal/kg[9]. Sarc and Lorben have been describing characterization, classification, production, application and quality assurance of RDF that is increasingly used in a wide range of co-incineration plants[10]. However, there has been no research on the quality of RDF explicitly needed in the cement industry. This research would analyze the main characteristic of RDF that needed to substitute coal in cement industry. Quality of RDF as an alternative fuel will be formulated using Quality Function Deployment (QFD). One of the stages in the QFD method is to look for user needs and prioritize the main variables are following with customer needs. The QFD method is also widely used to develop renewable energy system based on specified requirements and the quality characteristics of the existing system, for example in solar energy [11] and wind turbine[12].

Besides, an investigation in the RDF production is done to ascertain whether the RDF output of production follows the target. Evaluation of the production process is carried out using the Root Cause Analysis (RCA) method. This method has been widely used to improve product quality and productivity[13].

II. METHODOLOGY

The methodology used in this research began with an analysis of RDF quality that was equivalently the needs of the cement industry, using QFD. Based on the QFD method, link the voice of the customer with technical requirements then given weights with a value of 1 (low), 3 (medium), and 9 (high). The assessment weight is used in the House of Quality (HOQ) analysis in the QFD matrix.

HOQ consists of several combined matrices, each of which contains interconnected information between one matrix and another. All matrices at HOQ describe aspects of all processes for planning new products, services, or processes. The phases in the QFD include Phase 0 (planning QFD), Phase 1 (digging Voice of Customer), Phase 2 (building HOQ). The first step was determined the customer need. A five worker of the department of alternative fuel were invited in a Focus Group Discussion to prioritize the quality variable that needed in the cement industry.

Furthermore, the engineering metric (technical response) was designed to answer customer needs. Based on engineering metric, the product specifications can be formulated. Product specifications are carried out by determining benchmarking on need, which is comparing products similar to RDF. The HOQ matrix image can be seen in Fig. 1 [14]

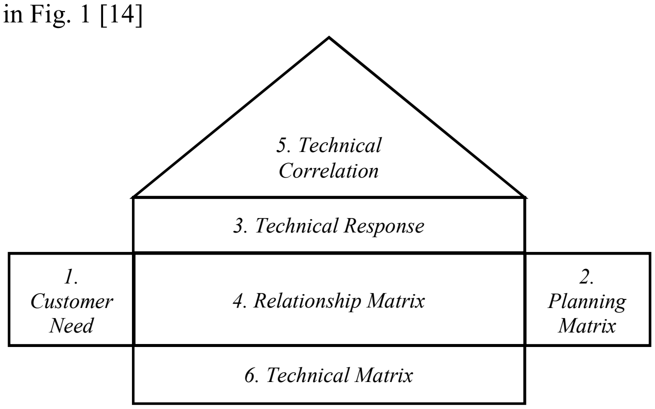

Figure 1. House of Quality Matrix

In the initial stage, point 1 in the HOQ is to determine Customer Need based on the voice of the customer. Therefore, point 2 is compiling the Planning Matrix in the form of metrics and units. Then, point 3 collecting Technical Response by connecting the parameters with Customer Need. Continued to point 4, namely the Relationship Matrix by benchmarking the products used as research objects with other similar products. Then point 5 is the technical correlation by connecting the metric with the other metrics. Continued point 6, namely the Technical Matrix by setting targets and final specs[14].

After priority quality parameters have been obtained, further evaluation of the RDF production process is carried out. A zero-waste project that is processing MSW into RDF in a cement industry was investigated using the RCA method. RCA is a procedure for identifying causal factor to provide resolving problem by determining what has happened, why it has happened, and what to be done to reduce the likelihood of reccurence[13].

III. QFD ANALYSIS

A. Determine Customer Need

The variable used in the quality analysis is the response of PT Semen Indonesia related to the consumption of RDF, the expectation of use of RDF, and rank of importance (1 = not important and 5 = very important) classified in several aspects. There are price, technical, and environmental. Price aspects include heating value and moisture content. Technical elements comprise chlorine levels and RDF size. Environmental consist of particulate levels, Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_2), Hydrogen Fluoride (HF), Hydrogen Chloride (HCL), Carbon Monoxide (CO), Cadmium (Cd), Mercury (Hg), Lead (Pb), Arsenic (As), and Nickel (Ni) [11].

