Experimental Studies on the Characteristics of Entrained Flow Coal Gasifier

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ABSTRACT

The clean coal technology R&D program was actively implemented by the Korean government since 1987. The program aimed to enhance the energy efficiency and coal utilization technologies as well as to reduce the emissions and greenhouse gases. Under this program, the coal gasification research were carried out 1 Ton/day oxygen-blown, entrained-flow coal gasifier for the several foreign candidated coals to be used for the demonstration IGCC power plant project to be construct by early 2000`s. Since July 1994 to up-to-date, KIER has conducted coal gasification experiments for twenty-nine runs, 1,054 hours totally. During the initial test runs in first year, a number of problems were encountered, however problems areas were remedied by appropriate measures, and then the gasifier system enable to run satisfactorily and coal slurry feed rate could maintain up to 200% of design capacity. This paper presents the experimental tests for gasificaton in 1998 with Cyprus Coal(bituminous) and Alaska Usibelli Coal(lignite) from the USA. The slurry concentration of Cyprus coal could prepare 58% 65%, however the Alaska coal was unable to make slurry concentration over 60% due to it's high viscosity. The O_2/coal rates were kept from 0.7 1.2, and heating values of syngas were analyzed as 1,600 2,050 Kcal/Nm^3 (HHV). Adding appropriate additive, viscosity of coal slurry could obtain 450 500cP for the concentration of 58% 65% coal water mixtures.

Introduction

Recently stringent environmental regulations and pressures are mounted by the global aspect for the abatement of environmental problems. Therefore, to use coal for combustion at the power plants are confronted by a number of restrictions. However the IGCC power generation systems have many advantages over conventional pulverized-coal combustors. These advantages include high energy conversion efficiency, reduced pollutant emissions, and the IGCC technology is evaluated as prospective nest generation technology, which provides on attractive option for reduction in CO_2 emission and environmental problems. Many countries such as the United States, Germany, and Japan, etc., have already invested significant amounts of R&D investment and spur to develop IGCC technologies.

At the moment, some of coal gasifiers for electricity generation such as Texaco, Shell, Prenflo processes have been constructed and commissioned for commercial operation, however there still exist a number of problems to be solved for the IGCC systems due to the complicated physical and chemical natures of coal during coal gasification.

Especially, one of key technologies to obtain successful performance of IGCC system is the gasification process, which is mainly influenced by coal type. It should be considered various physical and chemical phenomena during gasification such as coal characteristics, conversion of coal, heating value of synthesis gases, slagging behaviour, etc.. Therefore a number of advanced countries have already concentrated on research efforts to develop coal gasification technologies for IGCC continuously.

The Korean government has planned to construct the high efficiency commercial scale 300MWe IGCC power plant by 2000's, which imported processes will be aimed at the most promising technologies to optimize costs and efficiency. Considering on the tremendous capital investments for the IGCC plant construction, prior to construction of IGCC plant, it should be required to establish for firm foundation of IGCC technologies in order to reduce construction costs as well as capabilities enable to review and assessment for the selection of appropriate processes and coals to be used at IGCC plant. At the IGCC construction phase, if we could establish firm foundation of IGCC technologies, it is anticipated that we are able to substitute a lots of imported construction materials for domestic products and enhance the applications of domestic supplies and could reduce a great deal of construction costs respectively.

This study implemented to investigate complicated characteristics of recent imported coal from the United States as well as variety of coals imported from abroad. KIER has developed gasifier at KIER 1T/D bench-scale unit, entrained-flow coal gasifier. Since July 1994 29th to up to date, 1,054 hours coal gasification runs were carried out KIER 1.0Ton/day entrained-flow coal gasifier with coals imported from the USA, China, Canada, Australia and Indonesia. This paper presents gasification experiments were conducted during 1998 with the US and Australian coals at the KIER oxygen-slurry feed, entrained coal gasifier.

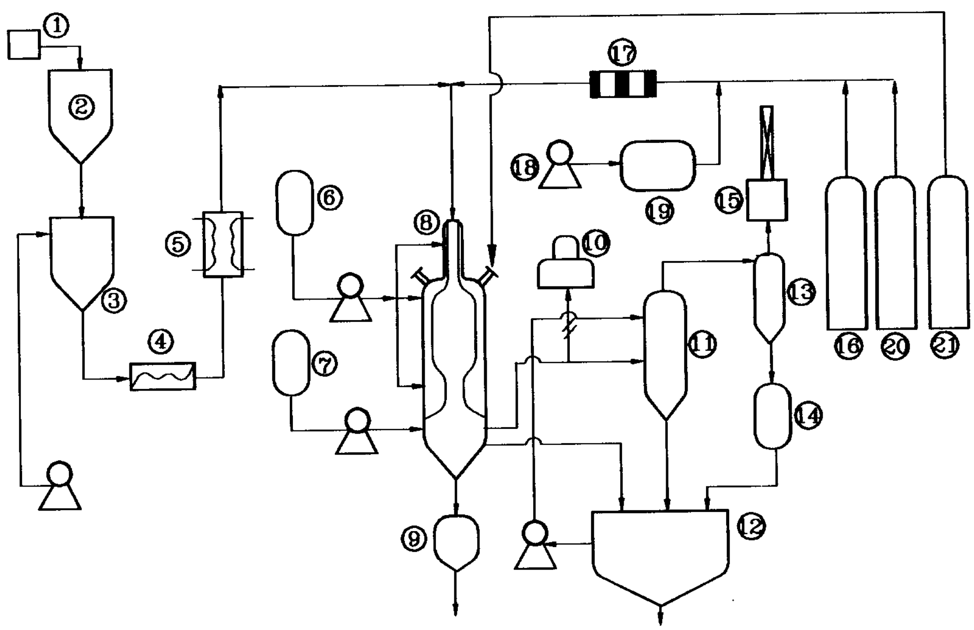
Experimental Facilities

A schematic diagram and overview of the KIER 1.0 T/D entrained-flow gasifier unit is given in Figure 1 and 2. In this gasifier, coal is fed into a high density alumina castable lined reaction vessel as a coal slurry (58 65%, w/w solids) and is one approach to solving the problem of feeding a solid feedstocks into a pressurized reaction vessel.

