Rashmeet Singh Monga et al. Int. Journal of Engineering Research and Applications www.ijera.com
ISSN : 2248-9622, Vol. 5, Issue 5, (Part -6) May 2015, pp.132-138

RESEARCH ARTICLE OPEN ACCESS

Chemical Looping Combustion of Rice Husk

Rashmeet Singh Monga[1], Ganesh R. Kale[2], Sadanand Y. Guhe[1]
[1](Chemical Engineering Dept., Jawaharlal Nehru Engineering College, Aurangabad, India)
[2](Solid and Hazardous Waste Management Division, CSIR-NEERI, Nagpur, India)

ABSTRACT
A thermodynamic investigation of direct chemical looping combustion (CLC) of rice husk is presented in this paper. Both steam and CO_2 are used for gasification within the temperature range of 500–1200˚C and different amounts of oxygen carriers. Chemical equilibrium model was considered for the CLC fuel reactor. The trends in product compositions of the fuel reactor, were determined. Rice husk gasification using 3 moles H_2O and 0 moles CO_2 per mole carbon (in rice husk) at 1 bar pressure and 900˚C was found to be the best operating point for hundred percent carbon conversion in the fuel reactor. Such detailed thermodynamic studies can be useful to design chemical looping combustion processes using different fuels.

Key Words*- Chemical* looping combustion, NiO, Rice husk, Thermodynamic study.

I. Introduction

CO_2 emission to the environment is mainly contributed by industrial power generation. Concerns for climate change phenomenon have started special procedures to reduce CO_2 emissions using CO_2 capture and storage techniques that capture CO_2 from energy-intensive processes and then store it in suitable geologic locations [1]. The concerns of increase in greenhouse gas emissions and an inevitable global warming crisis is reported by researchers. CO_2 is also largely generated by fossil fuel processing and it is a crucial greenhouse gas that affects the climate change [2]. Fossil fuels are at present the major energy resources and are likely to dominate for more several decades. Hence it is essential to continue the use of fossil fuels but also reduce the CO_2 emissions to the atmosphere [3].

The expectations from the Carbon capture and storage (CCS) technologies to help curb the greenhouse gas emissions and ensure a sustainable development of power generation and other energy-intensive industrial sectors are extremely high. Amongst them, chemical looping systems display a promising option to capture CO_2 with lower cost and energy penalty [1]. Chemical looping combustion (CLC) is a promising technology to utilize fossil fuel for combustion and prevent CO_2 dilution in the nitrogen rich flue gases. In this process, a solid oxygen carrier supplies the oxygen needed for CO_2 and water formation that is a nitrogen free product mixture. This avoids the major cost of CO_2 separation from the flue gases and also reduces the NO*x* formation. A good oxygen carrier readily reacts with the fuel gas and shall be reoxidized upon being contacted with oxygen. An oxygen carrier is generally prepared by a metal oxide and an inert binder that provide the oxygen storage, fluidizability and mechanical strength [4]. Chemical looping combustion (CLC) is a non-flame two-step combustion which produces a pure CO_2 stream for easy compression and sequestration. The process comprises of two interconnected fluidized bed reactors where the fuel reactor is a bubbling fluidized bed and the air reactor is a conventional circulating fluidized bed. It uses an oxygen carrier - a highly-reactive metal particle, to avoid the direct contact of air and fuel during the combustion, to indirectly transport oxygen from the air to the fuel. The products of combustion are kept separated from the rest of the flue gases namely nitrogen and excess oxygen [5]. The CLC system is composed of two reactors, an air and a fuel reactor, as shown in fig. 1

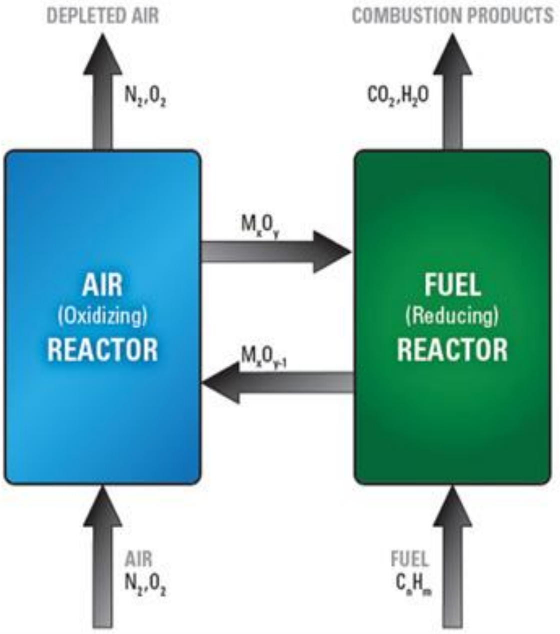


Fig. 1- Chemical-looping combustion system.

