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HYDRODYNAMIC STUDIES OF BIOMASS IN A COLD MODEL FLUIDIZED BED GASIFIER USING MATLAB CODING, A MATHEMATICAL MODELING APPROACH

Rajesh Tripathy
Department of Chemical Engineering, G H Patel College of Engineering & Technology,
Bakrol Road,Vallabh Vidyanagar-388 120.Gujarat. India.
Email : rajeshchemtech@gmail.com

ABSTRACT

Effects of different system parameters on the hydrodynamic behavior of a cold-model fluidized bed gasifier have been studied. Correlations developed for the Equivalence Ratio and Euler's number on the basis of regression analysis have been validated by using the MATLAB coding. Comparison of calculated values of Equivalence ratio and Euler number against the experimentally observed values gives the standard deviations of 1.89 and 10.8 respectively indicating a very good approximation. Chi-square (ξ^2) test gives 0.0002 and 18685.04 for Equivalence Ratio and Euler's number respectively implying the correlation fit to be satisfactory and suitable over a wide range of parameters for the industrial uses.

Key-words: Fluidized bed Gasifier, Equivalence ratio, Euler's number, Regression analysis, MATLAB coding

1. INTRODUCTION

Biomass is potentially an attractive feedstock for producing transportation fuels as its use contribute little or no net carbon dioxide to the atmosphere. Biomass is a complex mixer of carbonaceous materials such as carbohydrates (75%), fats (25%) and little amount of minerals like sodium, potassium and iron etc. Thermo chemical gasification of biomass is a well known technology which is classified depending on the type of gasifying agent used viz. air, steam, steam-oxygen, air-steam etc.

The technology of biomass air gasification seems to have a feasible application and has been developed actively for industrial applications. The hydrodynamic behavior of the fluidized bed gasifier using air as the gasifying agents can be studied using a cold model gasification unit.

Gasification is a two step process in which solid fuels (biomass / coal) is thermo-chemically converted to a low or medium energy content gas.

2. LITERATURE

The four main stages of gasification which occur at the same time in different parts of the gasifier are Drying Zone, Pyrolysis Zone, Oxidation Zone and Reduction zone.

Drying Zone:

Biomass fuels consisting of moisture content in the range of 5 to 35% are used in the gasifier. At the temperature just above 100 °C, the water is removed and converted into steam where the biomass sample does not experience any kind of decomposition.

Pyrolysis Zone:

When the temperature rises above 600^{o}C, thermal decomposition of biomass takes place in the absence of oxygen. This process (Pyrolysis) involves release of three kinds of products such as solid (char), liquid (oil) and gases (CO, H_2, and N). The ratio of products is influenced by the chemical composition of biofuels and operating conditions. The heating value of gas produced during this pyrolysis process is low (3.5 to 8.9 MJ/m^3). The dissociated and volatile components of the fuel are vaporized.

Oxidation Zone:

When the temperature rises above 700^{o}C, combustion takes place. Heterogeneous reaction takes place between oxygen and solid carbonized fuel, producing carbon dioxide as follows.

$$C + O_2 \rightarrow CO_2 \qquad (1)$$

Hydrogen in fuel reacts with oxygen in the air blast, producing steam as mentioned below.

$$H_2 + {}^{1}/_{2}\, O_2 \rightarrow H_2 \qquad (2)$$

Reduction Zone:

In this zone, a number of high temperature chemical reactions as mentioned below take place in the absence of oxygen.

$$CO_2 + C \rightarrow 2CO \qquad (3)$$

$$C + H_2O \rightarrow CO + H_2 \qquad (4)$$

$$CO_2 + H_2 \rightarrow CO + H_2O \qquad (5)$$

$$C + 2H_2 \rightarrow CH_4 \qquad (6)$$

These reactions show that heat is required during the reduction process. Hence the temperature of the gases goes down during this stage. If complete gasification takes place, all the carbon is burned or reduced to carbon monoxide, a combustible gas and some mineral matter is vaporized. The ash and char (unburned carbon) are only remaining. The yield gases produced during the gasification process are combiningly called as producer gas, whose composition is as follows.

Carbon monoxide: - 20-22%
Hydrogen: - 15-18%
Methane: - 2-4%
Carbon dioxide: - 9-11%
Nitrogen: - 50-53%

Some authors have proposed low-temperature gasification for efficient recovery of energy and materials from waste tyre [1]. Experiments were carried out in a lab-scale fluidized bed at 400–800°C with equivalence ratio (ER) of 0.2–0.6. Low heat value (LHV) of syngas was observed to increase with increasing temperature or decreasing ER, and the yield was found to be in proportion to ER linearly. The yield of carbon black was observed to decrease with increasing temperature or ER lightly.

Equivalence ratio (ER) and Euler's number (Eu) are defined as follows.

$$\text{ER}= \frac{\text{weight of oxygen (air)/weight dry biomass}}{\text{stoichiometric oxygen (air)/biomass ratio}} \qquad (7)$$

$$Eu = \frac{\Delta P}{\rho {u_0}^2} \qquad (8)$$

Mixtures of coal and biomass were co-gasified in a jetting, ash-agglomerating, fluidized-bed, pilot scale-sized gasifier to provide steady-state operating data for numerical simulation verification [2]. Sawdust (screened to −1.2 mm) and bituminous coals (screened from −1.2 to 0.25 mm) were mixed and pneumatically conveyed into the gasifier at an operating pressure of 3:03 M Pa. Feed mixtures ranged up to 35% by weight sawdust.

Syngas with optimized hydrogen yield was produced in a fluidized bed (with in-bed catalysis) gasification [3]. Four different bed materials such as inert quartzite as reference case, olivine and dolomite as natural catalysts, and Ni-alumina as artificial catalyst were used. The gasification tests were carried out at steady state in a pilot-scale bubbling fluidized bed, under operating conditions typical for gasification as reported in the literature.