The five responsible workers, who consist of one manager, one coal mill supervisor, one operation supervisor, two operation section experts in The Department of Alternative Fuels in the cement industry, and the two workers in Waste Processing Plant were invited in a Focus Group Discussion (FGD). Each customer need was equipped with an importance response (IMP) numbering 0 to 5 as an interval scale. It will be processed by prioritizing the characteristic of RDF based on Important Response Rank. Result of importance response is shown in Table 1.

TABLE I. CUSTOMER NEED

IMP	Customer Need
5.0	Water Content
4.0	Temperature Setting
5.0	Impurities Content
3.0	Pre-production Method

B. Design Technical Response

After customer need has been concluded, the engineer can design engineering metrics to answer customer need. Parameters design must be appropriate and related to customer need. For example, the first customer need, water content, is associated with calorific value because the water content level can reduce calorific value. Besides, the water content also effects on Nitrogen Oxide and Hydrogen Chloride that makes the burning process of RDF becomes imperfect. Then, the second is the temperature setting. The not optimal temperature setting can cause Chlorine, which interferes the engine performance. This condition produces a larger size of RDF due to RDF conditions that are not completely dry.

For the impurities content is correlated with ash content and particulate. This is because the levels of impurities can form ash and particulate. Ash produced can be reused as a raw material for cement production, while particulate can pollute the environment. The last customer need, pre-production methods, is correlated with the amount of Sulfur Dioxide, Hydrogen Fluoride, Cadmium, Mercury, Lead, Arsenic, Nickel, Chromium, Cuprum, and Cobalt. These elements can become environmental pollutants because there is no good management of waste before it was processed into RDF. Some pre-production methods what can be done include rough landfilling, drying and sorting process before entering the processing machine for further processing[15].

C. Arrange Product Specification

Based on engineering metric, the product specifications can be formulated into three aspects; there are namely price, technical, and environmental aspects. Calorific value and moisture content are categorized as price aspects. It is because the increase in water content will cause a decrease in calories, and the price of RDF will also decrease. For technical aspects there are Chlorine and size. Both of these parameters can interfere with the operational engine process. Also, there is ash content in the technical parameters. Ash formed during the production process can be reused as raw material for cement production. Other variables are classified as environmental aspects because they are emissions that can pollute the environment.

Then, the benchmarking was done by compared rankings of RDF interests with rice husks based on customer needs to be obtained from the questionnaire results with respondents from the managers of the Alternative Fuel of the cement industry. Rice husk was chosen because it is an alternative fuel that is often used, and its availability is adequate, the average utilization of rice husk reaches 51 thousand tons/year. Rice husk is easy to use because it does not require special requirements, except for total moisture of 20%. Utilization of alternative fuels as a substitute for coal is not only rice husk but also uses cocopeat with average utilization of 21 thousand tons/year. In 2017, 832 tons of tobacco, and 75 tons of resin were used. RDF was not compared to coal because it is classified as fossil fuels with higher emissions than alternative fuels. The RDF benchmarking with rice husk is shown in Table 2.

Furthermore, a comparative analysis between RDF and rice husk was conducted. Water content in rice husk is better than RDF. It is proven by the calorific value so that the optimal temperature setting was more easily achieved because rice husk is more flammable than RDF. While the level of heterogeneity in the impurities content in rice husk is lower than RDF because rice husk comes from more homogeneous processing.

