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Application of Decision Matrix for the Selection of the Best Conceptual Design for a Small Scale Solid Waste Fired Steam Boiler

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Abstract: *The evaluation and selection of the best conceptual design for any machine or equipment based on some decision criteria, often present some difficulties to engineering designers. This work presents the application of decision matrix for the selection of the best conceptual design for a small scale solid waste fired steam boiler. Applying the concept of decision matrix enables engineering designers and students to provide more accurate decision about problems involving conceptual design according to some given criteria. Different conceptual designs of the boiler were generated vis-a-viz: fixed grate with circular tube, fixed grate with stepped tube, moving grate, rotating grate, step grate and modular boiler. The criteria used for selecting the best small scale solid waste fired steam boiler, using the weighted decision matrix, were based on the following: waste treatment, energy recovery efficiency, manufacturability, feasibility, cost (planning, materials and construction), safety (environmental and direct health risk) and operational cost. The result reveals that the best conceptual design was the stepped grate which had a weighted score of 930 followed by the moving grate, fixed grate with stepped tube and fixed grate with circular tube having weighted scores of 830, 790 and 780 respectively.*

Keywords— Boiler, Conceptual design, Criteria, Ranking and Weighted Score.

1. NTRODUCTION

Decision matrix is a tool for comparing different conceptual design solutions against one another by applying specific criteria such as cost, operational efficiency, maintainability etc. There are two main phases in engineering design process, namely – conceptual design and detail design. In concept engineering design (CED), the purpose specified for the design requires information such as functional needs, operational constraints and evaluation criteria.

The selection of the best design is the ultimate goal of CED. The best concept that is selected is further developed in the detail design phase. It is often very difficult to evaluate many conceptual designs at random because one may possess some advantages over the other, but overall it may not be the best concept when a lot of other criteria are considered.

The aim of this work is to apply decision matrix for the selection of the best conceptual design for a small scale solid waste fired steam boiler. This work was carried out by applying certain criteria to a number of conceptual designs and comparing them against one another based on specified criterion. The end result of applying decision matrix is that it enables us to choose the best concept which is then developed further in the detail design. The application of decision matrix on the present work is limited to a small scale solid waste fired steam boiler.

According to Feyzi (et al, 2019) concept assessment and screening are popular variants of the decision method based on matrix. Karakus (et al, 2020) asserted that the concept of selection in engineering practice is most commonly done by applying decision matrix method. Using decision matrix helps to identify the strongest concept by employing an iterative evaluation that can test the comprehension and completeness requirement. Bakir and Atalik (2021) stated that the ratings of sustainable alternative options related to cost, environment and quality are also considered. Yalcinkaya (et al, 2020) asserted that the importance of the decision evaluation process is that it plays a significant role in the flow of scenario, because variant of the enterprise are interested in bringing out new products within a short period of time.

2. METHODOLOGY

The methodology used to carry out the specific objectives of this work is discussed in this section.

2.1. Conceptual Designs

The conceptual designs of the solid waste fired steam boilers was conceived using incinerators with heat recovery devices and are described in this section. They use different types of grates and are meant for the combustion of moderate volume of solid waste. The steam boilers are small scale designs which can be scaled up to meet the design specification of any particular unit. Water tube boiler is used as the heat recovery device in the combustion chamber of the steam boilers. The features common to all the concepts include;

i. Induced draft fan for introducing air into the combustion chamber according to stoichiometric requirement.

ii. Auxiliary burner used for start-up operation and igniting the waste, and also for maintaining the combustion chamber at a set point temperature.

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The design specifications of the solid waste fired steam boiler are:

i. To use combustible solid waste as a feed stock
ii. To be manufactured from mild steel (for combustion wall) and stainless steel (for boiler tube)

2.2 Proposed Conceptual Designs

The following conceptual designs are proposed based on the mode of feeding and operation.

2.2.1. Conceptual Design I: Fixed Grate Incinerator with Circular Boiler Tube

The fixed grate incinerator with circular boiler tube shown in Figure 2.1 consist of a stationary metal grate on which the waste burns and an ash tray below for collecting the waste residue. The inner wall of the combustion chamber is lined round with boiler tube and an economizer is installed at the exit of the combustion chamber to preheat the feed water before entering into the chamber. Waste feeding into the chamber is done in batch through the feed hopper equipped at the top of the chamber. The system is also equipped with instrument such as valves, pump, pressure gauge and thermometer to measure exit conditions of the steam (temperature and pressure).

