Biomass gasification for DRI production

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The Direct Reduction process can be carried out using syngas from biomass. Mathematical models of the integrated process gasification plus direct reduction have been used to evaluate flow rate, temperature and composition of the gas in the various steps of the whole process. Fluidised bed gasification and operation with technological oxygen at high pressures is the proposed solution to produce syngas. Best candidates for such application are biomass from forest and wood industry and agricultural residues. Both of such type of biomass are present and distributed in many European areas in such amount to make industrially possible their use, taking into account the logistic requirements. A cost between 30-60 €/t DRI is roughly estimated.
The characteristics of the syngas implies the adoption of purification steps, before the use of the syngas in the shaft furnace, using technologies permitting hot gas cleaning, to save energy efficiency of the process.

Introduction

Direct Reduction processes for producing DRI is seen a promising ways to reduce CO_2 emissions from steelmaking industry, maintaining high level of productivity and steel quality. Moreover DRI can be produced starting from different energy source, like methane, coal, biomass, waste. This increases flexibility and applicability of the process to different contexts and different energetic scenarios. In particular the DRI production using syngas from biomass is an attractive options because it increases the environmentally value and the flexible character of the process.

Modelling biomass based DRI production

The evaluation of feasibility of DRI production from biomass syngas has been carried out in the first phase of the ULCOS project.

The feasibility study has been carried out by means of mathematical models of the integrated process gasification plus direct reduction.

For this purpose, a mathematical model of the gasification step has been first developed.

The model assumes that gasification is a staged process subdivided in five different steps: pyrolysis, volatiles combustion, char combustion, char gasification and equilibrium reactions. Oxygen and steam are used as gasifying gases.

Kinetic parameters of pyrolysis and char combustion have been found in literature [1,2,3]. The model gives results in agreement with available experimental data of gas composition in fluidized bed with biomass from wood industry and agricultural residues.

Consequently the gasifier model has been considered suitable for predicting the composition of the syngas generated by the gasifier as a function of feedstock composition and gasification conditions, in particular: feedstock feeding rate, O_2 and steam flow rates.

In a second step, flow rate and composition of the syngas, calculated by the gasifier model, have been used as input for mathematical models of mass and energy balance of the integrated process.

Mass and energy balance calculations have been used to evaluate the biomass consumption and CO_2 production in process schemes of integrated cycles biomass gasifier plus direct reduction reactor.

Midrex® and HYL® processes (commercial technologies) have been taken as reference technologies for DRI production.
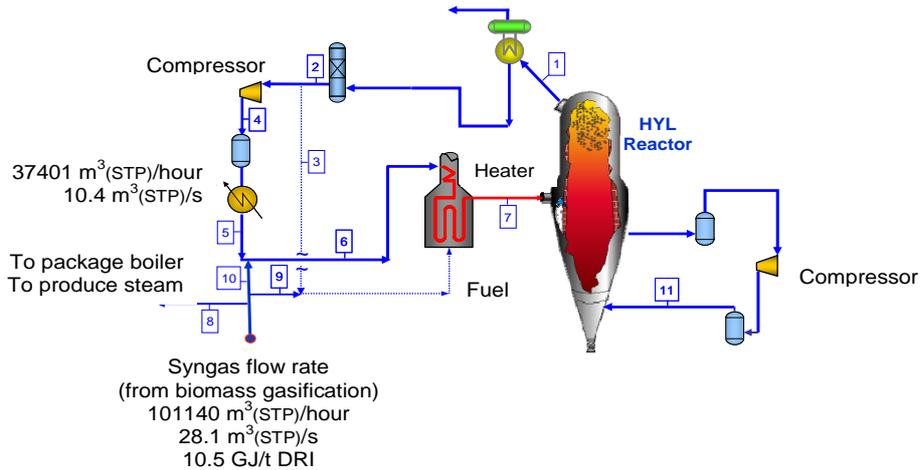
A number of possible configurations of the integrated process have been considered, including gas purification units, gas re-heating steps, gas re-cycling.