TABLE II. RDF BENCHMARK

Metric No.	***Need Nos.***	***Engineering Metric***		**IMP**	***Units***	**Rice Husk**
1	1, 2	*Price*	*Calorific Value*	5	kcal/kg	3300
2	1, 2		*Moisture Content*	5	%	3.65
3	2	*Technical*	*Chlorine*	4	%	-
4	2		*Size*	5	cm	-
5	3		*Ash Content*	5	%	8
6	3	*Environmental*	*Particulate*	5	mg/Nm^3	8
7	4		*Sulphur Dioxide*	5	mg/Nm^3	19
8	1		*Nitrogen Oxide*	5	mg/Nm^3	27
9	4		*Hydrogen Fluoride*	5	mg/Nm^3	5.46
10	1		*Hydrogen Chloride*	5	mg/Nm^3	5.46
11	4		*Cadmium*	5	mg/Nm^3	-
12	4		*Mercury*	5	mg/Nm^3	-
13	4		*Lead*	5	mg/Nm^3	-
14	4		*Arsenic*	5	mg/Nm^3	-
15	4		*Nickel*	5	mg/Nm^3	-
16	4		*Chromium*	5	mg/Nm^3	-
17	4		*Cuprum*	5	mg/Nm^3	-
18	4		*Cobalt*	5	mg/Nm^3	-
19	1		*CH4 (Organic Carbon & Hydrocarbon)*	5	mg/Nm^3	-
20	2		*Dioxin Furan*	4	mg/Nm^3	0.06

D. Design Relationship Matrix

Relationship matrix is a weighted stage of the value of the correlation between customer need and engineering metrics in each variable. Evaluation weight was divided into a weak relationship (▲) valued 1, moderate relationship (O) valued 3, and strong relationship (⊗) valued 9. For example, calorific value and moisture content were classified as strong relationships with water content because if the intensity high or the temperature setting was not optimal. It causes RDF products to contain high moisture content so that the calorific value was low.

While Chlorine is classified as a weak relationship because it affects the corrosion of the engine instead of RDF products, the size of RDF was classified as a strong relationship to the temperature setting because if the temperature is not optimal, it caused by RDF that not dried completely. Thus it inhibits the enumeration process. Besides, RDF content is classified as a strong relationship with the impurities content because it can be reused as a mixture of raw materials for cement production. However, particulate

RDF is classified as a moderate relationship with the impurities content because it has an impact on the environment, but it can still be re-used as ash.

The Sulfur Dioxide, Cadmium, Mercury, Lead, Arsenic, Nickel, Chromium, Cuprum, Cobalt, and Dioxin Furan are classified as weak relationships with the pre-production method because they tend to affect the environment rather than RDF products. For example, acid rain, irritants, toxicity, and hardness of the water. Also, CH_4 (Organic Carbon & Hydrocarbon) is classified as a moderate relationship to the pre-production method because it is caused by a storage system in conditions that are open before processing, but this variable also has an impact on environmental pollution. All of the relationships between variable is shown in table 3.

TABLE III. RATING WEIGHTING ON THE RELATIONSHIP MATRIX

Engineering Metric		**IMP**	*Water Content*	*Setting Temperature*	*Impurities Content*	*Pre-production Method*
			Customer Need			
1	*Calorific Value*	5	⊗	⊗		
2	*Moisture Content*	5	⊗	⊗		
3	*Chlorine*	4		▲		
4	*Size*	5		⊗		
5	*Ash Content*	5			⊗	
6	*Particulate*	5			O	
7	*Sulphur Dioxide*	4				▲
8	*Nitrogen Oxide*	4	O			
9	*Hydrogen Fluoride*	2				O
10	*Hydrogen Chloride*	2	O			
11	*Cadmium*	3				▲
12	*Mercury*	2				▲
13	*Lead*	3				▲
14	*Arsenic*	3				▲
15	*Nickel*	2				▲
16	*Chromium*	2				▲
17	*Cuprum*	2				▲
18	*Cobalt*	2				▲
19	*CH_4*	3	O			
20	*Dioxin Furan*	4		▲		

E. Determine Technical Matrix

The Technical Matrix is a stage to determine the final specs of RDF in accordance with the needs in the cement industry. It used as a reference in cement production. The final specs or target values are determined based on the Decree of the Minister of Environment and Forestry of the Republic of Indonesia in 2016 concerning Permits for the Management of Hazardous and Toxic Waste for the Use of Hazardous and Toxic Materials on the cement industry. The final specs of the RDF shown in Table 4.

