Influence of operating conditions on the air gasification of dry refinery sludge in updraft gasifier

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Abstract. In the present work, details of the equilibrium modeling of dry refinery sludge (DRS) are presented using ASPEN PLUS Simulator in updraft gasifier. Due to lack of available information in the open journal on refinery sludge gasification using updraft gasifier, an evaluate for its optimum conditions on gasification is presented in this paper. For this purpose a Taguchi Orthogonal array design, statistical software is applied to find optimum conditions for DRS gasification. The goal is to identify the most significant process variable in DRS gasification conditions. The process variables include; oxidation zone temperature, equivalent ratio, operating pressure will be simulated and examined. Attention was focused on the effect of optimum operating conditions on the gas composition of H₂ and CO (desirable) and CO₂ (undesirable) in terms of mass fraction. From our results and finding it can be concluded that the syngas (H₂ & CO) yield in term of mass fraction favors high oxidation zone temperature and at atmospheric pressure while CO₂ acid gas favor at a high level of equivalent ratio as well as air flow rate favoring towards complete combustion.

1. Introduction
Air gasification technology is being studied by many researchers for various types of fuels. Gasification is the conversion of hydrocarbons in the presence of air/steam or oxygen to produce syngas which is a mixture of hydrogen and carbon monoxide. Since there is a lack of information available in the open journals about gasification of dried refinery sludge (DRS) using updraft reactor, the goal of this work is to investigate the effect of three important process conditions namely oxidation zone temperature, operating pressure, and equivalence ratio on gas yield in term of mass fraction for of H₂, and CO (desirable) and CO₂ (undesirable). Taguchi orthogonal array design is used here to evaluate the optimum conditions for DRS gasification in updraft gasifier.

2. Taguchi Orthogonal Array Design (TOAD) Methods
TOAD is a classical factorial method of analysis used in processes involving many process variables. For the successful interpretation or prediction, TOAD requires numerous experiment data for optimization purposes. In classical statistical method, if the number of experiments to be carried out is “N” and the number of levels or factors (process variables) is “m”, this can be translated by the equation \( N = L^m \). Some of the experiments carried out may prove less significant or redundant. Omitting these less significant experiments or process variables gives huge saving and reduces the time frame or good analytical results and prediction. Selection of the favorable experiments can be obtained by. Using classical statistical methods for this purpose is not an easy task as indicated by Mahamuni & Adewuyi [8]. For our gasification of DRS both TOAD and DOE methods were used.
3. Results and Discussions

Table 1 lists the various factors and levels performed on a Taguchi orthogonal array design or TOAD simulation. For this simulation study, four factors were chosen (A: A for oxidation zone temperature, B: B for operating pressure, C: C for the flow rate of air, and D: D for equivalent ratio) and three levels for each factor were selected using a standard L9 Orthogonal array based on Kul and Cetinkaya [6], and Mohan and Ahmed [10] model. The description of gasification conditions are shown and highlighted in Table 1.

Table 1. DRS gasification factors and levels.

| Factor          | Levels |
|-----------------|--------|
|                 | 1      | 2     | 3     |
| A: A Temperature (CO₂) | 950    | 750   | 500   |
| B: B Pressure (bar) | 20     | 14    | 1.01  |
| C: C Air flow (L/min) | 280    | 240   | 180   |
| D: D Equivalent Ratio | 0.34   | 0.24  | 0.14  |

Next the statistical analysis of our equilibrium model results was carried out using analysis of variance (ANOVA) and tabulated in Table 2. The purpose of ANOVA is to investigate the factors which significantly affect the response factor which in turn grades the percentages contribution of each process variables mentioned above. This is then applied to the DRS gasification simulation results as per our present study. The Model F-value of for all the factors shows <1 except for factor D: D which is calculated to be 3.79 which implies there is an 8.61% chance that a "Model F-Value" this large value could occur. It should be noted that the ER is affected by air flow rate and feed rate. As a result the large value accounted is a result of combination of two variables in one.

Table 2. ANOVA Analysis for contributions of four factors on Carbon monoxide mass fraction

| Factors | DOF | Sum Sq.     | F Value | Prob>F | Cont. % |
|---------|-----|-------------|---------|--------|---------|
| A: A   | 2   | 4.033E-003  | 0.24    | 0.7927 | 7.45    |
| B: B   | 2   | 0.013       | 0.91    | 0.4524 | 23.23   |
| C: C   | 2   | 7.295E-003  | 0.47    | 0.6477 | 13.48   |
| D: D   | 2   | 0.030       | 3.79    | 0.0861 | 55.84   |

3.1 Carbon monoxide-mass fraction yield

The percentages contribution of individual factor for CO mass fraction using TOAD method on simulated results from Table 3 is shown in Figure1. From Figure 1, it can be seen that the highest contribution for CO yield is from ER factor which accounts for 55% followed by operating pressure factor (23%). The reaction temperature and air flow factors have smaller effect on the yield for CO mass fraction.
In accordance to Lijun et al., [7] high reaction temperature favor high conversion rate of carbon. Since there are few species of carbon produced during gasification reaction, it will be wise if we determine the four process variables on an individual basis to understand its sensitivity towards changing process variable and its effect to CO yield. The result from this operation is shown in Figure 2. From the same figure it can be observed operating the gasification process at ER of 0.28 gives the optimum process condition for maximum yield of carbon monoxide formation at high temperature and low pressure. Although Figure 2 shows that increase in reaction temperature and lower operating pressure and air flow rate favours high CO yield, but ER of 0.28 far exceed the other 3 process variable yield on CO.

Our results is in agreement with Konda et al [5] and, Atnaw et al [1], documented in their simulation study of downdraft gasification of oil-palm fronds using ASPEN PLUS that, the mole fraction of CO decrease sharply after 5 bar of the operating pressure. Khadse et al., [4] and (Lijun et al., [1] found that higher oxidation zone temperature maximize CO yield for biomass using updraft gasification.

3.2 Hydrogen-mass fraction yield
The percentages contribution of individual factor for hydrogen mass fraction is described in Figure 3. From the same figure it is can be observed that the oxidation temperature is the main factor which
contributes about 67% favoring increase H\textsubscript{2} yield followed by air flow rate about 34%. Pressure and ER on the other hand has little affect on the H\textsubscript{2} yield. Studies on effect of individual process variables’ contribution on H\textsubscript{2} yield was undertaken and presented in Figure 4. From the same figure it can be seen operating at high temperature and low flow rate favors high H\textsubscript{2} yield. The process pressure has little effect on H\textsubscript{2} mass fraction yield. Although lower flow rate also do show some significant increase in H\textsubscript{2} yield, a comprise must be made between flow rate and ER to maximise H\textsubscript{2} yield. This prediction is in agreement with literature as the yeild of CO and H\textsubscript{2} is known to decrease with pressure Higman and Van de Burgt, [3].

4. Conclusion
The TOAD statistical was successfully used as a tool to identify the most significant operating conditions on gasification of dry refinery sludge in updraft gasifier making use of ASPEN PLUS Simulator software. From our results and finding it can be concluded that the syngas yield in term of mass fraction favors at high oxidation zone temperature and at atmospheric pressure while CO\textsubscript{2} acid gas favor at a high level of equivalent ratio as well as air flow rate. This is because the reaction tends towards complete combustion by increasing of actual air flow. It can be concluded that the optimum operating conditions for CO and H\textsubscript{2} formation from DRS gasification is to operate the process system at atmospheric pressure 1.01 bar (114.7) Psi and under an equivalent ratio of 0.28, with an air flow rate of 240-280 l/min and at a moderately high temperature of 750 to 950°C.

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