Figure 1. KIER Entrained - Flow Coal Gasification Experimental Facilities.

The coal is coarsely crushed then wet ground with slurry water in the two stage vibrating mill particle size of less than 200 mesh. The resultant coal-slurry is pumped by screw pump with oxygen into the gasifier through a single burner is mounted on the top of the gasifier, which is adopted by coal water mixture, and then oxygen are mixed and sprayed downwards into the gasifier by burner. In this burner arrangement, the highest temperature was detected near at the top of the reactor.

The coal-slurry water provides the necessary steam for the gasification reactions, where the reaction occurs at 1200 1600 . The temperature control is via a proportion of oxygen/carbon and steam evaporating from coal slurry are maintained by sufficiently high to melt the minerals in the coals into a slag. In the gasifier, coal in coal water mixture reacts with oxidant and water for partial oxidation at high temperature, and is converted to syngas within a few seconds. Its main components are CO, H_2, and CO_2. The gasifier is designed for pressure vessel to sustain up to 25 kg/cm^2 and lined inside high alumina castable to maintain its



① Coal powder
② Primary coal slurry tank
③ Secondary coal slurry tank
④ Slurry feed pump
⑤ Slurry preheater
⑥ Burner and shell cooling water tank
⑦ Quench cooling water tank
⑧ Gasifier
⑨ Lock hopper
⑩ Analytical and data aquisition system
⑪ Gas scrubber
⑫ Settling pond
⑬ Cyclone seperator
⑭ Knock out drum
⑮ Flare stack
⑯ Oxygen storage tank
⑰ Oxygen & nitrogen evaporator
⑱ Air compressor
⑲ Aircompr. surge tank
⑳ Nitrogen storage tank
㉑ Gas storage tank for preheating

Figure 2 .Schematic Flow Diagram of 1.0 T/D Entrained-Flow Gasifier Unit

high internal reaction temperature at 1800 . Also cooling coil is inserted between the castable lining and reactor vessel to prevent from over-heating the reactor shell. Coal ash melts and makes slag, which flows down along the gasifier inside wall. Syngas and molten slag contact are cooled by water at the bottom of reactor before leaving the gasifier.

The water level is controlled by the automatic control valves, which are interacted with feeding quench water rate. The ash in syngas is removed at the syngas scrubber and further cools for syngas and then fed to sampling for analysis and burned at the flare stack. After cooling the syngas, the slag is discharged through the lock hopper. The coal gasification system was designed by considering safety aspects to stand high pressure and high temperature. Control systems of gasifier are integrated the sequence and interlock system so that they can be actuated at the emergency situations.

Experimental

Experiments for coal gasification were carried out 12 times in 1998. Cyprus and Alaska Usibelli coals from the United States were selected for this study and all of experiments were successful. This paper presents the experiment results of two candidated coal for Cyprus and Alaska coals from the USA. The experimental operation continued for two or three days each time including the preparation work. For the safety purpose, all of experimental facilities were checked before preheating gasifier. Gasifier was preheated until the temperature of the inside of reactor reached at 1200 1350 . The objective of this experiments was to understand the characteristics of coal gasification, such as reaction temperature, O_2/coal ratio, and gas composition, slag fluidity and characteristics depending upon coals.

During the gasification experiments, in the form of slurry, which concentrations were maintained from 58%, 60%, 62%, 65%, and fed into the reactor without any feeding problems. Coal Slurry were fed into the reactor from top to bottom and it was atomized with oxygen at the main burner nozzle tips. The product gases and slag were quenched in water vessel and slag and unburned carbon were discharged into slag hopper, located at the bottom of the gasifier. Collected pieces of slag were analyzed later.

a. Coal slurry preparation :

The characteristics of viscosity of coal-water slurry are influenced by rheological parameters such as concentration of additive, mixing times, and temperature. In order to efficiently operate slurry feed entrained-flow gasifier, coal slurry should be maintained as higher concentration, otherwise it should be kept lower viscosity and ideal rheological properties to be lasted even unchanged at high concentration.

Alaska and Cyprus coals selected for this experiments were already used for the conventional coal-fired power plant at KEPCO. Analysis of candidated coals were given in Table 1. In the preparation of slurry, the pulverized dry coals less than 74μ m were mixed with cation surfactant (CWM 1002) concentration of 0.3% and NaOH to reduce viscosity as well as to enhance the rheological properties of slurry.

Concentrations of coal slurry for this experiment, Cyprus and Alaska coals were maintained 58, 60, 62 and 65 wt.% respectively on the basis of dry coal. The viscosity of these were 450 ~ 1,520cP at the room temperature. However, slurry viscosity of Alaska coal at 62% was detected 4,800cp, which was unable to maintain slurry mixture over the 60wt.% due to its high viscosity.

Table 1. Analysis of Experiment Coals

Coal Sources	Cyprus(USA)	Alaska(US)
Proxiamte Analysis (dry basis, wt.%)		
Moisture	9.97	22.32
VM	42.24	36.73
Ash	3.56	11.74
FC	44.21	29.17
HV (Kcal/Kg, HHV)	6,050	5,399
Ultimate Analysis (daf, wt.%)		
C	66.37	48.24
H	5.44	6.07
N	0.95	0.62
S	0.16	0.12
O*	27.1	44.95

* By Difference

Table 2. Analysis of Ash Composition and Fusion Temperature

Coal Sources	Cyprus	Alaska
Ash Composition (wt.%)		
SiO_2	58.86	54.57
CaO	6.45	13.42
Al_2O_3	18.72	18.90
Fe_2O_3	11.38	4.94
TiO_2	0.68	0.58
Na_2O	0.36	1.06
K_2O	0.89	1.89
MgO	2.67	2.61
Ash Fusion Temperature ( )		
IDT	1,226	1,192
ST	1,237	1,227
HT	1,283	1,274
FT	1,294	1,291

b. Experimental Conditions

For the start-up of coal gasifier, it was preheated using LPG until the inner temperature of reactor reached about 1,200 ~ 1,300 to maintain sufficient heat inaction for initial start-up operation. Slurry feed rate with respect to rpm of the slurry pump was calibrated prior to the experiments. Coal feed rate was ranged from 30 to 50 Kg/hr to maintain reaction temperature. Slurry and oxygen were preheated to 70 ~ 250 , prior to feed into burner. Experimental conditions for this study were summarized in Table 3.