TABLE IV. FINAL SPECS OF RDF

Engineering Metric		**Final Specs**
1.	Calorific Value	≥2500 kcal/kg
2.	Moisture Content	≤20%
3.	Chlorine	≤1%
4.	Size	3-5 cm
5.	Ash Content	-
6.	Particulate	80 mg/Nm^3
7.	Sulphur Dioxide	800 mg/Nm^3
8.	Nitrogen Oxide	1000 mg/Nm^3
9.	Hydrogen Fluoride	10 mg/Nm^3
10.	Hydrogen Chloride	70 mg/Nm^3
11.	Cadmium	350 mg/Nm^3
12.	Mercury	5 mg/Nm^3
13.	Lead	35 mg/Nm^3
14.	Arsenic	1000 mg/Nm^3
15.	Nickel	<0.5 mg/Nm^3
16.	Chromium	800 mg/Nm^3
17.	Cuprum	<0.5 mg/Nm^3
18.	Cobalt	<0.5 mg/Nm^3
19.	CH4 (Organic Carbon & Hydrocarbon)	10-100 mg/Nm^3
20.	Dioxin Furan	35 mg/Nm^3

IV. ANALYSIS OF QFD RESULT

Based on the results of the data analysis above, each variable that affects the quality of RDF has an important response which can be sorted from the most important variables as in Table 5. IMP Rank is obtained from the value of importance response mode in each engineering metric variable; the total mode value is then added up. To get the importance percentage obtained from the mode value of each variable divided by the total of all the values obtained. Then the average importance response in all engineering metric variables is divided by the sum of results and used as a percentage. Therefore, in improving the quality of RDF, it is more important to prioritize aspects that have a higher importance response to be in accordance with customer need. The rank of an important variable that prioritized to be a quality parameter of RDF was shown in table 5.

Quality improvements are adjusted to the final specs that have been determined. Variables that have the highest level of importance according to their aspects are as follows:

1. Price aspect: moisture content and calorific value.
2. Technical aspect: size and ash content.
3. Environmental aspect: particulate and mercury

TABLE V. VARIABLE BASED ON THE HIGHEST IMPORTANCE RESPONSE

Importance	***IMP Rank***
Size	7.2%
Particulate	7.2%
Moisture Content	7.2%
Mercury	7.2%
Calorific Value	7.2%
Ash Content	7.2%
Sulphur Dioxide	5.8%
Nitrogen Oxide	5.8%
Dioxin Furan	5.8%
Chlorine	5.8%
Nickel	4.3%
Cadmium	4.3%
Arsenic	4.3%
Lead	2.9%
Hydrogen Chloride	2.9%
Cuprum	2.9%
Cobalt	2.9%
Chromium	2.9%
CH_4 (Organic Carbon & Hydrocarbon)	2.9%
Hydrogen Fluoride	2.0%

V. EVALUATION OF RDF PRODUCTION

Succeeding the quality parameters of RDF expected by the customer are obtained. Six primary parameters prioritized by a cement industry including RDF size 3-5cm, particulate 80 mg/Nm3, humidity level ≤20%, mercury 5 mg/Nm3, calorific value ≥2500 kcal/kg and low ash content. Then, it is necessary to ensure that the operations of RDF produce the output as targeted.

A zero-waste project that is processing MSW into RDF in a cement industry was investigated using RCA analysis by a cause-effect diagram. The project was a trial production, and it produced 50 tons RDF in one month. Consider the output, it shows a quite high number of RDF reject that is not suitable with the purpose. For example, the calorific value of RDF was low due to the high humidity level. Also, the size of the RDF output was not homogeneously as the targeted.

These problems were analyzed using the RCA method by an identified causal factor in providing a resolved issue. The process started from determined what has happened, why it has happened, and what to be done to reduce the likelihood of recurrence.

The investigation on the RDF production focuses on four things, namely method, material, machine, and man. The observation on RDF production shows that the method of processing the waste does not has pre-production treatment.

The MSW material that was prepared was taken directly from open storage landfills that contain impurities such as soil, rocks, gravel. Besides, the landfill systems also cause waste dumped exposed to moisture and rain. These conditions can interfere with machine operation. While the maintenance process is not routinely scheduled yet, so when the machine was clogged, the production process should be stopped.

Furthermore, the machine can not cut the waste in homogeneous size because of the kind of blade that does not suit the type of waste. The lack of workers, procedures and job descriptions for the worker also contributes to the problem. This condition was described in a cause and effect diagram, as shown in figure 2 in the appendix.