The simulations indicate that the global performance of the process depends on the cycle configuration, type and number of implemented purification units, and important process parameters like heat losses of the reactors and temperature of the gas entering the direct reduction reactor.

Representative result of the model simulations is a consumption of 650 kg biomass (no additional fossil fuel), to be gasified with a mixture O_2/steam, for the production of 1 t of DRI.

Mass and energy balance of the integrated cycle, starting from a simulated syngas from biomass gasification, has been also supplied by HYL.

Figure 1 shows an example, based on HYL direct reduction process. In the simulation 600 kg of biomass (wood residues) generates 101140 m^3(STP)/h of a syngas, which is used to produce 100 t/h of DRI.

Figure 1. Mass and energy balance for a DRI process carried out with syngas from biomass gasification (calculations supplied by HYL).

Compressor

37401 m³(STP)/hour
10.4 m³(STP)/s

To package boiler
To produce steam

Heater

Fuel

HYL Reactor

Compressor

Syngas flow rate
(from biomass gasification)
101140 m³(STP)/hour
28.1 m³(STP)/s
10.5 GJ/t DRI

	1	2	3	4	5	6	7	8	9	10	11
H_2 (% vol)	33.5	40.9	40.9	40.9	55.3	48.2	48.2	38.8	38.8	38.8	36.0
CO (% vol)	23.5	28.7	28.7	28.7	38.8	43.4	43.4	49.5	49.5	49.5	4.0
CO_2 (% vol)	22.1	27.0	27.0	27.0	1.5	3.2	3.2	5.4	5.4	5.4	5.0
CH_4 (% vol)	2.0	2.5	2.5	2.5	3.4	1.9	1.9	0.0	0.0	0.0	51.0
H_2O (% vol)	18.9	0.9	0.9	0.9	1.1	3.3	3.3	6.3	6.3	6.3	4.0
Flow rate (m³/h)	162400	132900	4980	127920	94680	165490	165490	15350	15000	70790	100000
Temp (°C)	475	35	35	90	42	45	820	45	45	45	40

In the figure the flow sheet of this process is reported together with data of flow rate, composition and temperature of the gas in the different stages of the cycle, when the HYL is coupled with a biomass gasifier.

Gasification technologies and biomass characterisation

According to the large quantity of gas to be introduced only systems of fluidised bed gasification and operation with technological oxygen at high pressures is proposed. The application of biomass gasification technology to supply reducing gas for DRI and CO_2 capture and storage, requires sufficient heating value (LHV), and no nitrogen. These criteria can be fulfilled with the operation with oxygen of technical purity (95% O_2).

Figure 2 shows a map of different gasification process for biomass.

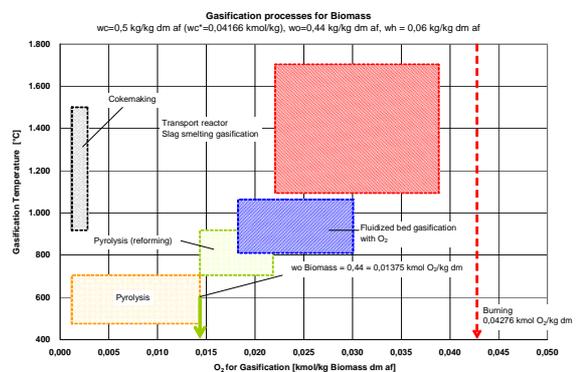Figure 3 shows LHV as a function of carbon contents of various types of combustibles.
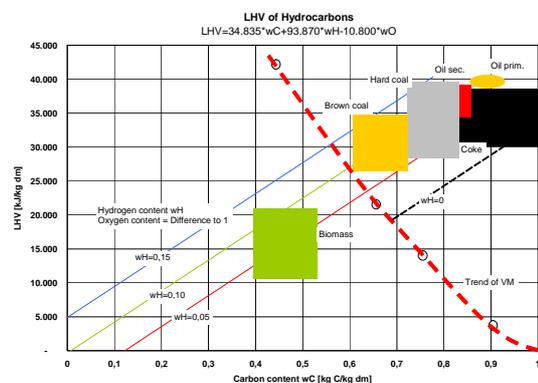

Figure 2. Gasification processes.

