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Thermo-economic optimisation of the integration of electrolysis in synthetic natural gas production from wood

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Abstract

Converting wood to grid quality methane allows to distribute a CO_2 free, renewable energy resource in a conventional energy distribution system and use it in transportation applications. Applying a multi-objective optimisation algorithm to a previously developed thermo-economic process model for the thermochemical production of synthetic natural gas from wood, the present paper assesses the prospect of integrating an electrolyser in conversion systems based on directly and indirectly heated gasification. Due to an inherent lack of hydrogen for complete conversion of wood into methane and the possibility for rational use of oxygen, it is shown that electrolysis is an efficient and economically interesting option for increasing the gas output of the process while storing electricity and producing fuel that mitigates CO_2 emissions.

Keywords: Biofuels; Bioenergy; Gasification; Methanation; Electrolysis; Optimisation; SNG

1. Introduction

Thermochemical production of synthetic natural gas (SNG) from wood by means of wood gasification, methane synthesis and further CO_2 removal from the produced gases offers several interesting features. A widely available and renewable energy source which is not in competition with food production is used in a process that may be operated as a CO_2 sink if CO_2 sequestration is realised. Clean gaseous fuel is produced and distributed in existing networks. Its use in transportation applications would allow to cut greenhouse gas emissions in a domain where few solutions for mitigating CO_2 emissions and using lignocellulosic biomass exist.

Currently, different process designs are under investigation [1,2]. From the atomic composition of wood, they all have in common that the gas produced by gasification lacks of hydrogen for completely reforming the carbon into methane, which results in a by-production of CO_2. Furthermore, the overall process is exothermic and cogeneration of electricity is therefore possible. For this reason, integrating an electrolyser in the system would allow to increase the methane yield by adding hydrogen to the carbon flow and to produce pure oxygen that is needed for the gasification process while using the cogenerated power. Alternatively, by importing renewable electricity, the process is a way of storing green electrical power in the form of SNG.

Using the process modelling approach described in [3] and further developed in [1], this paper aims to analyse the integration of electrolysis and its impact on the process design and performances.

2. Process description

2.1. Block flow diagram

A general block flow diagram of the process superstructure with the investigated technological alternatives is shown in Fig. 1. In a first process step, chipped wood with properties described in Table 1 is dried to avoid severe exergy losses and enhance the formation of CH_4 during gasification. Indirectly heated, steam blown gasification in

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Nomenclature

Roman letters

$\dot{m}$	mass flow, kg/s
c	concentration, %vol
C_{GR}	grass roots cost, k€
C_{OP}	operating costs, €/MW h
C_P	total production costs, €/MW h
$e_{a,i}$	specific avoided CO_2 emissions assigned to substance i, kg/MW h_i
$e_{p,i}$	specific CO_2 emissions assigned to the production of substance i, kg/MW h_i
$e_{u,i}$	specific CO_2 emissions assigned to the usage of substance i, kg/MW h_i
p_g	gasification pressure, bar
p_m	methanation pressure, bar
$p_{s,p}$	steam production pressure, bar
r_{H_2}	additional hydrogen for methanation, wt%
s_i	stoichiometric coefficient of substance i, dimensionless
SN	stoichiometric number, dimensionless
SNG	synthetic natural gas
T_d	drying temperature, °C
$T_{g,p}$	preheat temperature of gasification agent, °C
T_g	gasification temperature, °C
T_m	methanation temperature, °C
$T_{s,b2}$	temperature of bleeding level i, °C
$T_{s,s}$	steam superheat temperature, °C
w^+	consumed electrical power (entering the system), kW
w^-	produced electrical power (leaving the system), kW