The main results of an experimental work on co-gasification of a Chinese bituminous coal and two types of biomass in a bench-scale fluidized bed are also reported in the present study [4]. Experiments were performed at different oxygen equivalence ratio, steam/carbon ratio and biomass/coal ratio. In addition, stabilization of co-gasification process was investigated. It was found that a relatively low oxygen equivalence ratio favors the increase of syngas yield ($CO+H_2$).

Different types of biomass such as wood shavings, cacao hulls, refuse derived fuel and Euphorbia tirucalli pellets were also gasified in a bench scale fluidized-bed reactor [5]. The process was optimized in order to produce a gas suitable as a fuel gas or for methanol production. The effects of the air factor, bed and freeboard temperature and feedstock properties on gas quality and thermal efficiency were determined.

3. MATERIALS AND METHOD

With silica as the bed materials (in the size range of 0.79 to 2.18 mm), the saw dust (of size 0.81 mm) obtained from a local timber mill was used as the feedstock. The proximate analysis and ultimate analysis reports of the biomass sample (saw dust) have been reported in Table-1 and Table-2 respectively. The chemical formula of saw dust was calculated to be $CH_{1.4}O_{0.8}$ from the ultimate analysis of the biomass sample.

The schematic diagram of the experimental set-up is shown in Fig.-1. The unit consists of a reciprocating pump, an air blower, a U-tube manometer, a screw feeder for feeding the biomass and bed materials, bubble cap distributor plate, fluidization column and a cyclone separator. The total height of the fluidizer is 195cm with the reactor diameter of 15 cm and freeboard diameter of 30 cm. Seven number of bubble caps are uniformly arranged there in the distributor plate. The biomass was fed by a variable speed metering motor. Air was used as the fluidizing agent and introduced by the air-blower below the distributor plate.

Experimental procedure

At first the starter switch of the air blower is turned on, so that air can flow into the fluidization column through air accumulator and bubble-cap distributor plate. Then screw feeder switch is turned on and the pump connecting to the screw feeder is initially set at 30-40 rpm speed. A known quantity of the bed materials and the biomass samples are fed to the column and the feeding rate of the bed material and biomass samples are measured. The flow rate of air at which complete fluidization takes place is noted down and the corresponding pressure drop across the bed is also noted. The same procedure is repeated several times for studying the effects of various system parameters (viz. the static bed height, density of the biomass samples, and feed rate of bed materials) on the bed behavior. The scope of the experiment is shown in Table-3.

4. RESULTS AND DISCUSSION

Regression Analysis

Experimental values of equivalence ratio and Euler's number are obtained by Eq. no.-(1) and (2).

The fluidization characteristics and bed dynamics of the cold model gasifier have been expressed in terms of equivalence ratio (ER) and Euler's number (Eu) which are correlated with the different system parameters as follows.

$$ER = 1.039\left[\left(\frac{H_s}{D_c}\right)^{0.205}\left(\frac{d_p}{D_c}\right)^{0.233}\left(\frac{\rho_s}{\rho_f}\right)^{0.09}\right] \tag{9}$$

$$Eu = 4E+06\left[\left(\frac{H_s}{D_c}\right)^{0.016}\left(\frac{d_p}{D_c}\right)^{0.046}\left(\frac{\rho_s}{\rho_f}\right)^{-0.099}\right] \tag{10}$$

The correlation plots for equivalence ratio (ER) and Euler's number (Eu) are shown in Fig.-2 and Fig.-3 respectively. The calculated values of the Equivalence ratio (ER) and Euler's number (Eu) obtained through these developed correlations are compared against the experimentally observed values. The comparison plots are shown in Fig.-4(A) and 4(B) for equivalence ratio (ER) and Euler's number (Eu) respectively.

MATLAB program

Considering the above mentioned system parameters MATLAB coding has been developed and the programme was run by varying these system parameters. The effects of these parameters on Equivalence ratio and the Euler's number were studied. These effects on Equivalence ratio are shown in Fig.-6 to 8 and the effects on Euler's number are shown in Fig.-10 to 12.

The experiments were carried out in a cold-model unit of the experimental gasification set up by varying the different system parameters. The equivalence ratio and the Euler's number, both were observed to increase gradually with the increase in static bed height and particle size of the bed material. But the increase in density of the bed materials was found to have different effects on Equivalence Ratio and Euler number. It was observed that the equivalence ratio increases and Euler number decreases with the increase in density. The effects of individual parameters on ER and Eu number have also been analysed by the MAT LAB coding and the similar trends were also observed which are shown in Fig.-5 to 10. The calculated values of ER and Eu obtained from the developed correlation were also compared with the values obtained from the programming which are listed in Table-4. The deviations from the experimental values were found to be less in both the cases (i.e. the equivalence ratio and the Euler's number). It is observed from Fig.-4(A) that comparison of ER is a better agreement in comparison with that of Euler number as seen from Fig.-4(B).

The standard deviation, mean deviation and correlation fit in terms of Chi-square (ξ^2) as listed in Table-5 imply that the developed correlations for the ER and Eu are satisfactory even though calculated values of ER agrees well the respective experimental values. With the help of the above MATLAB coding the simulation was also done for a FBR which indicates that the effective rate constant of the process increases with the increasing inlet gas flow rate but decreases with the increase in reactor size.

The carbon conversion efficiency and equivalence ratios were found out for the hot model unit of the fluidized bed gasifier.

5. CONCLUSION

The MATLAB coding has been developed for the catalytic fluidized bed reactor system to study the effects of various important hydrodynamic, operating and design parameters on the reaction rate kinetics. It is concluded from the simulation that the percentage conversion in a FBR increases with the static bed height, residence time and the rate constant. But the selectivity of the process decreases with the increasing conversion and reaction rate constant.

