Comparative CFD Analysis of Single-Stage and Two-Stage Entrained Flow Coal Gasifier for Different Firing Condition

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ABSTRACT

We describe here our progress toward developing high-filtering computational fluid dynamics (CFD) models of commercial-scale gasifiers for use in single-stage up and down flow and two-stage up-flow gasifier of fired condition in gasification process. Coal gasification process is regulated by several operating parameters. The type of coal gasifier and coal gasification process, the chemistry of coal gasification and classification of coal gasification process. The comparative of single-stage and two-stage entrained flow coal gasifier in different firing of performance enhancement. The exit temperature and exit mass flow rate is good for REI model and Petcoke and Illions #6 types of coal is to be tested for both the gasifier testing and found that Petcoke is better than Illions #6 in the process of single stage down flow gasifier. The carbon conversion and cold-gas efficiency is better forREI model and higher heating value (HHV) of syngas is DOE model. The gasifier performance is varied with length and found that when length of gasifier increases we will get better performance.

Keywords-- Type of Coal and Type of Gasifier, Coal Gasification Process, Coal Gasification Reaction, Entrained Flow Gasifier, Entrained Flow Gasification Process, Single-Stage and Two-stage Process, Up and Down Fired Process, High Heating Value (HHV), Cold-as Efficiency (CGE).

I. INTRODUCTION

Coal is an abundantly available energy source and coal gasification is a primary way to produce liquid fuels for transportation and gaseous fuels for heating and chemical production. Coal combustion and gasification are the processes to utilize coal for production of electricity and this application. Global energy demand is increasing day by day. Coal is an abundant source of energy but not a reliable source as it results into high CO_2 Emissions. Coal gasification process is regulated by several operating parameters. Some technologies for producing liquid fuels and gaseous fuels have been commercialized for quite some years and some are still under development. Another reason for coal gasification is necessity to develop advanced power generation system. The world electric utility industry has greatly depended on the relative abundance of coal. Clearly, the expanded use of coal is still vital to future electrical power generation and the expanded use of coal must be carried out in an environmentally acceptable and economically competitive manner.

II. LITERATURE REVIEW

1. Coal Gasification Processes are divided into several categories, 4 types of coal gasification processes are demonstrated respectively, and these are moving bed, fluidized bed, entrained bed, and molten bed. Some typical or advanced gasifiers introduced are restricted to these in commercial operation and those in large size pilot plant.
2. Entrained flow slagging gasifiers are found to be the most popular type of gasifier used in commercial gasification projects for the production of electricity, chemicals and fuels. There are several different types of entrained flow slagging gasifiers.
3. In this paper we have described recent progress on developing CFD models for two commercial-scale gasifiers, including a two-stage, coal slurry-fed, oxygen-blown, and pressurized, entrained-flow gasifier and a scaled-up design of the transport gasifier.

III. METHODOLOGY

The CFD Analysis of Entrained Flow Gasifier:

The steady-state, CFD entrained flow gasifier model has been benchmarked through comparisons of model predictions with reported performance for generic one- and two-stage gasifiers. The internal dimensions of commercial gasifier designs are proprietary information. Hence, the geometry of the gasifiers used in this study is based on a combination of publicly available information and engineering judgment. For comparing the predicted gasifier performance we focus on characteristics of the syngas generated, in addition to the basic flowfield features.The principle items of interest are the carbon conversion and the syngas temperature, composition, higher heating value (HHV, kcal and kcal/Nm^3), and cold-gas efficiency (CGE). Hence, the CFD entrained flow gasifier model can be used in studies to investigate

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design and process changes to improve gasifier performance. Further details on the gasifier study are provided below.

1. Single-stage Up-Flow Fired Gasification Process in Entrained Flow Gasifier:

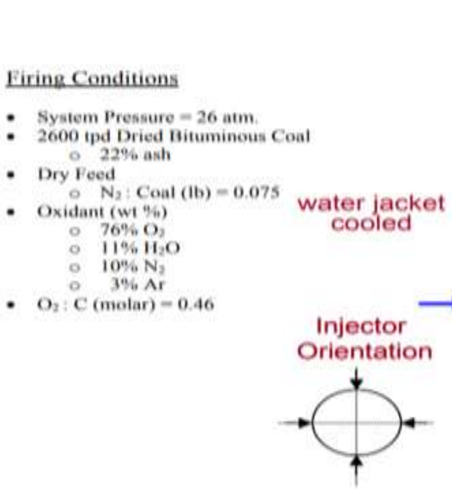

Figure-1: Schematic of single-stage, up-fired gasifier and summary of process conditions.