Greek letters

Δh_i^0	lower heating value of substance i, MJ/kg
ΔH_r^0	standard heat of reaction, kJ/mol
Δh_{vap}	latent heat of vaporisation, MJ/kg
Δk_i^0	exergy value of substance i, MJ/kg
ε	energy efficiency, %
η	exergy efficiency, %
μ	mean value
Φ_w	wood humidity, wt%
ρ	correlation coefficient, dimensionless
σ	standard deviation

an internally circulating fluidised bed usually operating at around 850 °C and atmospheric pressure and directly heated, oxygen blown pressurised fluidised bed gasification operating at around 800 °C are considered as gasification technologies [5,6]. The oxygen necessary for the latter might be supplied externally or produced on-site using either ion transfer membranes [7] or electrolysis. After gasification, the obtained gases need to be cleaned from impurities to prevent methanation catalyst damage. Being rich in H_2, CO and CO_2, the gas is reformed at around 300–400 °C in an internally cooled, pressurised fluidised bed reactor where a sufficient amount of steam is added to avoid carbon deposition [8]. The synthesis gas is dried and CO_2 is removed in order to increase its calorific value and meet the condition of a Wobbe index between 13.3 and 15.7 kW h/N m^3 specified for the injection into the gas grid. As excess heat is available from methanation and the flue gases from gasification, the integration of a steam

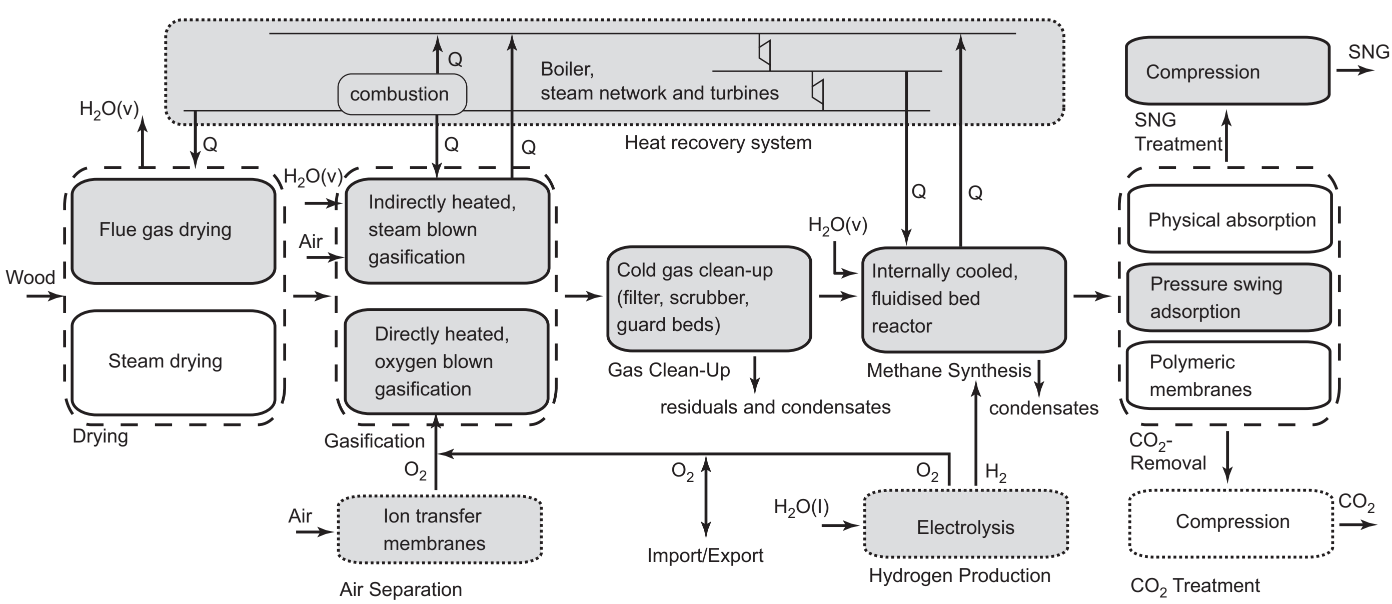

Fig. 1. Process superstructure. Dashed boxes assemble competing technologies and dotted ones are used for optional equipment. The process configurations examined in this paper is shown shaded.