The comparison of the calculated values of the Equivalence ratio and the Euler's number obtained through Regression analysis and MATLAB programming against the experimentally observed values for the laboratory scale cold-model fluidized bed gasifier unit indicates that the developed correlations (eq. no. 9 and 10) validated. Again the chi-square test justifies the correlation fit to be satisfactory. From the modeling it was observed that concentration of hydrogen will increase initially as ER increase but there will a decreasing trend at high values. It represents the oxygen quantity introduced into the reactor but also affects the gasification temperature under the condition of autothermal operation while excess amount of gas will dilutation of the product gas. But theoretically higher ER means higher gasification temperature,

which can accelerate the gasification and improve the product quality to a certain extent. So there is a contradictory factor of ER.

This indicates that these correlations can suitably be used over a wide range of system parameters. These models can also be scaled up suitably for pilot plant units or for industrial uses. Thus these developed correlations can be used as the basis for the designs for the industrial fluidized bed biomass gasifier.

With the results of present cold model unit of fluidized bed gasifier further calculations such as calorific value determination for the biomass samples and steam decomposition can be carried out for the hot model gasification unit. Various modeling techniques like CFD can also be applied for the biomass gasification process in a fluidized bed gasifier. Now-a-days the ASPEN PLUS software also finds wide scope to simulate the biomass gasification process which is now being emphasized by the present researchers.

Nomenclature

ER : Equivalence ratio
Eu : Euler's number
H_s : Static bed height, m
d_p : Diameter of the bed materials, mm
D_c : Diameter of the fluidized bed column, cm
ΔP : Pressure drop, $N.m^{-2}$
U_o : Superficial velocity, $m.s^{-1}$
d_p : Diameter of the bed material, mm

Subscripts

TGA : Thermo gravimetric analysis.
Exp : Values obtained through experimentally.
Cal : Values obtained through dimensionless analysis.
Prog : Values obtained through MAT LAB programming.
Dev : Deviation.

Greek Letters

ρ : Density, $kg.m^{-3}$
ρ_s : Density of bed material, $kg.m^{-3}$
ρ_f : Density of air, $kg.m^{-3}$
ξ^2 : Chi-square.

REFERENCES

[1] Lv, P. M., Z. H. Xiong, J. Chang, C. Z. Wu, Y. Chen, J.X. Zhu, "*An experimental study on Biomass air-steam gasification in a fluidized bed*", Bioresource Technology 95 (2004): pp. 95-101.

[2]McLendon, T. R., A. P. Lui, R. L. Pineault, S. K. Beer, S. W. Richardson, "*High-pressure co-gasification of coal and biomass in a fluidized bed*", Biomass and Bioenergy 26 (2004):pp. 377–388.

[3]Miccio, F., B. Piriou, G. Ruoppolo, R. Chirone, "*Biomass gasification in a catalytic fluidized reactor with beds of different materials*", Chemical Engineering Journal 154 (2009):pp. 369–374.
[4]Li, K., R. Zhang, J. Bi, "*Experimental study on syngas production by co-gasification of coal and biomass in a fluidized bed*", International journal of hydrogen energy 35 (2010): pp. 2722–2726.
[5]Schoeters, J., K. Maniatis, A. Buekens, "*The Fluidized-Bed Gasification of Biomass:Experimental Studies on a Bench Scale Reactor*", Biomass 19 (1989): pp. 129-143.

Table-1: Results of Ultimate Analysis

Types of biomass	Amount (mg)	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulphur (%)	Oxygen (%)
Saw dust	8.94	45.78	5.32	0	0.07	48.83

Table-2: Results of Proximate Analysis

Biomass samples	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)
Saw dust	8.8	87.57	1.94	1.69

Table-3: Scope of the experiment

Materials	**H_s (cm)**	**d_p (mm)**	**ρ_s (kg/m^3)**
Silica	2.5	1.65	1602
Silica	3.0	1.65	1602
Silica	4.5	1.65	1602
Dolomite	6.5	1.65	1602
Dolomite	4.5	2.25	1602
Dolomite	4.5	1.65	1602
Calcium carbide	4.5	1.2	1602
Calcium carbide	4.5	0.75	1602
Calcium carbide	4.5	1.65	1602
Al balls	4.5	1.65	2940
Al balls	4.5	1.65	1201
Al balls	4.5	1.65	2700

Table-4: Comparison of calculated values of the ER and Eu using MAT LAB coding with the experimentally observed values.
(A) For static bed height

Parameters	**Equivalence ratio (ER)**			**Euler's number (Eu)**		
H_s/D_c	ER-exp	ER-prog	% dev	Eu-exp	Eu-prog	% dev
0.167	0.49	0.487	-0.61	1337529	1532800	14.6
0.2	0.5	0.508	1.6	1363386	1537800	12.8
0.3	0.53	0.552	4.15	1366528	1547800	13.3
0.43	0.59	0.59	0	1369164	1556500	13.7