In CLC, the solid oxygen carrier is circulated between the air and fuel reactors. The fuel is fed into the fuel reactor where it is oxidized by the lattice oxygen of the oxygen carriers and the reaction in the fuel reactor is almost endothermic.

$$(2n + m)\ Me_xO_y + C_nH_{2m} \rightarrow (2n + m)\ Me_xO_{y-1} + mH_2O + nCO_2.$$

Once fuel oxidation is completed; the reduced metal oxide $M_yO_{(x-1)}$ is transported to the air reactor where it is reoxidized according the reaction:

$$Me_xO_{y-1} + \tfrac{1}{2}\ O_2 \rightarrow Me_xO_y$$

The flue gas stream from the air reactor will have a high temperature and contain N_2 and some unreacted O_2.

Transition metal oxides, such as Ni, Fe, Cu, and Mn oxides are reported as reactive oxygen carriers. Ni-based oxygen carriers have exhibited the best reactivity and stability during multi-redox cycles [6]. Henrik Leion et al. has investigated the feasibility of using three different solid fuels in chemical-looping combustion (CLC) using NiO as oxygen carrier in a laboratory fluidized-bed reactor system at 970°C. They reported that the NiO particles also showed good reactivity with methane and a syngas mixture of 50% H_2 and 50% CO also showed good fluidizing properties without any signs of agglomeration [7]. Tobias Mattisson et al. have investigated the feasibility of using NiO as an oxygen carrier with CH_4 as fuel and in the temperature range 700–1200°C during chemical-looping combustion and their result showed that the yield of CO_2 and H_2O decreased with increase in temperature [8]. M.M. Yazdanpanah et al. has presented a reactor model for combustion of CH_4 with $NiO/NiAl_2O_4$ oxygen carriers in the fuel reactor of a 10 kW CLC pilot plant. The model shows good agreement with experimental results considering some kinetic and hydrodynamic modifications, including impact of gas adsorption by falling particles in the bubble phase on the gas exchange coefficient and thermodynamic limitation of CO and H_2 combustion [9]. C. Saha et al. have carried out an experimental investigation pertaining to CLC of a Victorian brown coal using NiO and CuO as oxygen carriers at 950 °C (NiO) and 800°C (CuO) and have reported the high reactivity of CuO as compared to NiO during cyclic operation [10]. Magnus Rydén et al. have examined the Ce, Ca, or Mg stabilized ZrO_2 oxygen carriers by redox experiments in a batch fluidized-bed reactor at 800–950°C, using CH_4 as fuel. The experiments showed good reactivity between the particles and CH_4 [11].

Many studies have also demonstrated the feasibility of using CLC for both gaseous and solid fuels [12]. The chemical looping process was mainly targeted towards efficient carbon capturing [13, 14] and hydrogen production [15, 16]. Rutuja Bhoje et al. have done theoretical study of chemical looping combustion of methane to consider some key technology development points to help the process engineer choose the right oxygen carrier and process conditions [17]. X. Wang et al. have developed a three-dimensional numerical model to simulate the CLC process in the fuel reactor using a bubbling fluidized bed of oxygen carrier made from 14 wt% of metal oxide CuO and 86% wt of inert material Al_2O_3 and a coal gas from coal gasification containing 55 vol. % CO, 30 vol. % H_2 and 15 vol. % CO_2 [18].

India produces approximately 120 million tons of paddies each year which gives around 24 million tons of rice husk and 4.4 million tons of rice husk ash every year. Rice husk is a high calorific value renewable fuel and can be used for electricity generation in efficient manner [19]. Rice husk can be used as fuel and has oxygen in its structure [20]. The CLC of rice husk has not been studied so far in literature.

II. Process Design:

The conceptual process design for CLC of rice husk is shown in figure 2. The process scheme consists of a CLC fuel reactor and air reactor. Preheated rice husk, CO_2, H_2O and NiO from air reactor are fed to the fuel reactor in calculated amount to convert the rice husk to CO_2, and H_2O. The fuel reactor products were assumed to be in thermodynamic equilibrium at the exit of the reactor. Complete conversion of rice husk and maximum CO_2 production are targeted in the fuel reactor. It is assumed that the NiO oxidizes the carbon and hydrogen in rice husk to CO_2 and H_2O in the CLC fuel reactor. The moles of OC (NiO) for fuel reactor are varied depending on the stoichiometric requirement of reaction between rice husk and NiO. Complete conversion of rice husk to CO_2 and H_2O is desired; however the conversion is limited by thermodynamic equilibrium.