Figure 3. Low calorific values of combustibles as a function of carbon content.

Biomass availability, logistics and cost

From the analysis on biomass availability in European regions best candidates for application in steel industry are biomass from forest and wood industry and agricultural residues.

From recent literature the potential supply of forest residues and forest industry by-products can be deduced [4, 5].

The energy potential of wood fuel in EU is estimated to around 1300 PJ/year. A large number of data on biomass availability are reported in terms of energy (it can be assumed the equivalence 1 t biomass ~ 10 GJ, or 1Mt ~ 10PJ).

In EU15, agriculture is the most important land use in geographic terms occupying 40% (130 million ha) of the total land area (323 million ha).

Also Europe is one of the world's largest and most productive suppliers of food and fibre with the European Union accounting alone for 10% of the global cereal production and 16% of global meat production.

The total resource potential of agricultural crop residues has been estimated to 1064 PJ/year for EU and 306 PJ/yr for the Accession countries.

Classifications of available biomass country by country are available [5].

A number of logistic requirements must be satisfied for a realistic industrial use.

The biomass supply logistics is characterized by a wide area distribution of biomass; time and weather-sensitive crop maturity; variable moisture content; low bulk density of biomass material and a short time window for collection with competition from concurrent harvest operations.

The analysis carried out in the first phase of ULCOS project showed that a supply cost around 3 €/GJ can be foreseen and a straw density of 3-5 t/hectare are required.

In the case of biomass used for DRI process (at least 1 Mt/year), according to the results of the process models the biomass availability must be at least 650 kt/year.

The analysis carried out in the first phase of ULCOS project showed that to maintain the supply cost at an acceptable level, a distance from the DRI plant of max 50 km must be considered.

Areas with these biomass concentration are present in several region of Europe, most of which currently have not a real biomass employment policy.

Specific studies are available to evaluate logistic aspects and their impact on economic balance of substitution of fossil fuel with biomass.

An Italian study [6], carried out on the province of Cremona, is based on a total of 226 kt/year of biomass.

It takes into account the costs for collection of agricultural residues, culture of short rotation forestry, transport and transformation (including construction, management and maintenance of power plants)

An important output of the study is the optimisation of number and distribution of localisations of the plants for biomass collection and pre-treatment in view of a final utilization in a single power plant

Cost estimation for biomass are carried out on the basis of:

- Cost for collection or production
- Preparation
- Transport
- Quality (mainly calorific value)

In the context of energy generation several studies are available concerning cost evaluation[7].

ENEL, the main Italian electrical energy company, has produced several studies about use and cost of biomass for energy production, taking into account also logistic aspects [8,9].

Table 1 summarizes main figures used for estimating the cost of pellets and chips from wood industry and agricultural residues, on the basis of physical characteristics [9].

Table 1. Characteristics and prices of three type of biomass.

	Wood industry residues		Agriculture residues
Properties	Pellet	Chips	
Density	250-400 kg/m³	600-700 kg/m³	15-300 kg/m³
Humidity	40-55%	8-12%	30%
Low Calorific Value	~10MJ/kg ~3.3 GJ/m3	~16MJ/kg ~11.2 GJ/m3	~12MJ/kg ~2.6 GJ/m3
Size	1÷100 mm	6÷12 mm	
Price	~60 €/t ~6 €/GJ	160÷180 €/t ~10,6 €/GJ	30÷50 €/t ~3.8 €/GJ

The final price of biomass depends on the material quality and transport. This second aspect is extremely variable, due to the large fluctuations of oil and fuels prices.

At the begin of the 2008 a transport cost of the order of 0,05-0,10 €/t per km was estimated, increasing the prize of 10-30% (biomass collected in a radius of 50 km).

Integration of biomass gasification and DRI production

The requirements of the reducing gas for the DRI production are well known, both in terms of major and minor components [10].

The required characteristics of the syngas implies the adoption of purification actions before the use of the syngas in the shaft furnace, using technologies permitting hot gas cleaning, to save energy efficiency of the process.