Since ash fusion temperature for coals were 1,290 ~ 1,380 at reducing atmosphere, therefore gasification reaction were carried out 1,300 ~ 1,500 . The gas chromatography was equipped with two columns (Porapak N and molecular seive 13X) and 10-port valve switching system. Composition of Carbon dioxide and methane from syngas were analyzed by infra red analyzer, which are monitoring operating conditions at coal gasifier.

Table 3. Experimental Conditions for Entrained Flow Gasifier

Parameters	Gasification Conditions
Coal slurry concentration (wt.%)	58, 60, 62, 65
Coal slurry Viscosity (up at 20)	450 ~ 1,520
Coal slurry feed temperature ( )	70
Coal feed rate (Kg/hr)	25 ~ 50
Oxygen/Coal ratio (wt./wt.)	0.6 ~ 1.2
Oxygen feed temperature ( )	100 ~ 200
Gasification temperature ( )	1,300 ~ 1,550
Reactor Pressure (atm)	0 ~ 5

Result and Discussion

a) Reactor Temperature

Temperature distribution inside reactor depends upon the feed rate of coal and oxygen unless heat loss is considered. Gas temperature changes with respect to the rate of O_2/coal in the gasifier were shown in Figure 3.a,b. Considering the ash melting temperature and heat losses from the reactor, desired O_2/coal ratio were at least 0.6.

Figure 3.a and b show the effect of reaction temperature changes in coal gasifier with respect to the oxygen/coal ratio for Cyprus and Alaska coals. As shown in Figure 3a and b, reaction temperature in gasifier were gradually increased, depending upon oxygen/coal ratio increased. It was found that the oxygen/coal ratio effects carbon conversion more significantly than the steam/fuel ratio.

In a short residence time reactor like an entrained gasifier, the oxygen/coal ratio is critical to the conversion since the heat produced form reactions supports the endothermic gasification reactions. In this studies, O_2/coal ratio were not need to exceed beyond 0.9. To obtain higher carbon conversion and increase cold gas efficiency, O_2/coal ratio between 0.8 and 0.9 is required for this gasifier.

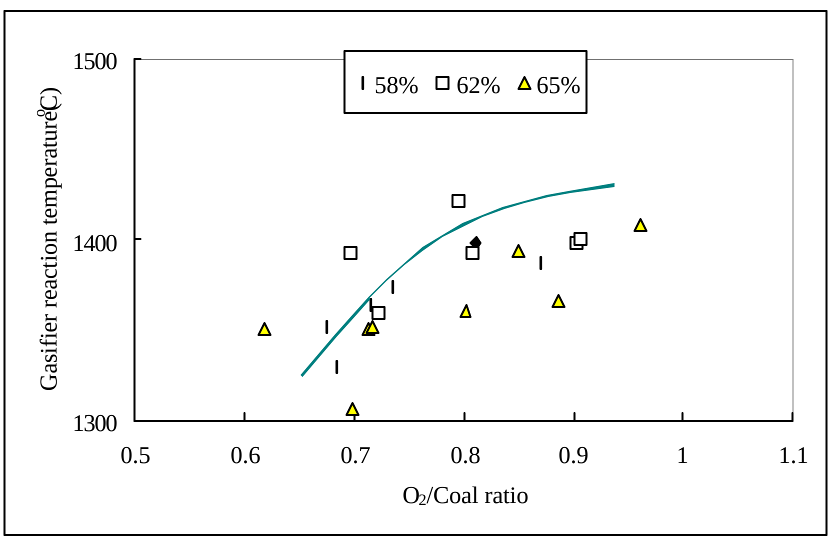


Figure 3.a. Gas temperature changes with respect to the ratio of O_2/coal in gasifier for Cyprus coal

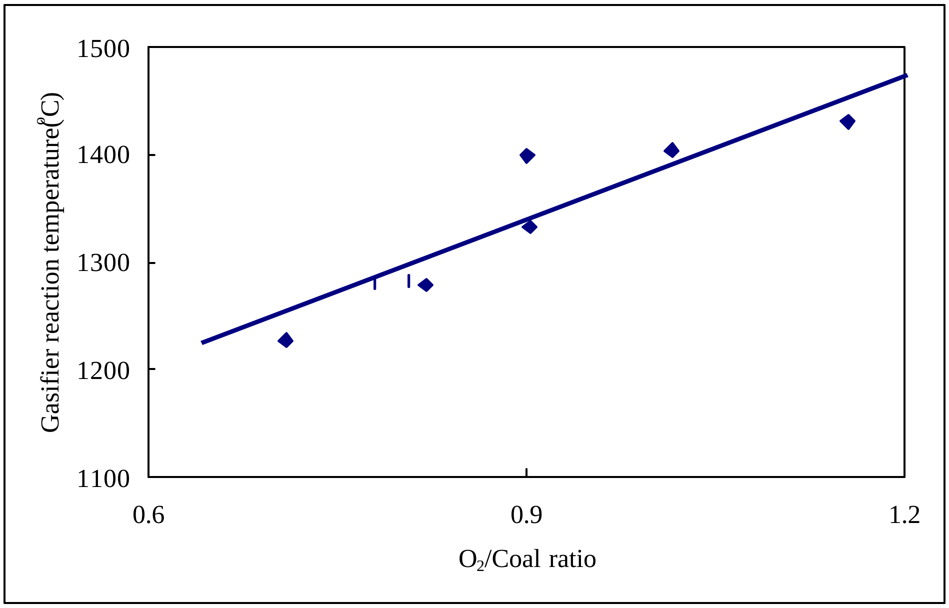


Figure 3.b. Gas temperature changes with respect to the ration of O_2/coal in gasifier for Alaska coal