(B) For particle diameter

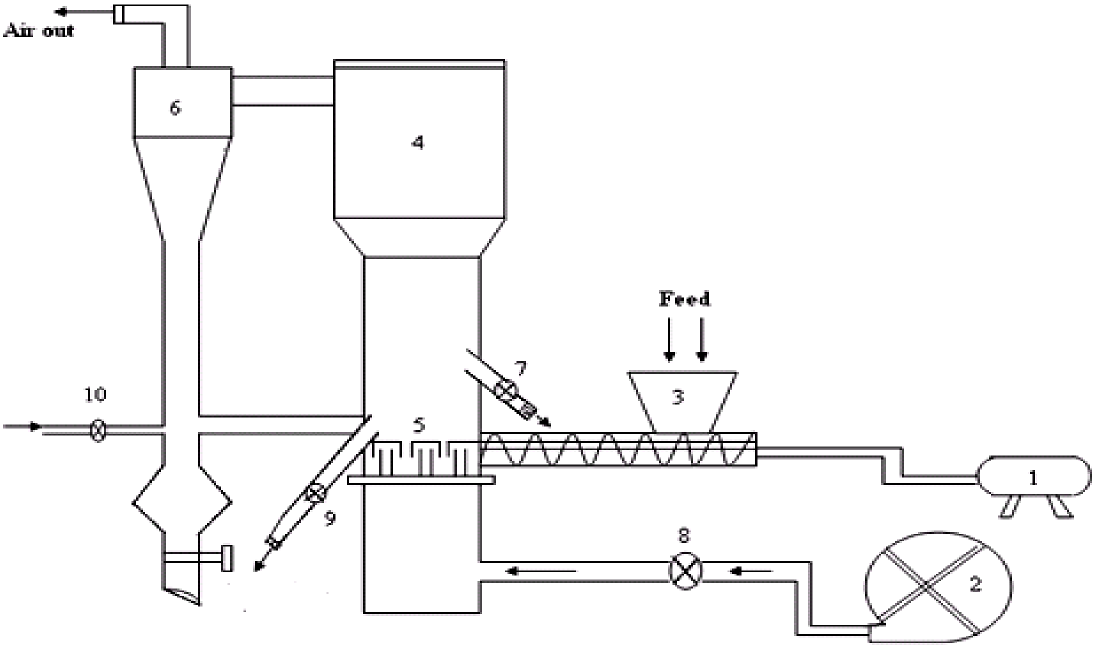
Parameters	**Equivalence ratio (ER)**			**Euler's number (Eu)**		
d_p/D_c	ER-exp	ER-prog	% dev	Eu-exp	Eu-prog	% dev
0.015	0.58	0.589	1.55	1335665	1567900	17.4
0.011	0.55	0.55	0	1366528	1547300	13.3
0.008	0.5	0.51	2	1332678	1526500	14.5
0.005	0.46	0.456	-0.86	1263782	1490600	17.9

(C) For particle density

Parameters	**Equivalence ratio (ER)**			**Euler's number (Eu)**		
ρ_s/ρ_f	ER-exp	ER-prog	% dev	Eu-exp	Eu-prog	% dev
1125.6	0.54	0.535	-0.92	1478464	1558500	5.41
1501.4	0.57	0.552	-3.16	1440357	1543800	7.18
2530.5	0.58	0.578	-0.34	1335665	1483900	11.09
2755.4	0.59	0.583	-1.18	1325353	1467500	10.72

Table-5: Comparison of the calculated values of the ER and Eu with the experimentally observed values and Chi square values for the correlation-fit**.**

Equivalence Ratio(ER)			**Euler's number(Eu)**		
Standard deviation, %	Mean Deviation,%	Chi square(ξ^2)	Standard deviation, %	Mean deviation%	Chi square(ξ^2)
1.89	-0.049	0.0002	2.64	10.8	18685.04



1.	Pump	6.	Cyclone separator
2.	Air blower	7.	Biomass out
3.	Screw feeder	8.	Valve
4.	Fluidized bed reactor	9.	Bed material out
5.	Bubble cap	10.	Valve