From the causal effect diagram, it could be analyzed what the improvement process needs to be done to reduce the problems. The priority of improvement process with root cause analysis shows that it is necessary to do pre-production treatment of RDF on MSW material by drying, conduct screening process to reduce particulate content, and ensure the design of blades on the shredder that can fit the material type. These priority improvements are chosen based on the target rank expected as an RDF needed by the cement industry.

VI. CONCLUSION

The results of the qualitative analysis using the Quality Function Deployment (QFD) method can be concluded that the quality variables that are acceptable based on price aspects are moisture content and calorific value, while technical aspects are the size and ash content. Then, variable based on environmental aspects are particulate and mercury. Six primary parameters prioritized by a cement industry including RDF size 3-5cm, particulate 80 mg/Nm^3, humidity level ≤ 20%, mercury 5 mg/Nm^3, calorific value ≥ 2500 kcal/kg and low ash content.

Improving the quality of RDF can be done by reducing the water content in RDF, setting the right temperature in the drying machine, reducing the impurity content, and conducting the pre-production method. Pre-production treatment can be carried out, such as by drying and screening the material before production. Besides, it is necessary to ensure the design of blades on the shredder that fits the material. This research provides an overview of the cement industry to design a quality RDF production process to meet the standards as an alternative fuel for substituting the coal.

APPENDIX

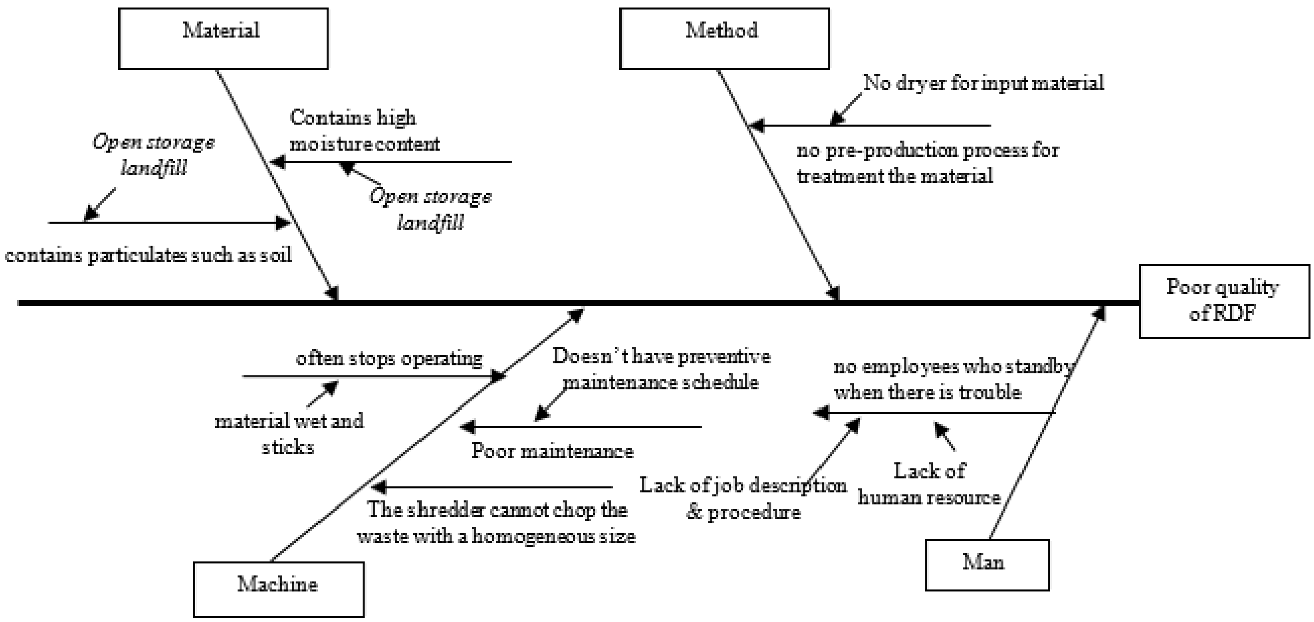

Figure 2. Cause and Effect Diagram

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