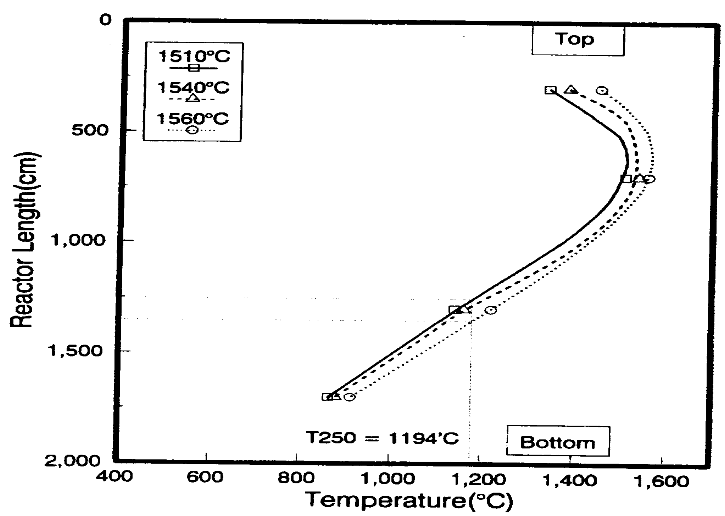


Figure 4. Gasifier wall temperature distributions relating to the reaction length for Cyprus coal.

Figure 4. shows the distribution of wall temperature of reaction respect to the length of reaction. The wall temperature of reactor was decreased as lowering the position of reactor because gasification of carbon by combustion with oxygen is highly exothermic and/or high rate of heat losses were detected due to the insufficient insulation thickness of wall and the flange connections.

Figure 5 shows the schematic diagram of gasifier before and after external wall insulated. Coal gasifier was insulated with two layers of high density and low density alumina castable inside gasifier to present heat loss from reactor. The inner part was insulated by castable specified as (high density ; 100mm thick., k_1=1.5W/m·K, low density ; 250mm thick.,

k_2=0.8W/m·K). To evaluate the heat losses and effect of reactor wall, 54mm, k_3=0.056W/m·K insulation material was attached external wall.

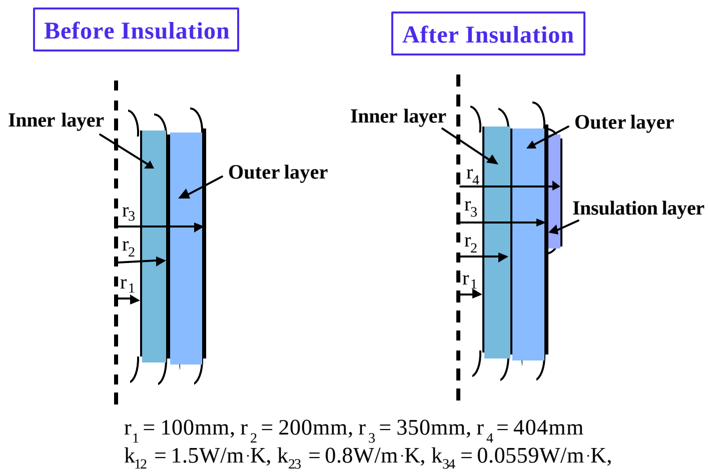


Figure. 5. Overview schematic diagram of gasifier before and after outer wall insulation

As shown in Figure 6 and 7, heat losses were able to reduce 50% after insulated and heat loss were mainly detected at flange connection and down the reactor effluent.