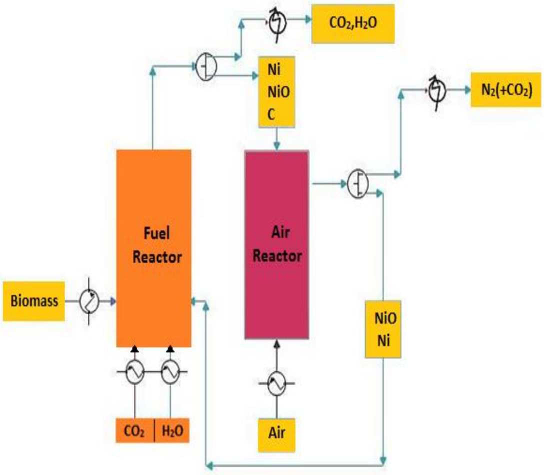


Fig. 2- Process diagram

The OC (NiO) is reduced (to Ni) in the CLC fuel reactor. The products of the CLC fuel reactor go through a gas-solid separator and the gaseous products mostly containing CO_2 and H_2O can be cooled for CO_2 separation and sequestration with heat recovery or recycled back as required. The solid products of the CLC fuel reactor containing OC are transferred to the air reactor, in which preheated air is added to completely oxidize coke to CO_2 and regenerate the reduced OC. Complete conversion is assumed in these oxidation reactions.

The regenerated oxygen carrier (NiO) is separated from the air reactor product stream using a gas-solid separator and is recycled to the fuel reactor. The air reactor is the major source of thermal energy in this process. It is safely assumed that both the air and fuel reactors operate at same temperature and pressure conditions.

Table 1- Rice husk composition [21].

Species	**C**	**H_2**	**O_2**
Moles	1	0.6402	0.3052

The base composition of rice husk taken were 1 mole C, 0.6402 moles hydrogen (H_2), 0.3052 oxygen (O_2). According to rice husk composition reaction involved in fuel reactor assumed to be

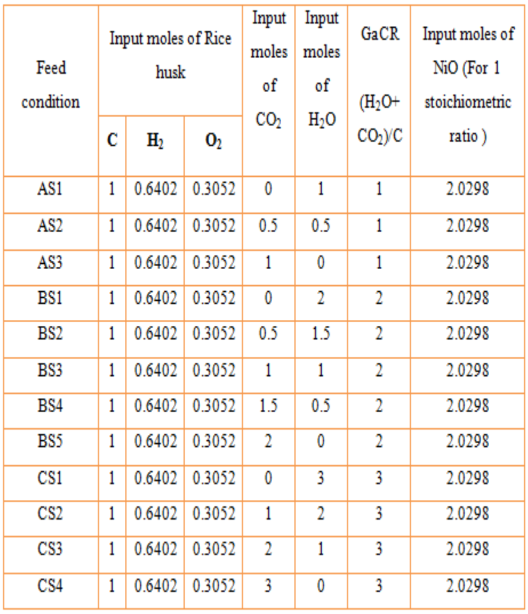
$$C + 0.6402H_2(g) + 0.3052O_2\ (g) + 2.0298NiO = CO_2\ (g) + 0.6402H_2O\ (g) + 2.0298Ni. \quad (1)$$

III. Process Methodology*:*

Thermodynamic analysis of the system helps us to determine the optimum conditions that can maximize the yield with low energy consumption [22]. HSC Chemistry software version 5.11 is used to generate the thermodynamic equilibrium data for CLC fuel reactor in this process study. The thermodynamic equilibrium calculations in the Gibbs routine of HSC Chemistry are done using the Gibbs free energy minimization algorithm. The Gibbs program searches the best combination of most stable species in which the Gibbs free energy of the system can achieve its minimum at a fixed mass balance (a constraint minimization problem), constant pressure, and temperature. Hence no chemical reaction equations are required in the input.

The chemical species such as C(s), CO_2 (g), H_2 (g), CO (g), H_2O (g), CH_4 (g), H_2O (l), O_2 (g), NiO (s) and Ni (s), that are usually found in CLC reaction system considered in this study. The input species fed to the fuel reactor were rice husk with oxygen carrier, H_2O (g), and CO_2 (g). The material balances are done by Equilibrium Composition module of HSC Chemistry and the results were used to calculate reaction enthalpy by Reaction Equation module of HSC Chemistry software.

Table 2- Fuel reactor feed condition with NiO in stoichiometric ratio.



