Journal of Energy Storage 2 (2015) 64–79

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Synthetic natural gas via integrated high-temperature electrolysis and methanation: Part II—Economic analysis

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ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form 6 June 2015
Accepted 23 June 2015
Available online 25 July 2015

Keywords:
Solid oxide electrolysis
Synthetic fuels
Methanation
Thermal integration
Trechnoeconomic analysis

ABSTRACT

This part II work is built on the energy performance results of part I and focuses on the cost of producing synthetic natural gas and sensitivity scenarios around main economic variables.

Capital costs for each plant section have been evaluated taking into account operational parameters such as pressure and temperature of the SOEC. The costing and financial methodology is based on a discounted cash flow analysis that was used to calculate the specific cost of synthetic natural gas (SNG) which ensures economic profitability of the investment.

The co-electrolysis case has higher capital, operating and maintenance costs; however it shows a weaker dependence on the electricity cost due to its higher plant efficiency. The impact of key parameters such as electrolysis stack cost, cell degradation rate and carbon dioxide feedstock cost were further investigated. Both "state-of-the-art" and "target" scenarios were defined to account for the expected enhanced technological maturity of the SOEC technology that is expected to occur in the following decade.

For the co-electrolysis case, break-even electricity prices (i.e., costs that yield an SNG cost comparable to that of fossil natural gas) of 8 $/MWh and 67 $/MWh were calculated for "state-of-the-art" and "target" scenarios, respectively.

1. Introduction

In part I steam electrolysis and co-electrolysis based plants for SNG production via integrated SOEC-methanation systems were designed and analysed from a thermodynamic point of view. A LHV efficiency of 76.0% for steam electrolysis and 81.4% for co-electrolysis system were calculated, respectively. An input DC power of 10 MWe for electrolysis was chosen for both systems in order to fix the size of the plant. The overall plant efficiency can be considered almost scale-independent by using a modular solid oxide cell technology, even though the efficiency of some BoP components (e.g., compressors) is quite scale-dependent. On the other hand, plant power affects the economic assessment, because the escalation of some capital costs depending on size is generally nonlinear. However, the plant size assumed in part I has not been changed in this part II as the chosen 10 MWe could represent an ideal commercial module for power-to-gas in Europe [1].

Economic aspects of synthetic methane production based on renewable energy were studied in the works of Davis and Martin [2,3]. Authors studied SNG production through integrated low-temperature water electrolysis and methanation, providing a detailed economic analysis that is able to calculate the synthetic methane production cost.

In this work plant capital and annual costs have been considered in order to build a detailed cash flow analysis. Annual costs include operating and maintenance items, energy input (i.e., electricity) as well as material streams (e.g., CO_2 and H_2O) input cost. Each cost item will be described in the following sections.

Energy performance estimation (see part I) showed the importance of a good thermal integration within integrated SOEC-methanation plants. In this second part, pinch analysis methodology is further extended to design the heat exchanger network (HEN), which will represent the main investment cost of the whole plant.

Solid oxide cells degradation has been also taken into account because of its impact on economics. As will be discussed, degradation implies the installation of an additional active area (i.e., spare capacity) to compensate for decaying electrochemical cell/stack performance, translating in extra costs.

The main goal of this second part is the evaluation – through a detailed methodology explained in the following sections – of the as-produced SNG cost (in particular of its COP—"Cost of Product"),

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http://dx.doi.org/10.1016/j.est.2015.06.004
2352-152X/

Nomenclature

AC	Alternating current
BoP	Balance of plant
CCS	Carbon capture and storage
CE	Co-electrolysis
CS	Carbon steel
DC	Direct current
DCF	Discounted cash flow
DOE	U.S. Department of Energy
DTU	Technical University of Denmark
ECO	Economizer
EPRI	Electric Power Research Institute
EVA	Evaporator
GCCSI	Global Carbon Capture and Storage Institute
GHG	Greenhouse Gas
HEN	Heat exchanger network
IEA	International Energy Agency
IRROE	Internal rate of return on equity
LHV	Lower heating value
NETL	National Energy Technology Laboratory
NG	Natural gas
NGCC	Natural gas combined cycle
R&D	Research and development
SE	Steam electrolysis
SH	Super-heater
SNG	Synthetic natural gas
SOC	Solid oxide cell
SOEC	Solid oxide electrolysis cell
SOFC	Solid oxide fuel cell
SS	Stainless steel
ZOGB	Zinc oxide guard bed

Parameters

ΔT_{ml}	Logarithmic mean temperature difference (K)
A	Area
An	Annuity ($)
ASR	Area specific resistance ($\Omega\,cm^2$)
B_1,B_2	Constant values for BEC calculation
BEC	Bare erected cost ($)
C	Equipment cost attribute
c	Specific heat ($kJ\,kg^{-1}\,K^{-1}$)
CEPCI	Chemical Engineering Plant Cost Index
CF	Cash flow ($)
CI	Cost index
COP	Cost of product ($/MWh)
D	Diameter (m)
deg	Degradation rate, initial ASR increase percentage over 1000 h
Dep	Depreciation ($)
EPCC	Engineering, procurement and construction cost ($)
ETOC	Escalated total overnight cost ($)
Exp	Operating expenses ($)
F	Factor for bare module cost
FOM	Fixed operating and maintenance cost ($/year)
G	Mass flow rate ($kg\,s^{-1}$)
i	Discount rate
IDC	Interest during construction ($)
IE	Interest expense ($)
I_F	Faradic current (kA)
j	Current density ($A\,cm^{-2}$)
k_1, k_2 and k_3	Constant values for PEC calculation
L	Length (m)
LCOP	Levelized cost of product ($/MWh)
M	Construction duration expressed (months)
MDD	Monthly debt disbursement ($)
n	Debt repayment period (years)
N	Operational period (years)
NF	Number of fluids
NPV	Net present value ($)
p	Pressure, (bar or Pa)
PEC	Purchased equipment cost ($)
PR	Principal repayment ($)
r	Rate
RD	Residual debt ($)
Rev	Operating revenues ($)
S	Heat exchange surface (m^2)
SC	specific cost ($ m^{-2} or $/kW)
t	Time (h)
TASC	Total as-spent cost ($)
TDD	Total debt disbursement ($)
TOC	Total overnight cost ($)
TPC	Total plant cost ($)
Tx	Taxes ($)
U	Overall heat transfer coefficient ($kW\,m^{-2}\,K^{-1}$)
V	Voltage (V)
VOM	Variable operating and maintenance cost ($/h)
W	Power (kW)
z_1, z_2 and z_3	Constant values for pressure factor calculation
γ	Cost scaling factor
ξ_D	Debt fraction
ξ_E	Equity fraction
ϕ	Heat flow rate (kW)

Subscripts

0	Base condition in terms of pressure and temperature
1	Reference year
2	Desired year
a	Required attribute
b	Base attribute
BM	Bare module
c	Cold
cap	Capital cost escalation
d	Debt
e	Equity
el	Electric
en	Enclosure
ext	External
f	Foundations
h	Hot
in	Initial
k	Generic year
lim	Limit
m	Generic month
M	Material
max	Maximum
op	Operative
p	Pressure
rect	Rectifier
rev	Reversible
SOEC	Solid oxide electrolysis cell
st	Stack
t	Tax
T&P	Transport and placement
tn	Thermoneutral