Hot syngas purification is an important issue, largely studied [11,12]:

Taking into account the requirements of the reducing gas to be injected in the shaft furnace, and also the characteristics of the gas top gas to permit gas recycling and CO_2 capture and storage, the following gas purification steps can be envisaged.

Dust abatement

This operation can be performed at temperature (800-900 °C) and pressure (10-12 bar) conditions of the syngas, with ceramic filter candles or with cyclone systems. Systems for alkalis removal can be used in sequence with dust abatement, using solid sorbents [13]. The benefit is the reduction of erosion problems in the flow lines, limitation of accumulation of ashes in the shaft furnace, and the protection of syngas purification units based on catalyst and sorbents, like reactors for desulphurisation and tar removal.

Tar abatement

Tar is the product of condensation of hydrocarbons present in the syngas. In principle tar and hydrocarbons could be entered into the shaft furnace, without significant effect on the performance of the reduction process. However two reasons suggest to adopt options for the removal of such compounds.

The first is that some hydrocarbons could not react in the shaft furnace, moving the problem of tar abatement downstream. Even if in this case the problem should be less heavy, the presence of hydrocarbon compounds in the gas exiting from the shaft furnace could be detrimental for its recirculation.

The second reason is that possible deposits of tar could be detrimental for the life cycle of components and lines.

The occurrence of this problem depends on the general architecture of the flow lines.

In any case a tar removal step at high temperature, immediately after the gasifier, can be performed by auto-thermal reforming. This is an oxidation of hydrocarbons by means of a combination of oxygen and steam. The process requires no external energy source and do not change significantly the gas quality.

From an engineering point of view it consists in a simple reactor, located just after the gasifier, with minor impact on cost and operation complexity.

The only key point is the use of appropriate catalysts to enhance the tar reforming.

Catalyst for tar abatement are currently used in the oil refining industry. Cheaper catalyst based on Ni/dolomite and Ni/Olivine have been also studied.

From industrial experience and literature data catalytic tar destruction systems with removal efficiency higher than 90% are available [14].

S compounds abatement

The sulphur has a negligible effect on the direct reduction process[10], however the control of sulphur is essential for the commercial value of DRI and for the quality of the top gas, specially in view of CO2 capture and storage.

Various well assessed technologies are available for sulphur removal from gas deriving from combustion and gasification, working with cooled gas like wet-scrubber.

A possible useful option to eliminate or reduce the content of this gas is the use of economic earth alkaline sorbents as calcite or dolomite that have the advantage of working at high temperatures as 850°C or 990 °C[15,16].

Such materials can be used directly inside the gasifier or in separated reactors.

The first option implies no significant cost increase (except the cost of materials).

The adoption of separated reactor implies, also in the case of tar abatement, cost for installation and maintenance of a relatively simple reactor.

On the basis of the available information, hot desulphurisation system should be effective to fulfil the requirements of sulphur content in the reducing gas, for which accepted values are comprised between 100 ppm and 3000 ppm, depending on the final destination of the DRI[10].

Conclusions

Biomass from forest, wood industry residues and agriculture residues are available in many regions. Areas in which distribution and logistics satisfy the requirements for the use of such biomass in steel industry are available.

A cost comprises between 30 and 60 €/t DRI is roughly estimated; although the rapid variation of oil prices can affect significantly, in the future, the transport cost, hence the final cost.

The characteristics of the considered biomass together with the available studies on biomass gasification suggests syngas purification needs.

The most important purification step is desulphurisation.

This operation is currently performed in syngas at industrial scale with system in which the gas is cooled.

Hot desulphurisation would increase strongly the global efficiency of the process.

Purification of syngas from sulphur compounds at high temperature are under development. The operation can be performed both inside the gasifier and in external units (in this second case the purification efficiency is much higher), by using appropriate abatement systems

Other purification steps, like dust and tar can be considered not strictly necessary for the iron ore reduction step in the shaft furnace. However the implementation in the cycle of specific units for dust and tar abatement would increase the life cycle of plant components and flow lines.

Acknowledgements

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