Figure-1: **Experimental set-up of a cold model fluidized bed gasifier**

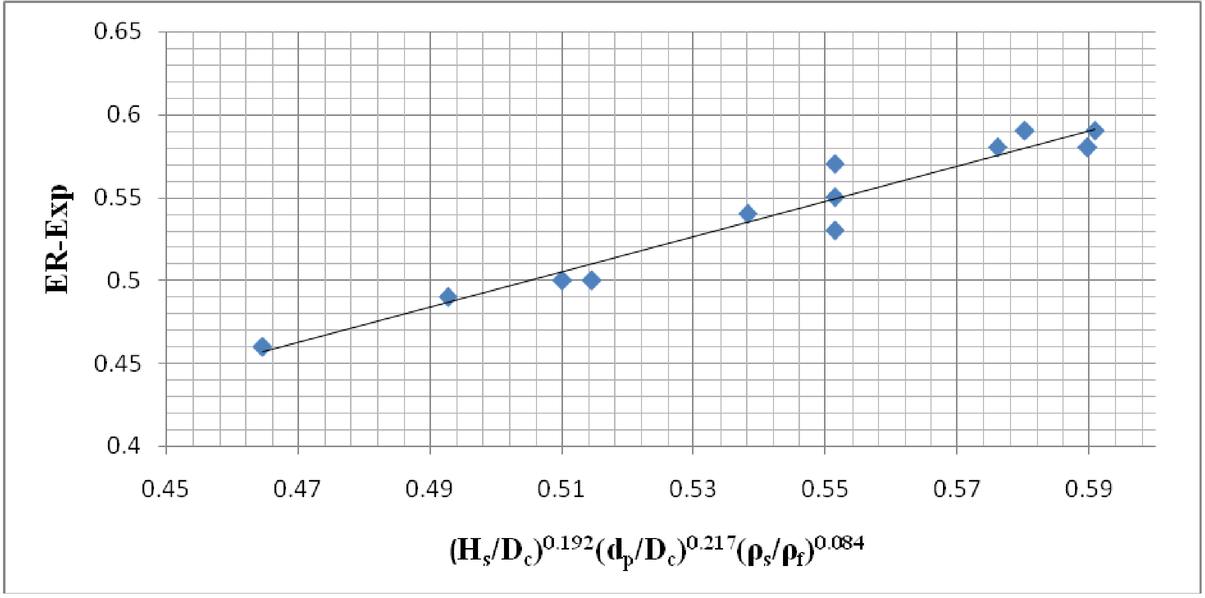


Figure-2. Correlation plot for ER against the system parameters

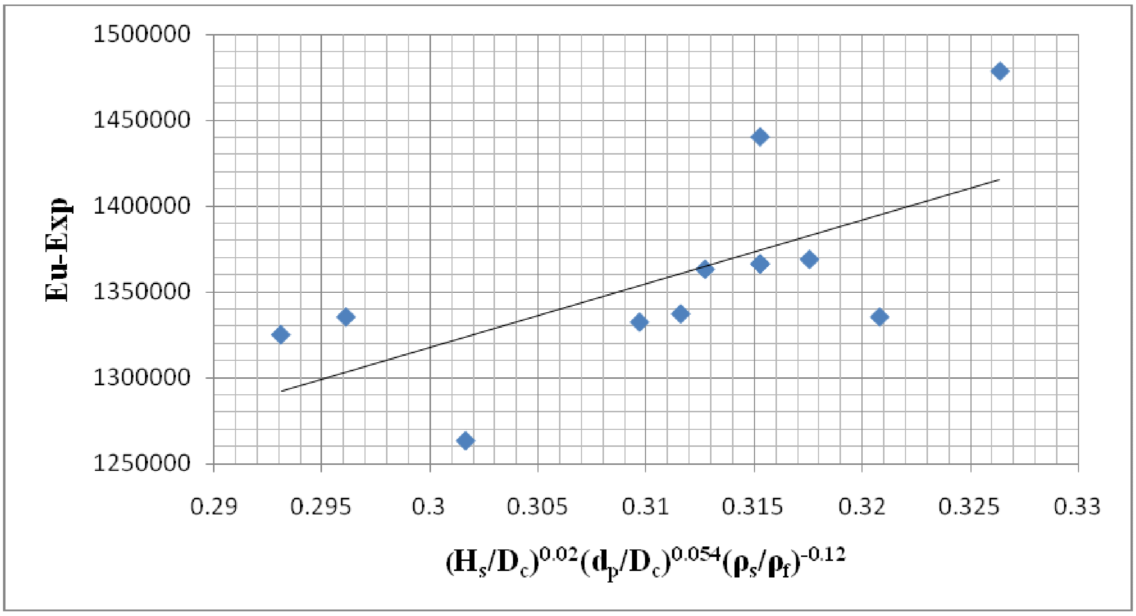


Figure-3. Correlation plot for Eu against the system parameters

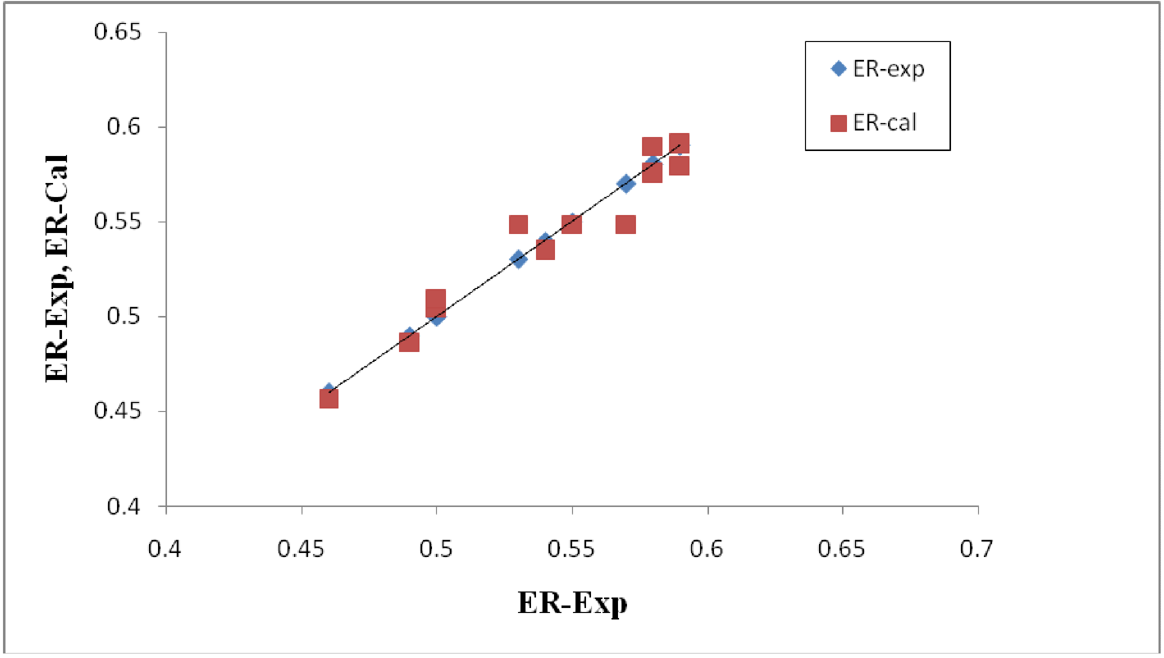


Figure-4(a) Comparison of calculated values of equivalence ratio obtained from Dimensionless analysis against the experimental ones.