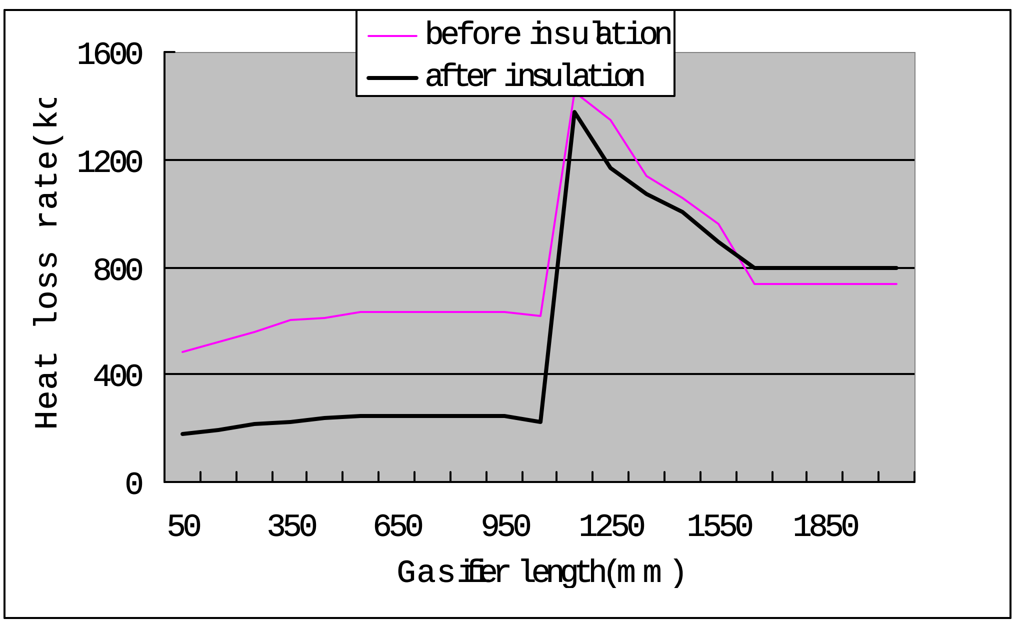


Figure 6. Compare heat loss rate in the gasifier

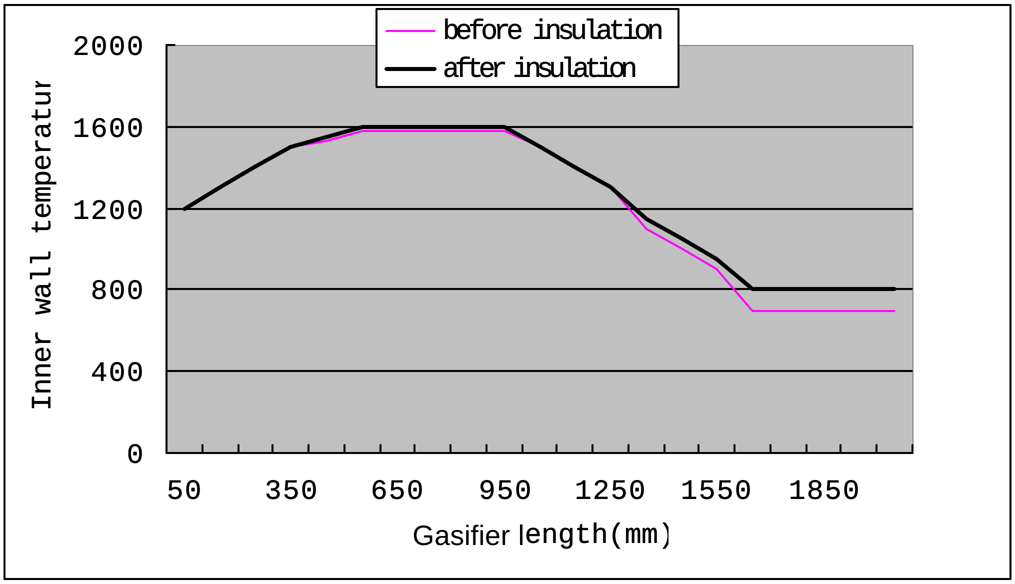


Figure 7. Compared inner wall temperature distribution in the gasifier

b) Product Gases

Gasification reactions are degermined by the reaction conditions, primarily temperature and the concentration of reactants. The reaction temperature depends upon the coal feed rate, heat required for the gasification and the heat loss. Evaporation of moisture content is the first step after then coal slurry, being maintained 58 ~ 65 wt% on the basis of dry coal, feed into the gasifier. Then pyrolysis and combustion, a series of consecutive and paralled reaction takes place. After these reactions product gases from gasification are highly enthothermic reaction with steam. Effects of reaction temperature and O_2/coal ratio on the product gas compositions are shown in Figures 8 through 11.

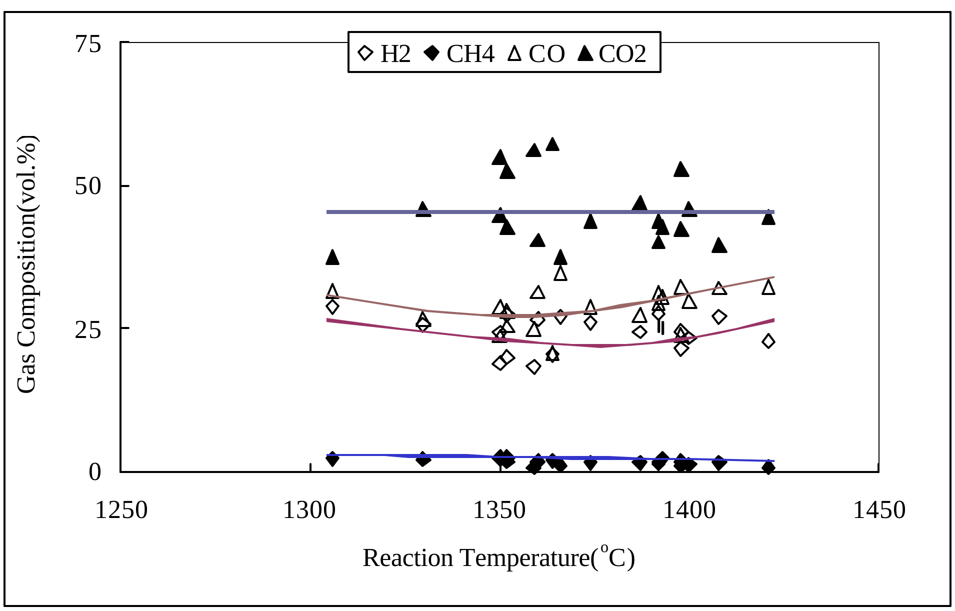


Figure 8. Effect of reaction temperature on the product gas composition at variable O_2/coal ratio for Cyprus coal

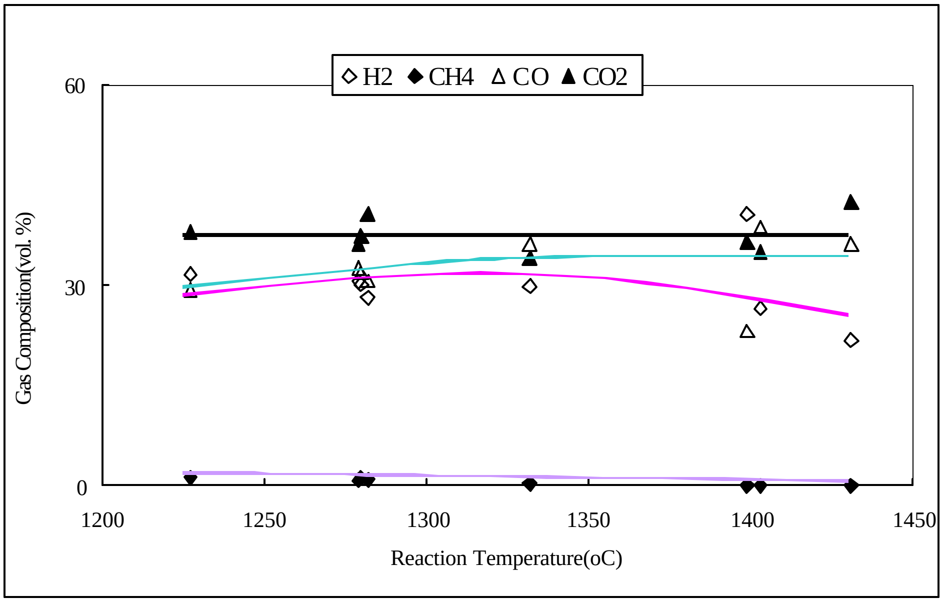


Figure 9. Effect reaction temperature on the product gas composition at variable O_2/coal ratio for Alaska coal

As shown in Figure 8 and 9, the formation of monoxide carbon and hydrogen increase in the range of 1,350 ~ 1,450 , while it increase relatively small in the higher temperature ranges. The formation of carbon monoxide increase by the gasification of char-CO_2 as the oxygen feed rate increases, otherwise CO_2 decreases slightly due to char-CO_2 reaction.