Simulations have been performed for a single-stage up-flow, dry-feed gasifier that uses a water jacket to cool the refractory. The geometry and process conditions for the gasifier are summarized in Figure-1. Our interest in this configuration is the availability of flowing slag model results that have been published by other researchers. The comparisons are intended to build confidence in the predictive capability of the model developed in this project.

2. Single-stage Down Fired Gasification Process in Entrained Flow Gasifier:

The process conditions and gross gasifier geometry used for these simulations are summarized in Figure-2.

The shape of the single-stage gasifier is based on information for a pilot scale facility and then scaled for commercial-scale systems. We assume a L/D ratio of 2, where L is the length of the main chamber and D is the internal diameter to the refractory surface. At the point where injector exhausts into the gasifier chamber, we assume the coal-water slurry is traveling at about 60 m/s and the oxidant stream has an average velocity of about 100 m/s. The process conditions are similar to those used for the two-stage gasifier, but with slightly more oxidant as per usual practice for a single-stage gasifier.

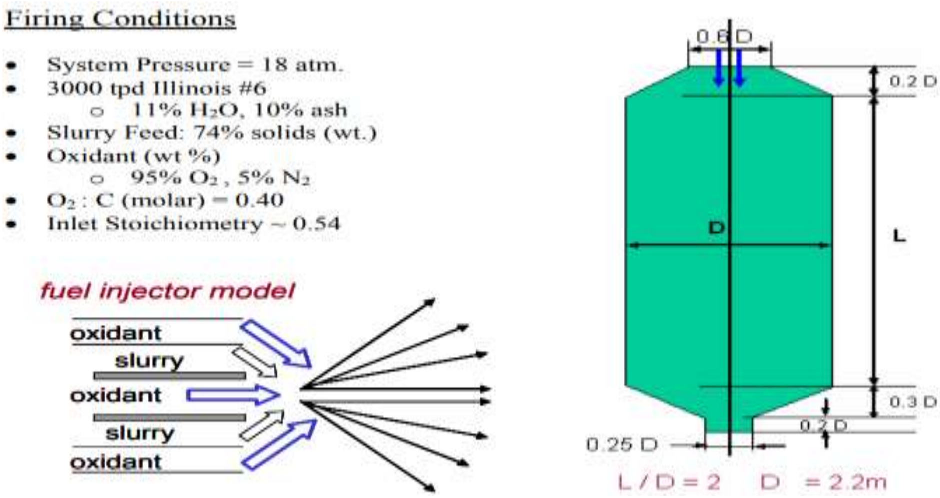

Figure 2: Schematic of one-stage, slurry-feed, down flowgasifier and process conditions.

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3. Two-Stage-Up Flow Fired Gasification Process in Entrained Flow Gasifier:

The process conditions and gross gasifier geometry used for these simulations are summarized in Figure 3. The shape of the two-stage gasifier is based on information contained in the two-stage gasifier contains three levels of symmetrically placed injectors. The bottom two levels of injectors are oriented as per a tangential-firing system to create a strong swirling flowfield that spirals upward along the axis of the gasifier. The system pressure for the gasifier is set at 18.2385 bar. The slurry and oxidant temperatures are to be 422 K and 475 K, respectively. All of the oxidant and 78% of the coal is uniformly distributed amongst the fuel injectors in the first stage and the remaining coal is uniformly distributed across the injectors in the second stage. No oxidant is injected into the upper stage.