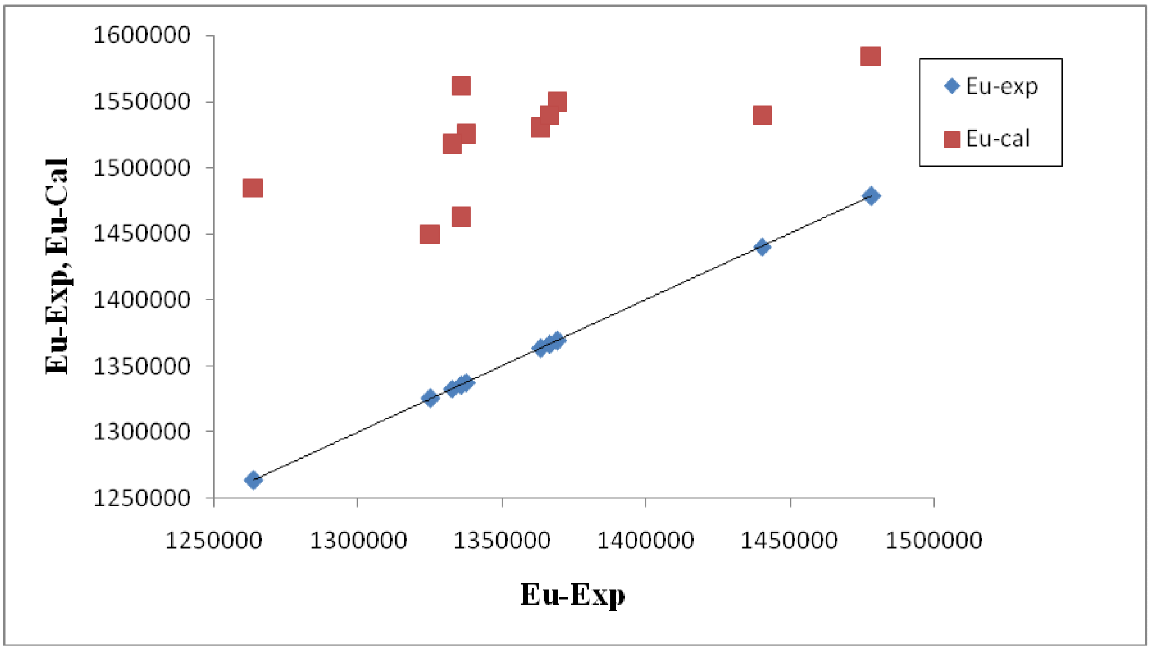


Figure-4(b) Comparison of calculated values of Euler's number obtained from Dimensionless analysis against the experimental ones