Figure 10 and 11 show the effect of O_2/coal ratio on the syngas composition for Cyprus and Alaska coals. The composition of syngas products shows similar tendency to those of Figure 10 and 11 as CO and H_2 gradually increase, otherwise CO_2 decrease at the O_2/coal ratio over the range 0.8 .

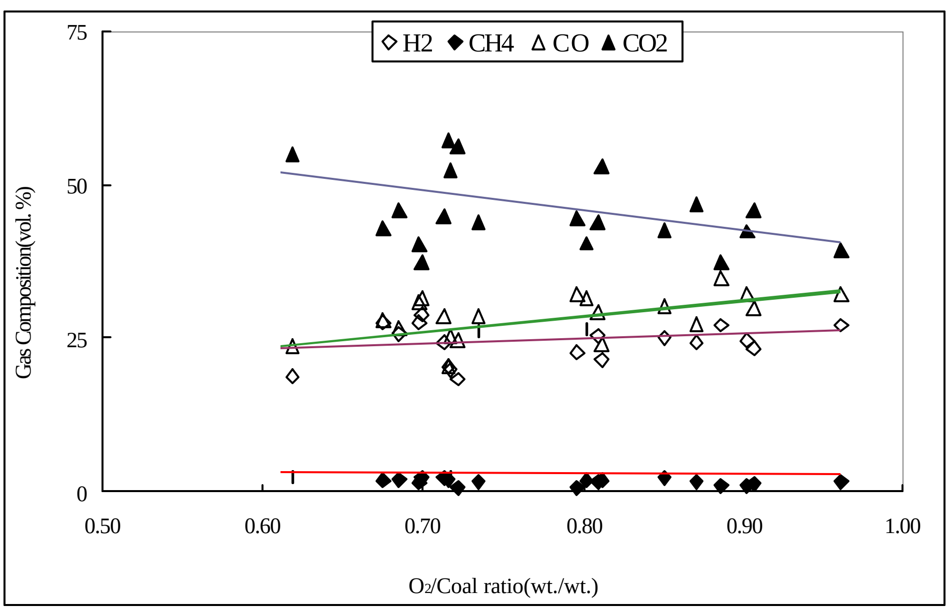
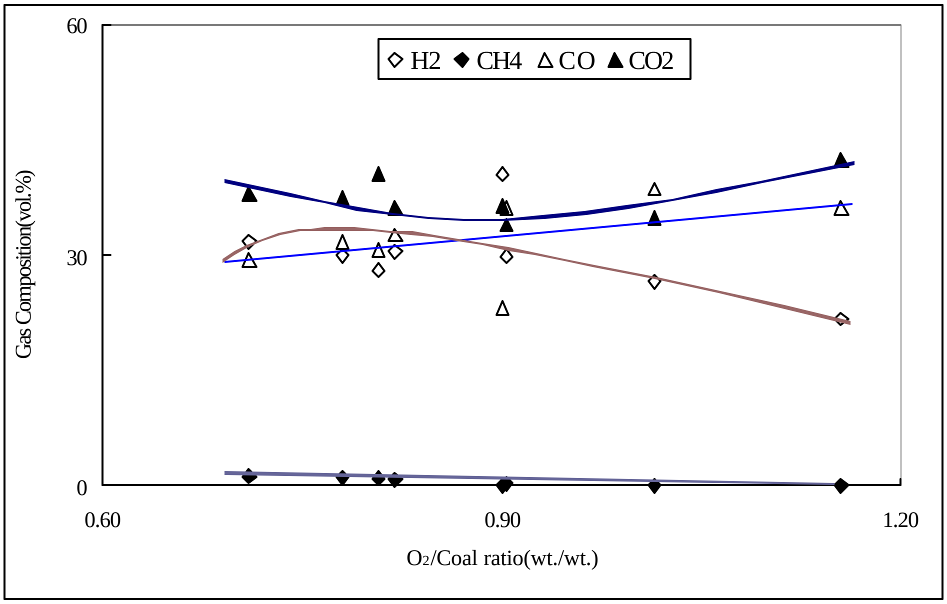


Figure 10. Effect of O_2/Coal ratio on the syngas composition for Cyprus coal



Fgure 11. Effect of O_2/Coal ratio on the syngas composition for Alaska coal

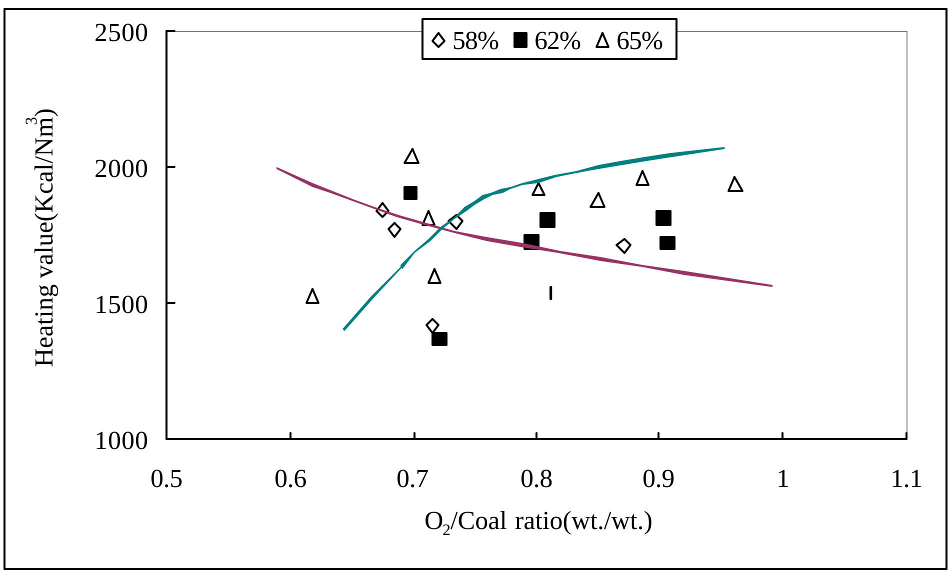


Figure 12. Effect of O_2/Coal ratio on the Heating value of syngas for Cyprus coal with various slurry concentration

Figure 13 and 14 show the effect of O_2/coal ratio on the heating value of syngas with slurry concentration on 58~65 wt.% for Cyprus coal and 58 wt.% for Alaska coal. Esperimental results of Cyprus coal show that heating values of syngas gradyally increase at the higher slurry concentration as well as higher oxygen feed rate, otherwise heating value decrease lower slurry concentration for Alaska coal. As can be seen from the figures, the carbon conversion decrease when the water/coal ratio is increased. This is due to the latent heat of evaporation of water which absorbe a large amount of heat in the reactor and lowers the reaction temperature as well as heating value.