Feed condition	Input moles of Rice husk			Input moles of CO_2	Input moles of H_2O	GaCR (H_2O+ CO_2)/C	Input moles of NiO (For 1 stoichiometric ratio)
	C	H_2	O_2				
AS1	1	0.6402	0.3052	0	1	1	2.0298
AS2	1	0.6402	0.3052	0.5	0.5	1	2.0298
AS3	1	0.6402	0.3052	1	0	1	2.0298
BS1	1	0.6402	0.3052	0	2	2	2.0298
BS2	1	0.6402	0.3052	0.5	1.5	2	2.0298
BS3	1	0.6402	0.3052	1	1	2	2.0298
BS4	1	0.6402	0.3052	1.5	0.5	2	2.0298
BS5	1	0.6402	0.3052	2	0	2	2.0298
CS1	1	0.6402	0.3052	0	3	3	2.0298
CS2	1	0.6402	0.3052	1	2	3	2.0298
CS3	1	0.6402	0.3052	2	1	3	2.0298
CS4	1	0.6402	0.3052	3	0	3	2.0298

1 mol carbon (in rice husk) is used as basis for all calculations in the temperature range of 500–1200˚C for the entire process. The feed gasifying agent-to-carbon ratio (GaCR) ranging from 1 to 3 was used in this study. The CLC of rice husk using both gasifying agent (CO_2 and H_2O) and oxygen carrier (NiO) is studied with intermediate steps of increase in CO_2 moles (with simultaneous decrease in steam moles) for constant GaCR ratios. These feed conditions for CO_2 and steam input per mole carbon (in rice husk) are shown in Table 2. These inputs were used to calculate the thermodynamic equilibrium composition in the CLC fuel reactor. The oxidation reaction in the air reactor is exothermic.

It is presumed that, according to stoichiometric amount given by the air is supplied to the air reactor:

$$Ni + 0.5O_2 = NiO \quad (2)$$

$$C + O_2 = CO_2 \quad (3)$$

IV. Results and Discussions:

4.1. Effect of Amount of oxygen carrier:

The stoichiometric quantity of NiO was varied according to fuel reactor reaction of oxygen carrier:

$$C + 0.6402H_2(g) + 0.3052\ O_2\ (g) + 2.0298\ NiO = CO_2\ (g) + 0.6402H_2O\ (g) + 2.0298\ Ni$$

Stoichiometric amount of NiO reqd. (S) = 2.0298

Assuming S = 2.0298

$$1.25*S = 2.53725$$
$$\text{And} \quad 1.5*S = 3.0447$$

The effect of stoichiometric amount of oxygen carrier on CLC of rice husk was investigated for 1, 1.25, and 1.5 stoichiometric of NiO in fuel reactor.

Some side reactions also take place in the fuel reactor and hence the conversions in the fuel reactor are limited by thermodynamic equilibrium constraints. It was necessary to study the equilibrium product composition of the CLC fuel reactor at 1 bar pressure. Since, the OC is generally used in excess of the stoichiometric requirement in CLC processes to enhance the syngas and CH_4 conversion in the fuel reactor. Hence two more cases (1.25S and 1.5S) using higher amounts (1.25 times and 1.5 times the stoichiometric requirement) of OC were also studied.

4.1.1. (CH_4 + CO + H_2) formation:

The (CH_4 + CO + H_2) compositions in product gases at 1 bar pressure and at 700°C of the CLC fuel reactor for different inputs of OC and different input feed conditions are shown in Figure 3. It was observed that the H_2, CO, and CH_4 emissions from the fuel reactor decreased with increase in the amount of OC. At constant GaCR, it was also observed that the (CH_4 + CO + H_2) moles generally decreased with increase in feed CO_2 moles (with simultaneous decrease in H_2O moles). The maximum amount of (CH_4 + CO + H_2) exit moles were found to be 0.19 moles for case CS1, while the minimum quantity of (CH_4 + CO + H_2) exit moles were observed to be 0.02 moles (AS1).

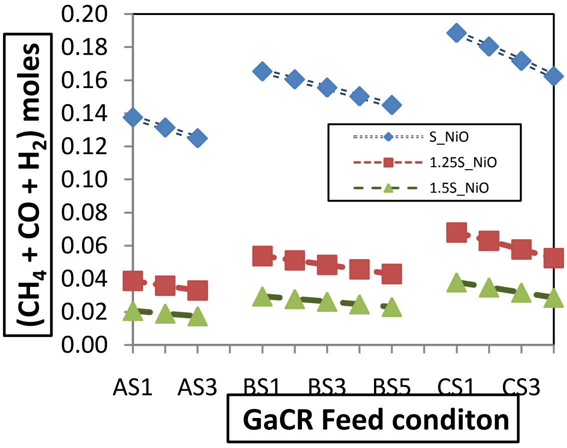


Fig. 3- (CH_4 + CO + H_2) moles emitted from the fuel reactor at 700˚C.