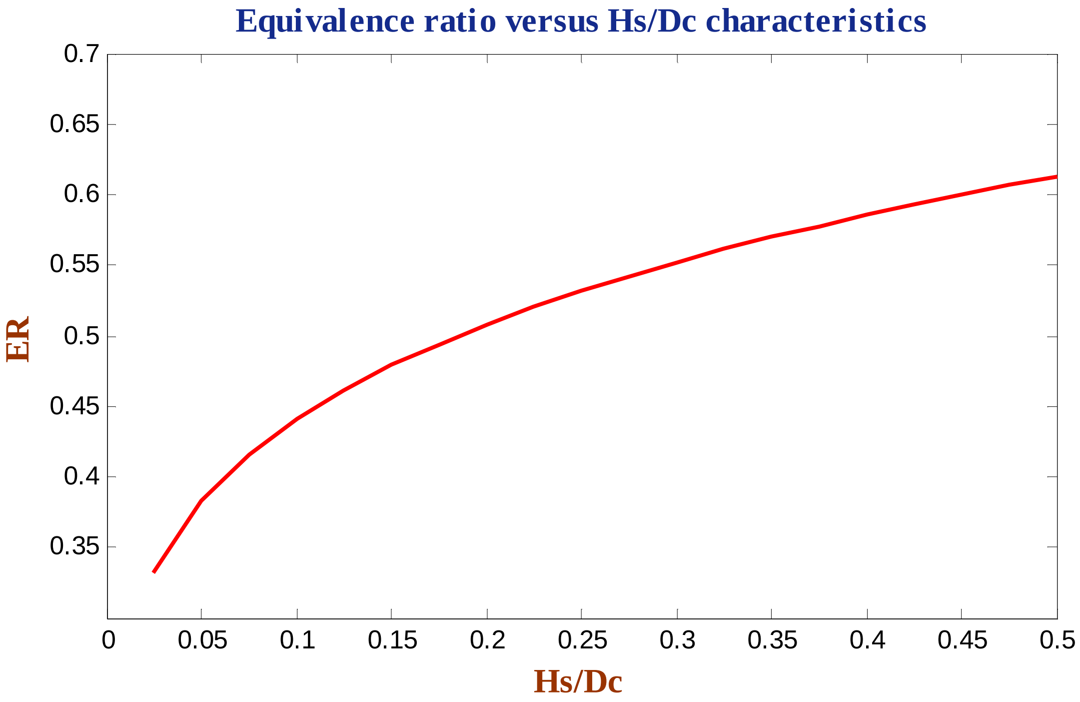


Figure-5. Effects of static bed height on Equivalence ratio

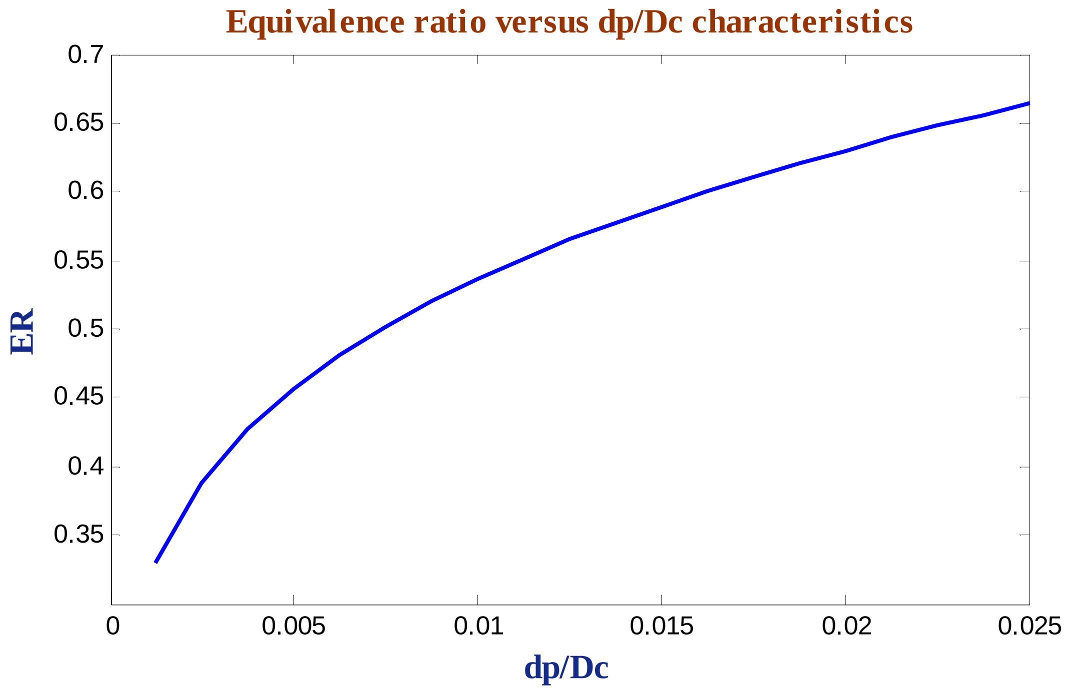


Figure-6. Effects of particle diameter on Equivalence ratio

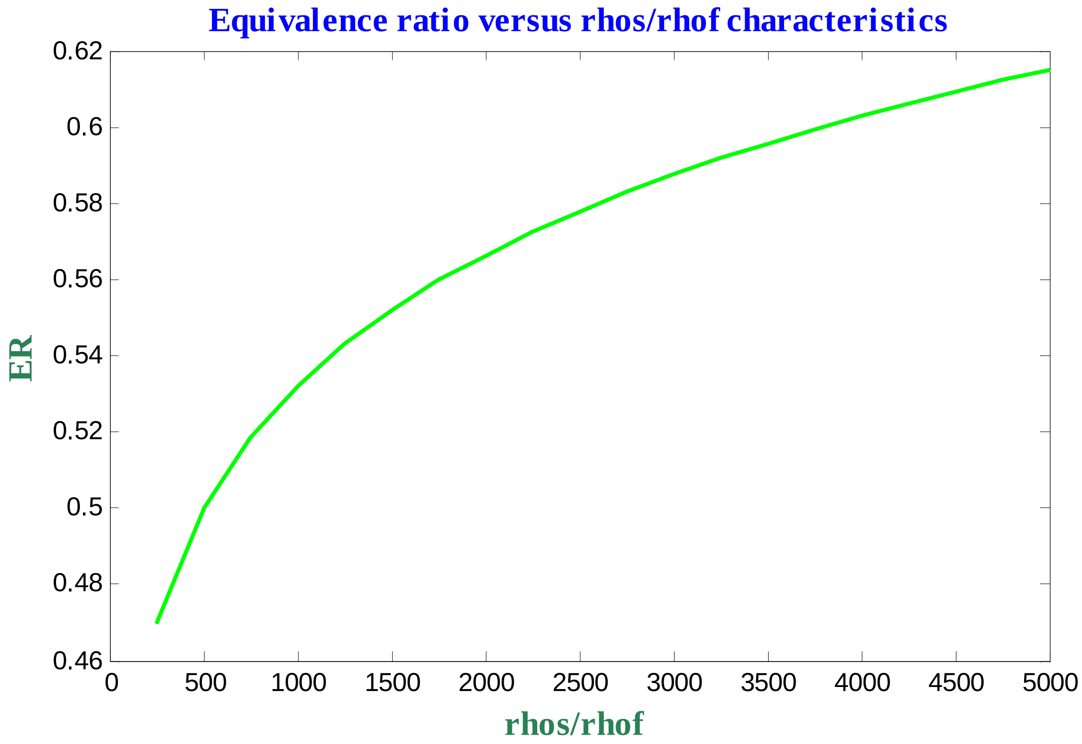


Figure-7. Effects of particle density on Equivalence ratio