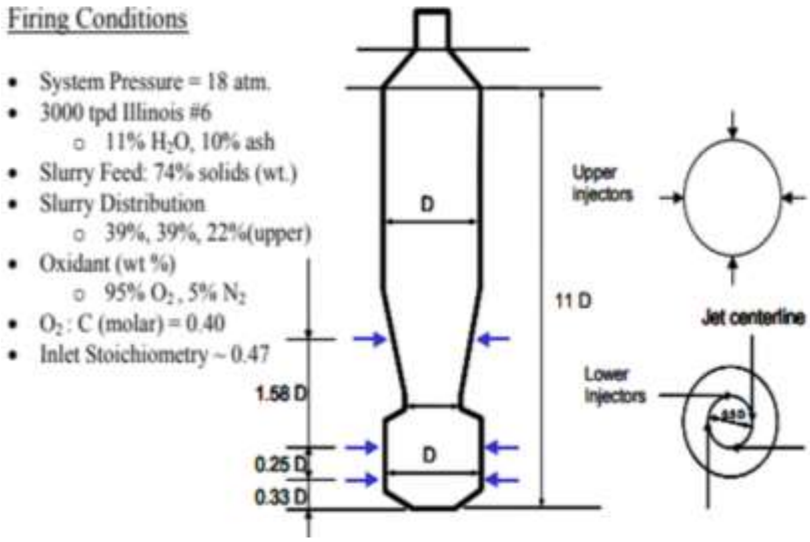

Figure-3: Schematic of two-stage up-flow configuration and summary of process condition

IV. RESULT AND DISCUSSION

Predicted Exit Conditions for Flowing Slag Results in Single Stage Up-flow Gasifier:

Table 1 lists the gasifier performance in terms of syngas exit conditions for the simulations conducted by Seggiani, Benyon and this project (REI). Overall, the three models qualitatively predict the same trends and about the same magnitudes. The model results predict a liquid slag thickness of a few millimeters and a solid slag thickness that varies between 10-20 mm. Based on the coal and flux material properties, the critical viscosity should be about 1625 K, which the model predicts to be achieved, implying that a solid slag layer should exist. In addition, our slag model results indicate very high gas temperatures near the bottom of the gasifier, resulting in a high heat flux and thus potentially creating a situation where it is too hot for solid slag to exist on the bottom face of the gasifier. As shown is figure-4 in comparisons of flowing slag model results.

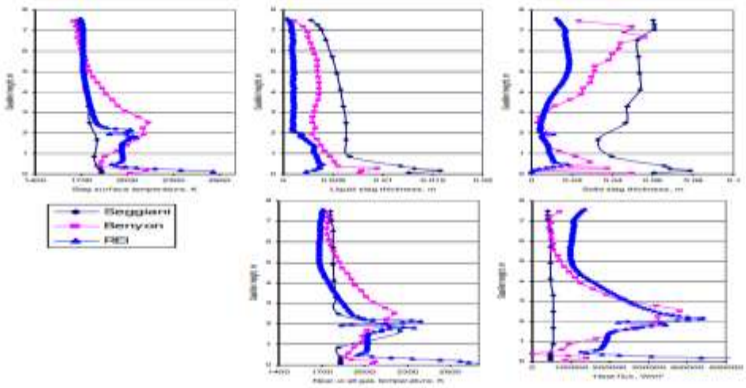

Figure 4: Comparisons of flowing slag model results. Shown are the predicted slag surface temperature (top, left), liquid slag thickness (top, center), solid slag thickness (top, right), near wall gas temperature (bottom, left) and heat flux to the slag (top, right).

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Table 1: Comparison of Predicted Values for Single-Stage, Dry-Feed Up-Flow Gasifier.

Exit Conditions	**Seggiani**	**Benyon**	**REI**
Gas Temp. K	1803	1650	1790
CO (wt %)	76.5	70.9	76.8
CO_2 (wt %)	3.2	10.0	6.0
H_2 (wt %)	1.8	1.8	1.9
H_2O (wt %)	-	-	3.2
N_2 (wt %)	-	-	10.1
Deposition (%)	-	-	4.7
Carbon Conversion (%)	-	-	99.99
HHV, kcal/kg	2463.314	2361.579	2569.496
Cold-Gas Efficiency (%)	-	91.5	80.5

Predicted Flow field in Single Stage down Flow Gasifier:

Also shown in Table 2 are the results from a DOE-funded study that employed an ASPEN analysis for plant with a single-stage gasifier for comparable operating conditions as used in this simulation (same coal, slurry flow rate, but higher gasifier pressure and oxidant flow rate). As noted in previous reports, altering the system pressure has had little effect on the gas composition predicted with our gasifier model. All REI values are reported at the exit of the gasifier. The listed DOE results for syngas temperature, mass flow, and heating value are assumed to be at (or near) the gasifier exit. The listed DOE gas composition is assumed to be the composition after the gas cleanup process. Despite the inconsistencies, there is reasonable agreement between the two simulations.