4.1.2. CO_2 Emission:

The CO_2 emissions at 1 bar pressure and 700°C of the CLC fuel reactor for different inputs of OC and different input feed conditions is shown in Fig. 4. It was seen that the CO_2 emission from the fuel reactor increase with increase in the amount of OC. It was also observed that the product CO_2 moles generally decrease with increase in feed CO_2 moles at constant GaCR. The maximum amount of CO_2 emission was found to be 0.99 moles for case AS1, while the minimum CO_2 emission was observed to be 0.87 moles (CS4).

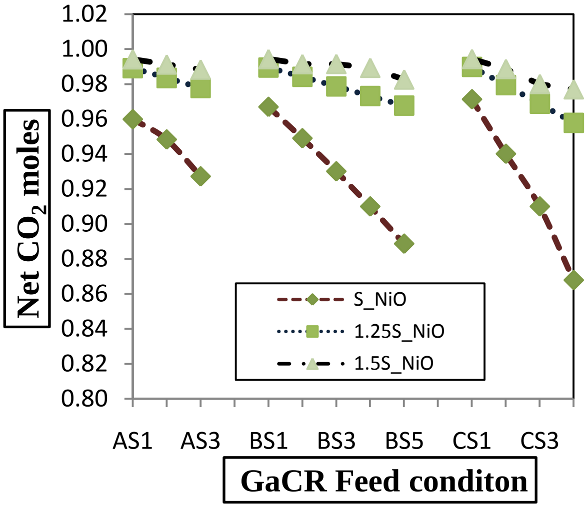


Fig. 4- CO_2 moles emitted from the fuel reactor at 700˚C.

4.1.3. Syngas ratio:

The syngas ratio at 1 bar pressure and at 700°C of the CLC fuel reactor for different inputs of OC and different input feed conditions is shown in Fig. 5. It was observed that the syngas ratio remains constant irrespective of increase in the amount of OC. It was also observed that the syngas ratio generally decreased with increase in feed CO_2 moles at constant GaCR. The maximum syngas ratio was found to be 5.73 (CS1), while the minimum of syngas ratio was observed to be 0.25 (CS4). This constant syngas ratio observation is reported for the first time in this paper.

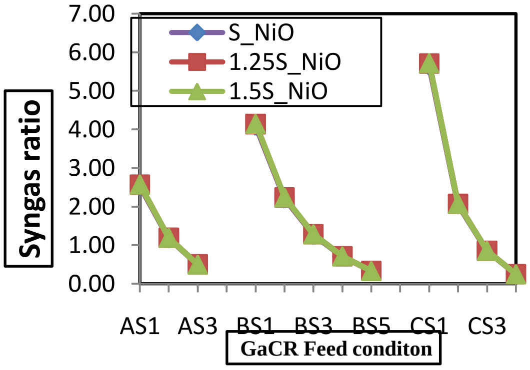


Fig. 5- Syngas ratio at 700˚C.

4.2 Effect of GaCR Conditions and Temperature.

4.2.1. Net CO_2 emission:

The Net CO_2 emissions from the CLC process is used to measure the CO_2 utilization and is shown in Fig. 6. The net CO_2 emission (moles) = CO_2 moles (in output) - CO_2 moles (in input). An increase in temperature from 500 to 1200˚C resulted in decrease in net CO_2 emission. At constant GaCR, increasing the CO_2 moles in the input (with simultaneous decrease in H_2O moles) decreased the net CO_2 emission in output. The net maximum CO_2 emission found in case CS1 (3 moles H_2O + 0 moles CO_2).

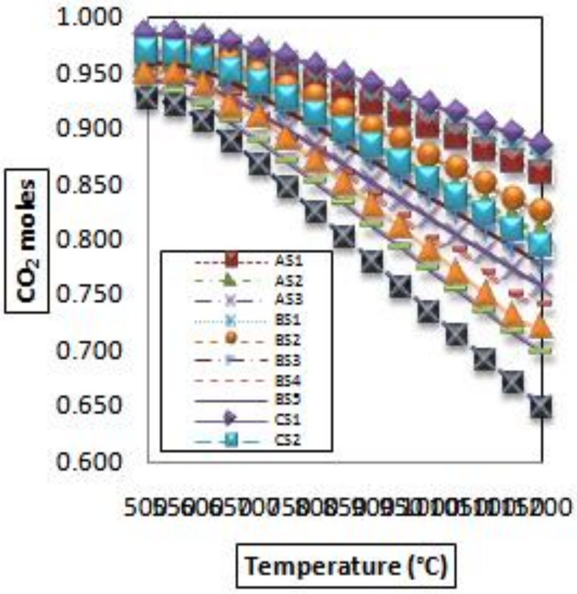


Fig. 6- Net CO_2 emission

4.2.2 H_2 and CO formation:

The H_2 formation increased with increase in temperature from 500 to 1200˚C. Increase in the CO_2 moles (with simultaneous decrease in H_2O moles) in GaCR ratio decreased the H_2 formation in output. The maximum H_2 formation was found in case AS1 (3 moles H_2O + 0 moles CO_2) fig. 7a. Similarly, increase in the process temperature led to an increase in CO formation. Increase in the CO_2 in GaCR ratio increased the CO formation in output. The minimum CO formation found in case AS1 (3 moles H_2O + 0 moles CO_2) as shown in fig. 7b.