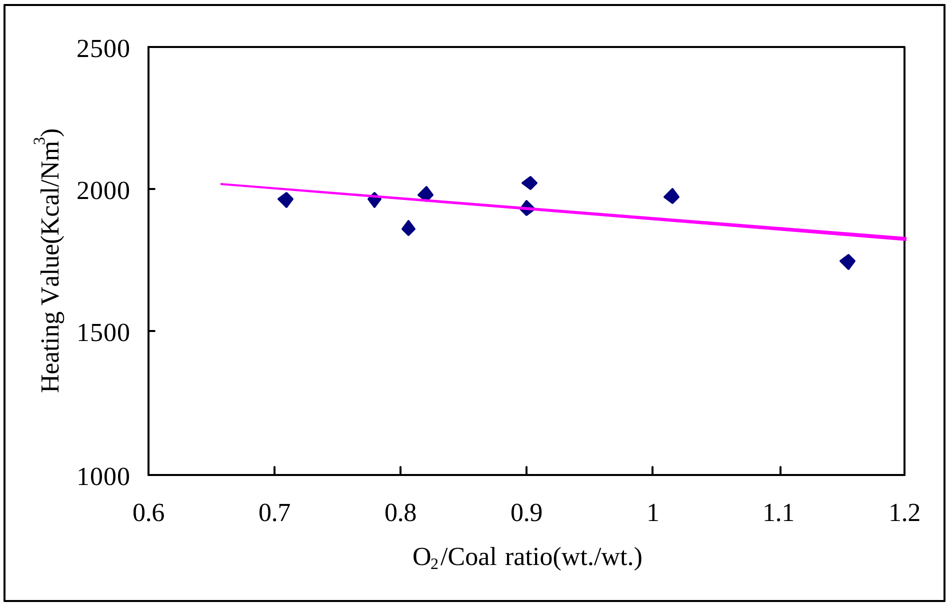


Figure 13. Effect of O_2/Coal ratio vs. Heating value of Alaska coal with 58% slurry concentration

Table 4. Syngas output with respect to the variable slurry concentration for cyprus Alaska Coal

Syngas composition(vol%)	Cyprus coal			Alaska coal
Coal Slurry conc. (wt.%)	58%	62%	65%	58%
H_2	20 ~ 26	18 ~ 27	18 ~ 28	21 ~ 41
CH_4	1.52 ~ 1.98	0.7 ~ 1.38	0.99 ~ 2.47	0.02 ~ 1.21
CO	20 ~ 29	29 ~ 32	23 ~ 35	29 ~ 39
CO_2	43 ~ 57	43 ~ 58	37 ~ 58	33 ~ 42
H_2 + CO	40 ~ 55	43 ~ 58	45 ~ 62	57 ~ 65
HHV(Kcal/Nm)	1,400 ~ 1,850	1,400 ~ 1,900	1,525 ~ 2,044	1,747 ~2,022

Table 4 shows the syngas output from the coal gasifier with respect to the various slurry concentration for candidated coals. It was analyzed that higher concentration of Coal-Water slurry runs produced more syngas and syngas for higher heating value. However gasification of 58% Alaska coal-slurry shows higher heating value gases and this is because the reactor was insulated during experiments, which could maintain appropriate O_2/coal ratio and higher reaction temperature.

c) Slag

The slagging phenomena in the gasifier are one of the most important considerations for the gasifier design and operation. Therefore appropriate operation temperature in the gasifier should be decided by ash slag melting and fluid temperatures. Mineral matters in the ash are mainly consist of Al_2O_3, SiO_2, K_2O, MgO, CaO, Fe_2O_3, etc., and the fusion temperatures of ash were mainly influenced by the aluminum-silicate complex. In order to predict the slag characteristics, many slag indices have been developed by analyzing mineral matters in coal ash such as base/acid ratio, silica ratio, ash fusion temperatures, T_{250}. As flux agent $CaCO_3$ was injected into the coal slurry to reduce ash melting temperatures. The experimental results were obtained on minimum ash melting temperature if 20-30% flux agent(CaO base) added to coal slurry and thereafter ash melting temperature were gradually increased over 30% of CaO concentration. The low ash fluid temperature and the high calcium oxide content of the ash suggested that fluxing was not required. This was confirmed by liquids temperature predictions based on a phase diagram approach for the major components, silica, alumina, iron oxide and calcium oxide.

Table 5. Slag composition of candidated coals

Components	Al_2O_3	SiO_2	CaO	Fe_2O_3	K_2O
Cyprus coal (wt.%)	29.72	54.12	4.87	9.35	0.69
Alaska coal (wt.%)	23.05	44.30	17.63	5.63	1.57

* Slag made from coal ash

After a thermal transition by the separation of inorganic substance or combined with glassy materials like silica, table 5 shows the slag compositions of Cyprus and Alaska coal. A slag prepared above the temperature suggested in ASTM was indicating the reduction of alkali components(Na_2O, K_2O, MgO). Iron in the formed slag on the wall of gasifier was found to form a metalic iron(Fe) due to the reducing gases and unreacted char. Metallic iron would be solidified on the wall or at the slag tap. Slag viscosity could be changed by its compositions. For the coal gasification, the collected slag composed differently of compostions of the slag prepared by ASTM. In major components of slag such as SiO_2, Al_2O_3, CaO, Fe_2O_3, it was found that SiO_2 contents was increased, while Al_2O_3, CaO and Fe_2O_3 were decreased because they were played as an oxide doner under a conversion environment in high temperature. Slag produced from coal gasification contained relatively a small amount of Al_2O_3 and Fe_2O_3, while SiO_2 content was remarkably increased because the flux agent was played a role of the prevention of srystallization of silica.