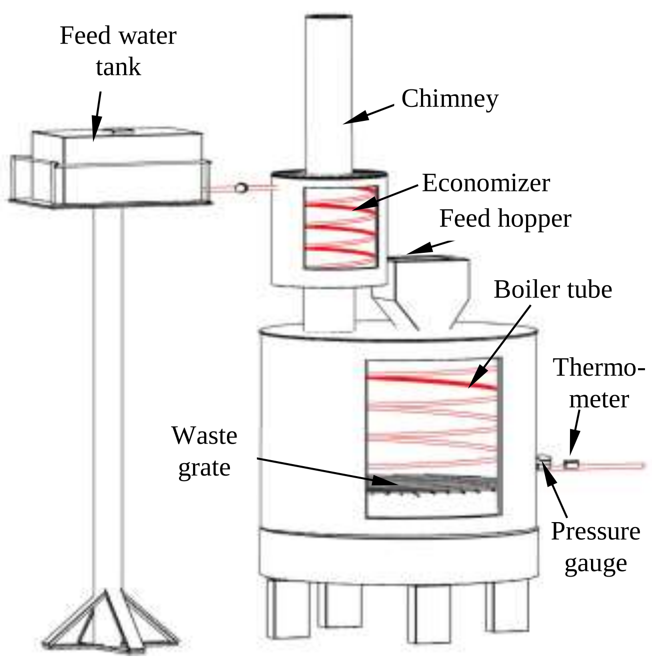

Figure 2.1: Sectional view of the fixed grate incinerator with circular boiler tube

2.2.2. Conceptual Design II: Fixed Grate Incinerator with Stepped Boiler Tube

This incinerator unit (shown in Figure 2.2) is provided with boiler tubes arranged in series of steps immediately above the waste bed to the point where the combustion gas leaves the chamber. Most of the heat is transfer to the water flowing in the tubes and so only a small amount of residual heat leaves the chamber, hence there is little need for an economizer to be installed. Waste feeding is done in batch into the hopper and delivers into the combustion chamber with the aid of a ram feeding mechanism.

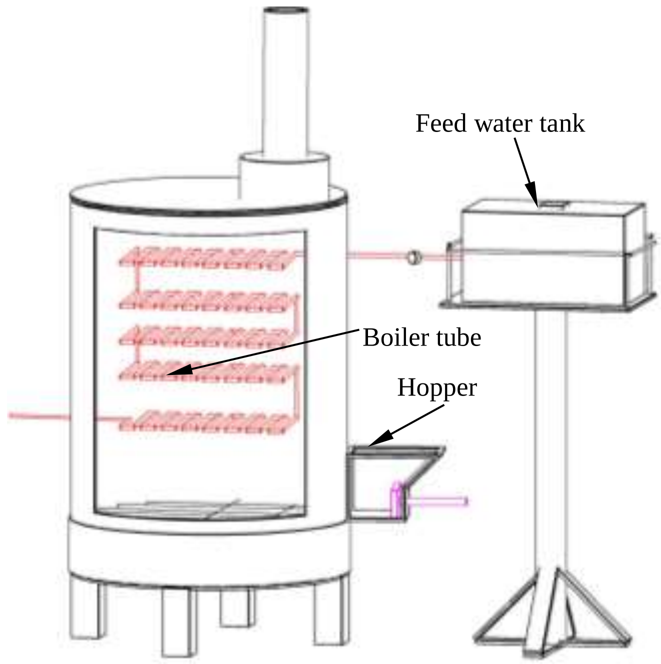

Figure 2.2: Sectional view of the fixed grate incinerator with stepped boiler tube.

2.2.3. Conceptual Design III: Rotating Grate Incinerator

The design of the rotating grate (Figure 2.3) consist of a cylindrical grate inclined at an angle to the horizontal and rotating inside a combustion chamber, as the grate rotate the waste is agitated by tumbling and slowly moving down the inclined grate. The combustion of waste occurs within the chamber and the residual ash is discharged from the end. This design is equipped with an economizer provided at the exit of the boiler unit.

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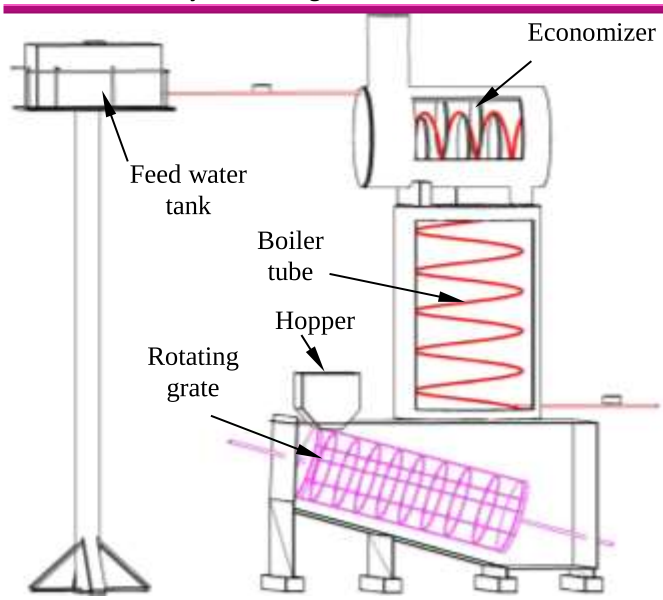

Figure 2.3: Sectional view of the rotating grate incinerator

2.2.4. Conceptual Design IV: Stepped Grate Incinerator

The stepped grate incinerator shown in Figure 2.4 consist of two stationary grates arranged in a series of steps and equipped with an external waste feeding ram, it also has an internal waste and ash transfer ram mechanism.