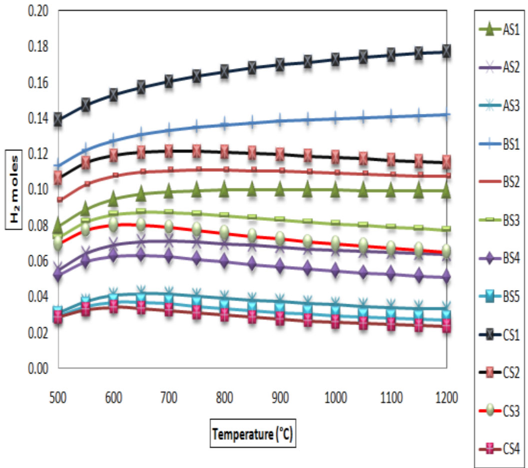


Fig. 7a- H_2 formation

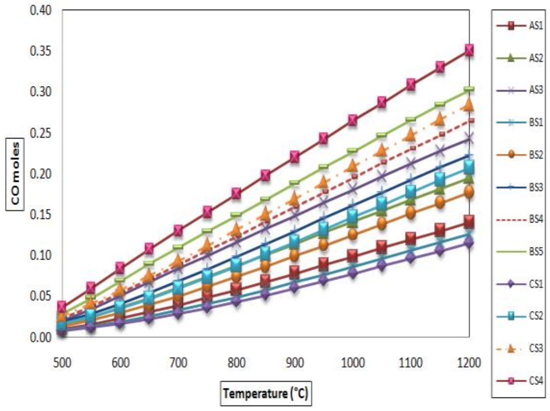


Fig.7b- CO formation

4.2.3. Syngas Yield:

The syngas yield is calculated by adding the H_2 and CO moles obtained from the process. As seen in Fig. 8, the syngas yield generally increased with increase in temperature from 500 to 1200˚C and for constant GaCR. Increase in the feed CO_2 moles led to a decrease in syngas yield, e.g. the syngas yield increased from 0.09 to 0.24 moles for case AS1, and the syngas yeild increased from 0.06 to 0.37 moles for case AS4 and 0.06 to 0.33 for BS5.

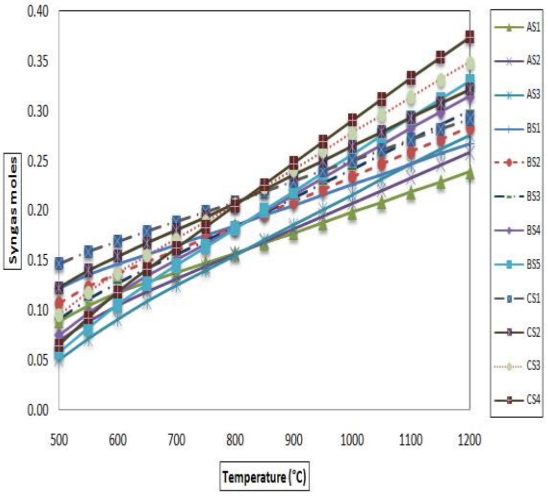


Fig. 8- Syngas Yield.

4.2.4. NiO conversion:

It is assumed that the CH_4, CO, and H_2 are oxidized to CO_2 and H_2O by means of NiO in the CLC fuel reactor. The oxygen carrier (NiO) gets reduced in the CLC fuel reactor. The NiO conversion slightly decreased with increase in temperature from 500-1200˚C. For e.g. the NiO conversion decreased from 93.75% to 88.23% in case of AS1 while it decreased from 93.21% to 81.57% in case of CS4 as shown in fig. 9.

The carbon conversion at 1 bar pressure is shown in Table 2. It was seen that as the temperature increased from 500–1200˚C, the carbon conversion reached its maximum (100%). It was observed that the 100% carbon conversion was achieved at relatively low temperature for higher GaCR.