Conclusion

1. The Cyprus coal(bituminous) 3 runs, 100 hours and Alaska coal(lignite) 3 runs, 118 hours were conducted stable gasification operation due to the their higher reactivity. The slag fussion temperatures were shown about 1,290 .

2. In order to perform stable operation of the gasifier, a number of operating parameters should be considered, such as concentration, rheological properties of coal slurry, reaction temperature, pressures, O_2/coal ratio, physical and chemical properties of coals. And also those parameters have strong influence to output from gasifier ; syngas compositions, heating values, carbon conversion and fluidity of molten slag. Especially the slagging behaviour in the gasifier are observed one of the most important considerations for gasifier design and operation.

3. In order to efficiently operate slurry feed entrained-flow gasifier, coal slurry should be maintained as higher concentration, otherwise it should be kept lower viscosity and ideal rheological properties to be lasted even unchanged at high concentration. The concentration of coal-slurry for Cyprus coal could be maintained up to 58%, 60%, 62%, 65% , which were enable to feed into the gasifier without any feeding problems. However, the Alaska coal was unable to maintain slurry concentration over the 60% due to its high viscosity.

4. During the experiments, O_2/coal ratio were maintained from 0.7 ~ 1.2 and especially Alaska

coal was required excessive oxygen feed due to it's higher inherent moisture contents. Throughout 12th experiment runs with two imported coals in the gasifier, coal slurry feed, coal conversion, syngas compositions and other operating conditions were shown as stable and good performance, except slag plugging problems exist at the bottom of reactor. Feed rate maintained with 2.5 times design rate and the heating value of syngas were detected as 1,600~2,050Kcal/Nm^3(HHV).

5. It was analyzed that substantial heat losses were detected from the reactor wall due to the insufficient insulation thickness adopted for reactor design and also cooling water coils in the castable were contributed to additional heat losses. To prevent heat losses from gasifier, experiments were conducted by Alaska coal after reinforcing with 45mm thickness insulation material(k=0.055W/m·K) at the external wall of gasifier. After reinforced external insulation, gasification system could run satisfactorily and the experimental results were shown that heat losses from the wall were reduced by approx. 50% less than before insulated. And also oxygen consumption was reduced significantly before insulation, otherwise H_2+CO syngas compositions were increased from 60% to 65% after insulation.

6. During the experiments using Alaska coal, slag plugging problems were seriously encountered at the bottom of reactor. It was analyzed that external insulation was somewhat contributed to enhance operatiing condition at gasifier, however it was unable to prevent heat losses from reactor effluent gases, which caused mainly to drop temperature at the bottom of gasifier on the slag tap hole, where temperature detected below the slag fluid temperature.

Originally KIER entrained-flow gasifier was designed by 0.5T/D. However, some of problem areas were remedied and greatly improved appropriate measures such as enlarged fuel nozzles at burner capacity, modified slurry feeding system and control system. Slurry feed rate into the gasifier could be able to maintain up to 1.5T/D design capacity and coal gasification system could run satisfactorily. In order to enhance the performance and to keep reliable operation for gasifer, it was analyzed that reactor should be modified properly to prevent heat losses and slagging problems in the near future.

Reference

1. B. W. Gainey, "Current Status and Projects for the use of clean coal technologies in power generation", The Australian Coal Journal No. 34, 1991.
2. Clean coal technology, options for the future, International Energy Agency, ETSU/DTI, 1993.
3. The Tampa Electric Integrated Gasification Combined Cycle Project, Demonstration of an advanced 250MW IGCC plant, U.S. DOE/Tempa Electric CO., 1996.
4. Cool Water Coal Gasification Program-First Annual Report, Palo Alto, EPRI, AP-2487, 1982.
5. C. Y. Wen and et al., "Entrainment Coal Gasification Modeling", Ind. Eng. Chem. Process Des. Dev., Vol 189, No. 4, 1979.
6. T. J. Park, J. H. Kim, H. J. Lee and J. G. Lee, Experimental Study on the Gasification Characteristics of Coal and Orimulsion in 0.5T/D Gasifier, Research Report KRC-93G-J13, KIER/KEPCO, 1995
7. T. J. Park, J. H. Kim, H. J. Lee and J. G. Lee, An Experimental Study on the Coal Gasifier and Purification System for IGCC Plant, KRC-90G-J07, KIER/KEPCO, 1993
8. T. J. Park, J. H. Kim, H. J. Lee, J. G. Lee, L. W. Smith and Coiln Paulson, Development of Coal Gasification Technology for IGCC, Collaborative Research Report, KIER/CSIRO, 1994

9. D. C. Kim, et. al., An Experimental Study on the Coal-Water Mixture and Combustion, KIER Report, 1987
10. H. J. Hurst, J. H. Patterson, F. Novak and J. G. Lee, Viscosity Study of Melts Derivated from KIER Coal Ashes, Investigation Report CET/IE365R, KIER/CSIRO Collaborative research for IGCC Technology, 1995
11. John E. ME Daniel, et. al., Tampa Electric Polk Power Status, Proceeding at 1998 Gasification Technologies conference, SF, USA, 1998
12. Clean Coal Technology Demonstration Program, US DOE, 1997
13. T. J. Park, J. H. Kim, et al., Status of Coal Gasification R&D in KIER, 1st China-Korea Joint Workshop in Coal Utilization Technology, September 2-6, Beijing, 1996.
14. Nicholas R. Soelberg, L. D. Smoot, et al, Entrained Flow Gasification of Coal [2], Fuel 1985, Vol. 64, June
15. T. J. Park, et al., Development of the Integrated Gasification Combined Cycle Technologies (I), KIER/KEPRI Research report, 1998