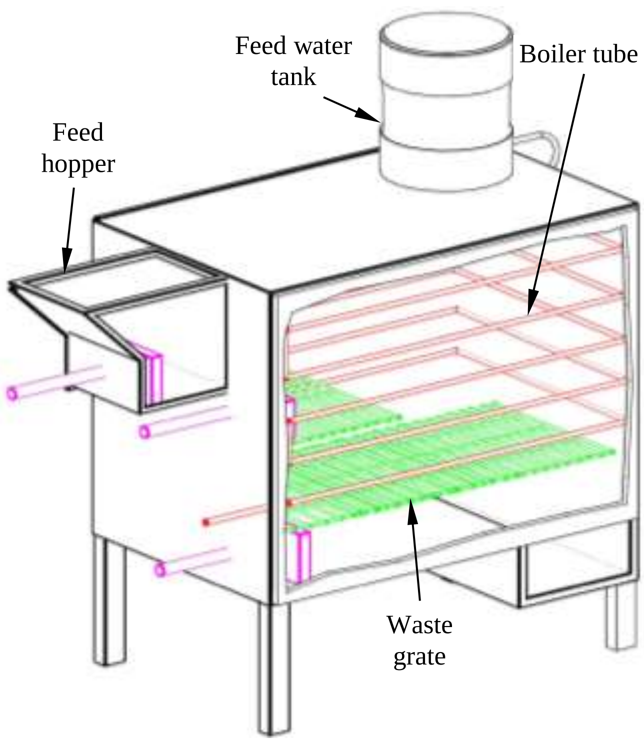

Figure 2.4: Isometric view of the stepped grate incinerator

2.3. Selection of the Best Conceptual Design

The best conceptual design is chosen by comparing each concept against a set of design criteria or requirements that give a quantitative basis for judging each design. The decision matrix is a popular way to formalize the engineering decision-making process. The decision matrix is a quantitative technique for calculating a number that specifies and justifies the optimum decision. A basic decision matrix involves creating a collection of criteria alternatives that are scored and totaled to provide an overall score that may be ranked. It is also not weighted, which allows for a quick choosing procedure. A weighted decision matrix, on the other hand, works in the same way as a basic decision matrix but adds the concept of weighing criteria in order of relevance. The higher the weighting given to a criterion, the more essential it is. To arrive at a result, each of the available possibilities is scored and then multiplied by the weighting assigned to each of the criteria. Table 2.1 provides the decision matrix for evaluating alternative conceptual designs for the solid waste boiler.

3.1. RESULTS AND DISCUSSION

Four conceptual designs were developed and evaluated using some chosen criteria based on the decision matrix. The most important criteria are;

- The waste processing performance of the steam boiler system: This determines to a large extent how effectively the waste is destroyed completely and reduced in quantity to the least, typically 80 – 95% of the original volume.
- The energy recovery by the boiler system: Determines temperature and pressure of steam that is produced.

The conceptual design VI (stepped grate incinerator) was eventually chosen because of the advantages it has over other concepts in terms of energy recovery. It has the highest total score of 930 from the weighting scale used to assign ratings to each criterion based upon a ten-point system. A drying grate is provided in this system in the case of waste having high moisture content. If moisture content is too high, more heat will be needed to vaporize the water and this will reduce the combustion temperature. Hence, more auxiliary fuel will be needed to raise the temperature and ensure normal combustion.

Table 2.1: Decision matrix for evaluating alternative conceptual incinerator designs

Criteria	Weighting (%)	Conceptual Designs			
		Design I	**Design II**	**Design III**	**Design IV**
Waste Treatment R × W	20	4 80	8 160	10 200	10 200
Energy Recovery R × W	20	6 120	8 160	8 160	10 200
Manufacturability R × W	15	10 150	8 120	8 120	10 150
Feasibility R × W	10	10 100	10 100	10 100	10 100
Cost (planning, material, construction) R × W	10	10 100	6 60	6 60	8 80
Safety (environmental and direct health risk) R × W	10	8 80	10 100	8 80	8 80
Operating Cost R × W	5	10 50	6 30	8 40	8 40
Maintainability R × W	5	10 50	6 30	8 40	8 40
Reliability R × W	5	10 50	6 30	6 30	8 40
Total Score	100	780	790	830	930
Rank		4	3	2	1
Selected?		No	No	No	Yes

- R rating/score (the maximum score is 10)
- W weighting

4.1 CONCLUSION

The selection of the optimum concept comes from a number of alternative concepts available by using the weighted decision matrix method. The conceptual model selected can be further developed (designed and constructed) into a prototype. The steam produced by this boiler can be used for various applications in process industries like the textile, sugar and brewery industry. Furthermore, the decision matrix unites several assessment alternatives in a common denominator, allowing decision-makers to make an objective evaluation.

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