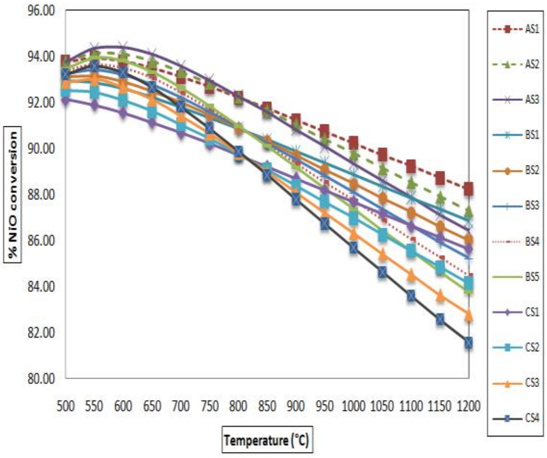


Fig. 9- %NiO Conversion.

4.2.5. 100% carbon conversion in fuel reactor:

It is very important for the CLC process to get 100% carbon conversion in the fuel rector as the unreacted carbon can go to in air reactor and form CO_2. The lowest temperature for 100% carbon conversion was found to be 900˚C in case CS1, so this point was found to be the best point for process operation.

Table 2- Carbon Conversion

% C conv.	500	550	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200
AS0	96.38	97.82	98.78	99.36	99.66	99.82	99.90	99.94	99.97	99.98	99.99	99.99	99.99	100.00	100.00
AS1	98.12	99.06	99.54	99.77	99.88	99.93	99.96	99.98	99.99	99.99	99.99	100.00	100.00	100.00	100.00
AS2	97.16	98.48	99.23	99.62	99.80	99.90	99.94	99.97	99.98	99.99	99.99	99.99	100.00	100.00	100.00
AS3	96.19	97.80	98.85	99.43	99.72	99.86	99.92	99.96	99.98	99.98	99.99	99.99	100.00	100.00	100.00
BS1	98.95	99.52	99.77	99.89	99.94	99.97	99.98	99.99	99.99	100.00	100.00	100.00	100.00	100.00	100.00
BS2	98.34	99.21	99.62	99.81	99.90	99.95	99.97	99.98	99.99	99.99	100.00	100.00	100.00	100.00	100.00
BS3	97.69	98.85	99.45	99.73	99.86	99.93	99.96	99.98	99.99	99.99	99.99	100.00	100.00	100.00	100.00
BS4	96.99	98.43	99.24	99.64	99.82	99.91	99.95	99.97	99.98	99.99	99.99	100.00	100.00	100.00	100.00
BS5	96.24	97.94	98.98	99.52	99.77	99.89	99.94	99.97	99.98	99.99	99.99	100.00	100.00	100.00	100.00
CS1	99.35	99.71	99.86	99.93	99.96	99.98	99.99	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00
CS2	98.54	99.33	99.69	99.85	99.92	99.96	99.98	99.99	99.99	99.99	100.00	100.00	100.00	100.00	100.00
CS3	97.55	98.81	99.44	99.74	99.87	99.93	99.96	99.98	99.99	99.99	100.00	100.00	100.00	100.00	100.00
CS4	96.35	98.09	99.10	99.59	99.81	99.91	99.95	99.97	99.98	99.99	99.99	100.00	100.00	100.00	100.00

V. Conclusion

This theoretical study was done to understand the material balances for process design of direct CLC of rice husk. The study considered the effect of temperature and effect of amount of oxygen carrier in the fuel reactor using steam and CO_2 as gasifying agents in steps. It was concluded that rice husk CLC using 3 moles H_2O and 0 moles CO_2 per mole carbon at 1 bar pressure and 900˚C is the best point to operate the process as hundred percent carbon conversion in the rice husk occurs in the process. The results obtained in this detailed study can be used for scale up of the process. Further Experimentation is required for the commercialization of the technology.

References

[1] Calin-Cristian Cormos, Letitia Petrescu, "*Evaluation of calcium looping as carbon capture option for combustion and gasification power plants*", *Energy Procedia*, *51*, 2014, 154 – 160.

[2] Zhongyi Deng, Rui Xiao, Baosheng Jin, Qilei Song, He Huang, "*Multiphase CFD Modeling for a Chemical Looping Combustion Process (Fuel Reactor)*" *Chem. Eng. Technol.*, *31(12)*, (2008), 1754–1766.

[3] M. A. Habib, H. M. Badr, S. F. Ahmed, R. Ben-Mansour, K. Mezghani, S. Imashuku, G. J. la O', Y. Shao-Horn, N. D. Mancini, A. Mitsos, P. Kirchen, A. F. Ghoneim, "*A review of recent developments in carbon capture utilizing oxy-fuel combustion in conventional and ion transport membrane systems*", *Int. J. Energy Res.*, *35*, 2011, 741–764.

[4] MohammadM. Hossain, Hugo I. de Lasa, "*Chemical-looping combustion (CLC) for inherent CO_2 separations—a review*", *Chemical Engineering Science*, *63*, 2008, 4433 – 4451.