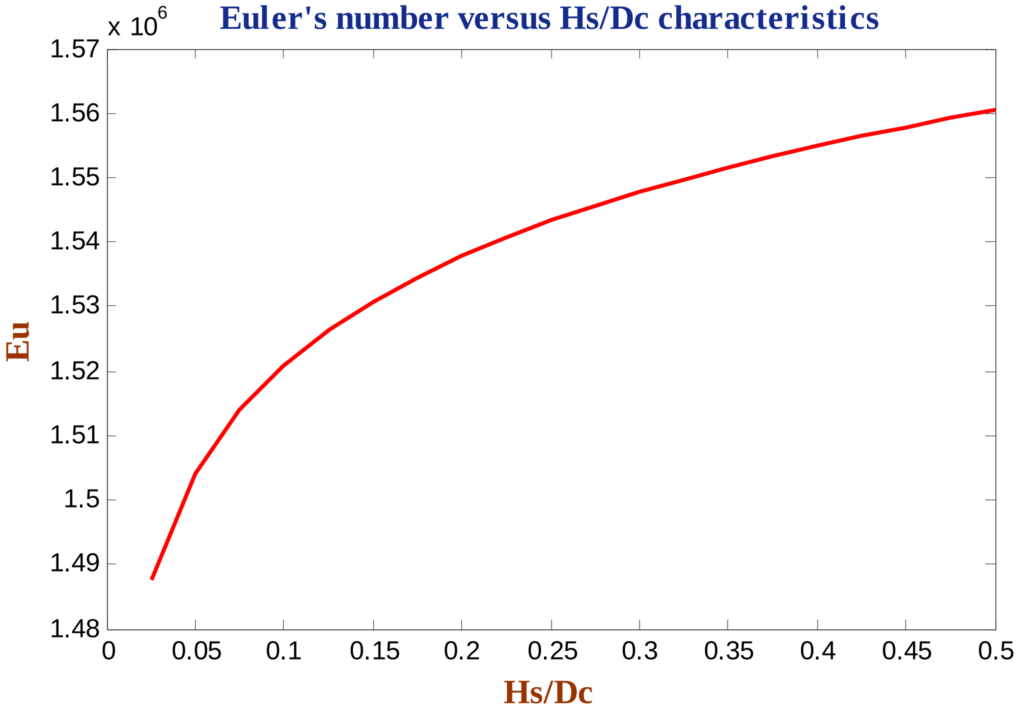


Figure-8. Effects of static bed height on Euler's number

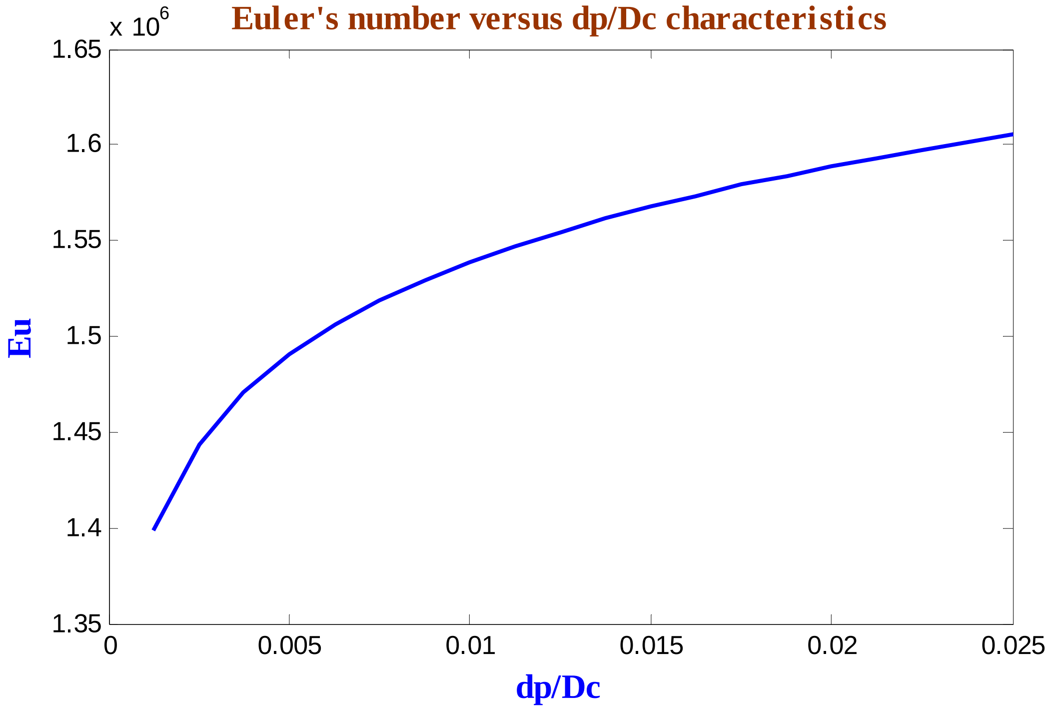


Figure-9. Effects of particle diameter on Euler's number

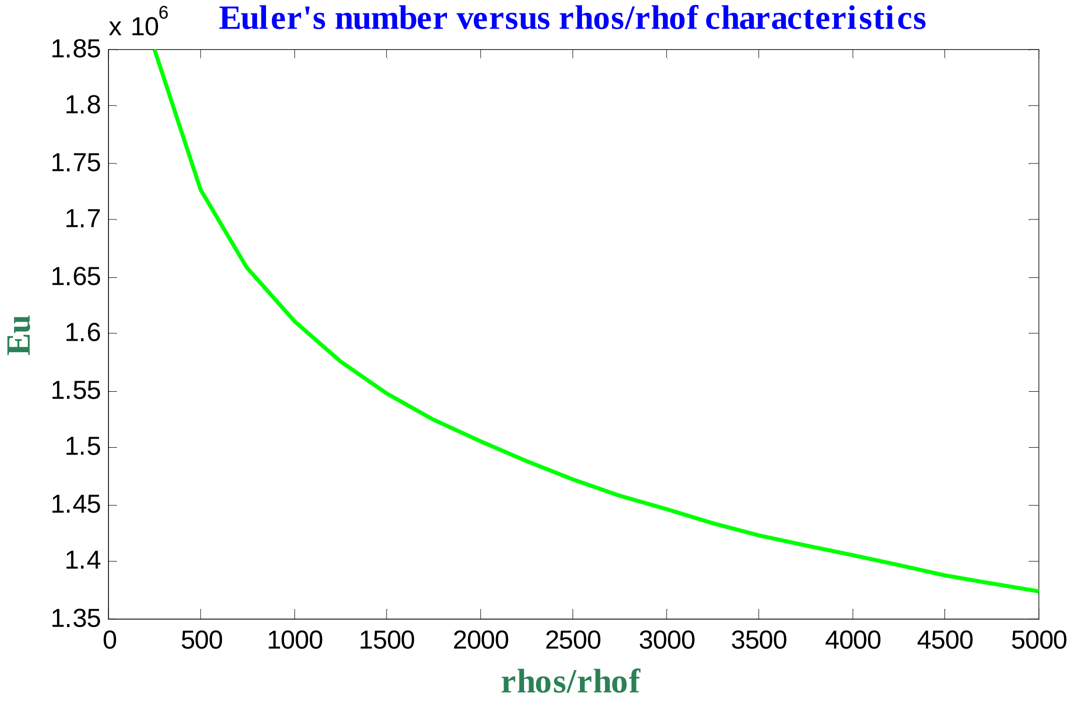


Figure-10. Effects of particle density on Euler's number