Firing Petcoke in Single-Stage down Flow Gasifier:

The Figures-5 and Figures-6 are the gasifier gross flowfields for a single stage firing Illinois #6 and Petcoke, respectively. Shown in Figure-5 are the predicted gas temperature and CO and H_2 species concentration (volume %) at mid-plane of the gasifier. Figure-6 contains the same plots as Figure-5, but for firing Petcoke instead of Illinois #6. Comparing the flowfield for firing Illinois #6 versus that of firing Petcoke, the only noticeable difference is for the CO concentration.

Listed in Table-3 is a comparison of average values for the onestage gasifier simulations.

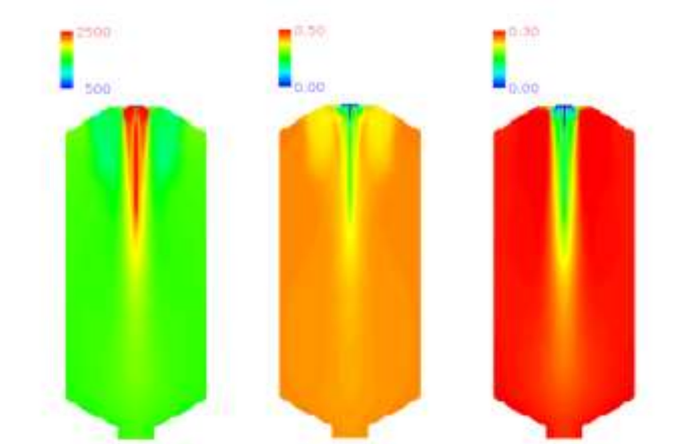

Figure-5: Shown for the one stage, slurry feed, down flow gasifier firing Illinois #6 are the gas temperature and CO and H_2 species concentrations at selected planes.

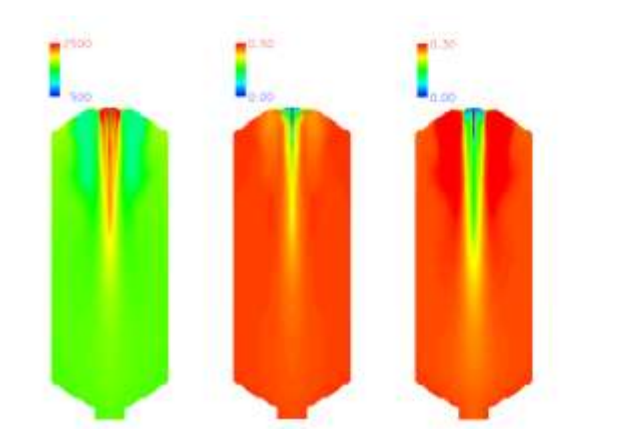

Figure-6: Shown for the one-stage, slurry-feed, down flow gasifier firing Petcoke are the gas temperature, and CO and H_2tspecies concentrations at selected planes.

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Predicted Exit Conditions in Two-Stage Up-Flow Gasifier:

Shown in the Table-2 are the average values for the syngas quantity and composition at the gasifier exit. From the table it can be seen that for the baseline conditions the model predicts a high carbon conversion (over 96%), cold-gas efficiency of about 81%, and a syngas heating value of about 2371.2 kcal/Nm^3. Listed in the table are values for the residence times of the gas and fuel particles. The strong swirling flow pattern provides the means to provide a seemingly long fuel residence time. Also shown in the table are predicted LOI (carbon content) in the fly ash escaping through the gasifier exit and in the slag on the walls.