[5] Jung, J. and I.K. Gamwo, '*Multiphase CFD based models for chemical looping combustion process: Fuel reactor modeling*." *Powder Technology*, *183(3)*, 2008, 401-409.

[6] He Fang, Li Haibin, and Zhao Zengli, "*Advancements in Development of Chemical-Looping Combustion: A Review*", *International Journal of Chemical Engineering*, *2009*, (2009).

[7] Henrik Leion, Anders Lyngfelt, Tobias Mattisson, "*Solid fuels in chemical-looping combustion using a NiO-based oxygen carrier*", *Chemical Engineering Research and Design*, *87(11)*, 2009, 1543-1550.

[8] Tobias Mattisson, Marcus Johansson, Anders Lyngfelt, "*The use of NiO as an oxygen carrier in chemical-looping combustion*", *Fuel*, *85(5–6)*, 2006, 736-747.

[9] M.M. Yazdanpanah, A. Forret, T. Gauthier, A. Delebarre, "*Modeling of CH_4 combustion with $NiO/NiAl_2O_4$ in a 10 kWth CLC pilot plant*", *Applied Energy*, *113*, 2014, 1933-1944.

[10] C. Saha, S. Bhattacharya, "*Comparison of CuO and NiO as oxygen carrier in chemical looping combustion of a Victorian brown coal*", *International Journal of Hydrogen Energy*, *36(18)*, 2011, 12048-12057.

[11] Magnus Rydén, Erik Cleverstam, Marcus Johansson, Anders Lyngfelt, Tobias Mattisson, "*Fe_2O_3 on Ce-, Ca-, or Mg-stabilized ZrO_2 as oxygen carrier for chemical-looping combustion using NiO as additive*", *AIChE Journal, 56(8),* 2010, 2211–2220.

[12] T. Mendiara, A. Abad, L. F. de Diego, F. García-Labiano, P. Gayán and J. Adánez, "*Biomass combustion in a CLC system using an iron ore as an oxygen carrier*." *International Journal of Greenhouse Gas Control, 19*, 2013, 322-330.

[13] Rein Kuusik, Andres Trikkel, Anders Lyngfelt, Tobias Mattisson, "*High temperature behavior of NiO-based oxygen carriers for Chemical Looping Combustion*", *Energy Procedia, 1*, 2008, 3885-3892.

[14] J. Adánez, P. Gayán, I. Adánez-Rubio, A. Cuadrat, T. Mendiara, A. Abad, F. García-Labiano, L. F. de Diego, "*Use of Chemical-Looping processes for coal combustion with CO_2 capture*", *Energy Procedia, 37,* 2013, 540 – 549.

[15] Aline Lima da Silva, Iduvirges Lourdes Müller, "*Towards H_2-rich gas production from unmixed steam reforming of methane: Thermodynamic modeling*", *Journal of Power Sources, 196,* 2011, 8568– 8582.

[16] Lin Zhu, Junming Fan, "*Thermodynamic analysis of H_2 production from CaO sorption-enhanced methane steam reforming thermally coupled with chemical looping combustion as a novel technology*" *Int. J. Energy Res*, (2014).

[17] Rutuja Bhoje, Ganesh R. Kale, Nitin Labhsetwar, and Sonali Borkhade, "*Chemical Looping Combustion of Methane A Technology Development View*", *Journal of Energy, 2013*, (2013).

[18] X. Wang, B. Jin, W. Zhong, Y. Zhang and M. Song, "*Three-dimensional simulation of a coal gas fueled chemical looping combustion process*." *International Journal of Greenhouse Gas Control, 5(6),* 2011, 1498-1506.

[19] Giddel M.R and. Jivan A.P, "*Waste to Wealth, Potential of Rice Husk in India a Literature Review*", *International Conference on Cleaner Technologies and Environmental Management PEC,* Pondicherry, India, (2007).

[20] XIE Jian-jun, YANG Xue-min, ZHANG Lei, DING Tong-li,SONG Wen-li, LIN Wei-gang, "*Emissions of SO_2, NO and N_2O in a circulating fluidized bed combustor during co-firing coal and biomass*", *Journal of Environmental Sciences, 19,* (2007), 109–116.

[21] MSW learning tools, Copyright © 2001 University of Central Florida.

[22] Rajesh Kempegowda, Suttichai Assabumrungrat, "*Thermodynamic Analysis for Gasification of Thailand Rice Husk with Air, Steam, and Mixed Air/Steam for Hydrogen-Rich Gas Production*", *Intenational Journal Of Chemical Reactor Engineering, vol. 8,* 2010, 1-25.