Firing Petcoke in Two-Stage Up-Flow Gasifier:

Listed in Table-3 are the gross gasifier exit values from the CFD simulation for firing Illinois #6 and Petcoke. Only minor differences in the gasifier performance are witnessed, most notably in the exit CO concentration and the predicted LOI for the unburned fuel exiting the gasifier and deposited on the walls. The predicted flow fields for firing Petcoke result in flow field patterns, gas temperature distribution, and major species concentrations that differ only slightly from those for firing Illinois #6 and thus are not repeated here. The similar flowfields are not surprising because the gasifier operating conditions for firing Petcoke were designed to provide a comparable gasifier temperature as for firing Illinois #6.

Table 2: Predicted Flow Field in Single Stage Down Flow and Two-Stage Up-Flow Gasifier in Comparison REI Model and DOE Model.

	Single-Stage Down Flow Gasifier		**Two-Stage Up-Flow Gasifier**	
	REI	**DOE**	**REI**	**DOE**
Average Wall Temp., K	1853	-	1705	-
Exit Temperature, K	1807	1650	1390	1300
Carbon Coversion, %	94.4	-	96.1	-
Exit LOl, %	33.7	-	19.7	-
DepositLOl, %	25.1	-	47.9	-
Deposition, %	3.5	-	3.3	-
PFR Residence Time, s	0.683	-	1.797	-
Particle ResidenceTime, s	0.041	-	0.926	-
Mole Fraction: CO	41.7%	41.8 %	42.5%	43.5 %
H_2	24.7%	30.8%	32.3%	32.5%
H_2O	21.3%	15.3%	13.8%	13.6%
CO_2	9.6%	10.2%	8.7%	8.6%
H_2S	0.8%	0.0%	0.8%	-
COS	0.0%	-	0.0%	-
N_2	1.8%	0.9%	1.6%	0.9%
Exit Mass Flow, kg/hr	245846.864	237682.208	223620.856	226342.408
HHV of Syngas, kcal/kg	2278.746	-	2723.488	-
HHV of Syngas, kcal/Nm^3	2112	2304	2371.2	2400
Cold-Gas Efficiency, %	74.4	-	80.9	-

Table 3: The Single-Stage down Flow and Two-Stage Up-Flow Gasifier in Comparison of Firing Illinois #6 Versus Petcoke.

	Single-Stage Down Flow Gasifier		**Two-Stage Up-Flow Gasifier**	
	Illinois#6	**Petcoke**	**Illinois #6**	**Petcoke**
Exit Temperature, K	1595	1669	1412	1406
Carbon Conversion, %	92.2	89.1	91.4	93.9
Exit LOI, %	22.4	79.6	34.2	76.7
Deposit LOI, %	53.1	97.9	47.9	96.4
Deposition, %	8.5	9.0	8.5	4.7
PFR Residence Time,S	0.80	0.78	0.83	0.83
Particle Residence Time, S	0.16	0.12	0.37	0.19
Mole Fraction: CO	43.4%	47.2%	43.3%	47.3%
H_2	29.7%	28.0%	32.7%	31.4%

H_2O	16.3%	14.6%	13.3%	11.0%
CO_2	8.1%	7.6%	8.1%	7.6%
H_2S	0.8%	1.1%	0.8%	1.2%
COS	0.0%	0.1%	0.0%	0.1%
N_2	1.7%	1.4%	1.6%	1.3%
Exit Mass Flow, kg/hr	234507.2552 9	236775.2 1714	22545.4 079	229971.33 159
HHV of Syngas, kcal/kg	2596.737	2598.404	2772.96 6	2807.433
HHV of Syngas, kcal/Nm^3	2313.6	2361.6	2380.8	2467.2
Cold-Gas Efficiency, %	80.9	82.1	82.9	85.5

V. CONCLUSION

This work presents some results of parameter studies using the developed simulation of the CFD model. The comparative of single-stage and two-stage entrained flow coal gasifier in different firing of performance enhancement. The prediction results were compared and validated against previously published results. The exit temperature and exit mass flow rate is good for REI model and Petcock and Illions #6 types of coal is to be tested for both the gasifier testing and found that Petcoke is better than Illions #6 in the process of single stage down flow gasifier. The carbon conversion and cold-gas efficiency is better for REI model and higher heating value (HHV) of syngas is DOE model. The gasifier performance is varied with length and found that when length of gasifier increases we will get better performance. So that gasifier all parameter are depend its length. The gasifier length is increasing its parameter is increasing.

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