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Cogeneration of power and methanol based on a conventional power plant in Germany

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ABSTRACT

The global increase in electricity production by wind and photovoltaic plants poses challenges for local electricity grids as well as for electricity markets. These renewable energy sources rely heavily on current weather conditions, by that producing electricity in a fluctuating manner. This results in temporary electricity surpluses causing temporarily low or even negative electricity prices. Additionally, a stable operation of the electricity grid must be maintained even locally.

To solve these problems, the intelligent coupling of the electricity, gas and heat sectors could be a promising approach. So called “Power-To-X” concepts such as Power-to-Heat (P2H) or Power-to-Fuel (P2F) cover technologies that aim to convert electrical energy into material energy storages, synthetic fuels and energy-intensive chemical raw products. For conventional power plants, the production of methanol is currently the most discussed option in Germany.

In this paper a techno-economic analysis of the implementation of a Power-to-Methanol plant (P2MeOH) into a conventional power plant is presented. This study is based on real power generation data of the real hard coal-fired power plant “Westphalia E” in Germany in 2017. It takes into account parameters such as P2MeOH invest costs, costs for carbon dioxide emission as well as electricity, methanol and oxygen market prices. The required mass and energy flows for the techno-economic analysis are calculated by a custom implemented thermodynamic model.

This study shows that an additional revenue could be generated under current market situations and that this possible revenue sums up to 5.2 million € per year. In ecological regards, around 150,000 tons CO_2 could be saved per year. The calculated P2MeOH invest costs amount to 137.5 million €. Additionally, it could be obtained that by far most costs are caused by the electrolyser. As further technical progress in that field is expected, this could lead to higher economic benefits in the future.

1. Introduction

The combustion of fossil fuels such as coal, oil and natural gas for energy generation is the source of million tons greenhouse gas (GHG) emissions per year by means of carbon dioxide (CO_2), a major driver of the global climate change. In Germany, 772 million tons of CO_2 have been emitted in 2016 due to energy consumption. Approximately 43% (332 million tons) of these emissions can be attributed to power and heat generation [2]. Compared to 1990, Germany reduced its carbon emissions by 23.2% at the end of 2012, thereby exceeding its target for the Kyoto Protocol by 21%.

For 2020, Germany has a voluntary target of 40% reduction [3]. Germany aims to go further, with a 80–95% reduction by 2050. Therefore, active measures such as storing CO_2 in geological formation (CCS) or CO_2 utilization (CCU) can play major roles to the future sustainable energy supply [4]. Carbon Capture and Utilization procedures are focusing on CO_2 retention by using of carbon dioxide as feedstock substituting fossil fuels. The utilization of CO_2 can be divided into different categories such as conversion to plastic materials or synthetic fuels.

The Power-to-X technologies are innovative energy storage concepts merging state-of-the-art technologies towards optimal operation and utilization of power plants. One of the most promising products deriving from the Power-to-X systems is methanol due to its easy storability and its wide range of applications. Methanol (MeOH) is a chemical raw material and the simplest of all alcohols. It has several uses being most often converted to formaldehyde, acetic acid and olefins for further transformation into plastics, solvents, adhesives and many other

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Nomenclature

C	Cost/Price
c_p	Specific isobar heat capacity
G	Gibbs function
H	Enthalpy
K	Equilibrium constant
$\dot{m}$	Mass flow rate
P	Power
P	Pressure
R	Universal gas constant
Rev	Revenue
S	Entropy
T	Temperature
V	Stoichiometric coefficient
X	Concentration

Greek Symbols

η	Efficiency

Subscripts

Ed	Educts
El	Electrical
F	Foundation
Min	Minimal load
MS	Methanol Synthesis
PP	Power Plant
Pr	Products
Th	Thermal
WGS	Water Gas Shift
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
GHG	Greenhouse Gas
IRR	Internal Rate of Return
LHV	Lower Heat Value
MeOH	Methanol
NPV	Net Present Value
P2F	Power-to-Fuel
P2H	Power-to-Heat
P2MeOH	Power-to-Methanol
P2X	Power-to-X
PEM	Proton Exchange Membran
RWGS	Reverse Water Gas Shift
Syngas	Synthesis gas

products of daily life. In 2014, 64 million tons of methanol were produced worldwide as shown in Fig. 1. By 2020, the demand is expected to increase to around 118 million tons per year. As a consequence of the increasing demand for different applications during the last decades, several synthetic processes were developed and today, most of the existing methanol is produced from natural gas. However, methanol can be made from numerous additional feedstocks such as coal, biomass, CO_2, etc., through its previous conversion into synthesis gas (syngas). The processes involved in the production of methanol from natural gas, coal and biomass are quite similar [6]: syngas is produced from the selected fossil fuels, for its conversion into methanol and subsequent distillation of crude methanol. As mentioned before, methanol can be produced from CO_2 through a catalytic hydrogenation via the input of hydrogen.

By using CO_2 separated from industrial processes for methanol production, GHG emissions can be reduced significantly by substitution of crude oil [7]. Several researchers have modelled and studied the methanol production process from CO_2 and H_2, most of them focus on the general thermodynamics of the methanol synthesis [8]. The goal of this paper is to present a techno-economic analysis of a methanol production plant designed for the minimal load of the chosen reference power plant "Westphalia E" in order to achieve maximum operational hours.

Thus, this paper is structured as follows: Section 2 introduces the process divided into the description of the reference power plant and the description of the Methanol production from CO_2. The following Section 3 shows the modelling and results of the thermodynamic simulation of the methanol synthesis from CO_2 and H_2. These results are the basis and inputs for the subsequent economic analysis, presented in Section 4.

2. Process description

2.1. Reference power plant "Westphalia E"

In this paper, the newly constructed unit E from the power plant Westphalia is taken into consideration. This unit is state-of-the-art based on the study from VGB PowerTech e.V.[1] [1]. A net electricity efficiency of about 46% on LHV basis can be achieved with steam parameters up to 600 °C/285 bar (ultra-supercritical) and thermodynamic optimization of the steam-water process [9]. The following Fig. 2 shows the operation of the particular power plant depending on the German spot market price for 2017.

It is assumed that the power plant Westphalia does not participate in the primary and secondary control energy market. This leads to the following operating results for 2017.

As expected the power plant operates in full load at high spot market prices and reduces its load to minimum to cut losses at low spot market prices over a short time period. At longer time periods the power plant is out of operation. The intermediate operation points result from the hourly average during startup and shut down. This leads to the three relevant operation point "Full Load", load lower than 30% full load ("Minimum Load") and "Zero Load" shown in the Fig. 2 and reinforced by Table 1.

2.2. Methanol production from CO_2

Methanol is an organic chemical compound and the simplest member of the group of alcohols. Under normal conditions, methanol is a clear, colorless, flammable and volatile liquid with an alcoholic odor. It is soluble with many organic solvents and in any proportion with water [11]. Conventionally, methanol is produced exclusively via the catalytic reaction of synthesis gas at 50 to 100 bar and 200 to 300 °C. The most widespread process is the synthesis gas production from natural gas. The conventional methanol synthesis has a carbon conversion of 50 to 80% per reactor run at a selectivity of the reaction to methanol of around 99%, depending on the pressure and temperature [11]. Within this paper, methanol is produced from CO_2 captured from flue gas and H_2 obtained from water electrolysis. Fig. 3 illustrates the methanol production process from CO_2.

The flue gas produced by the power plant (about 48 kg/s in full load) is assumed to consist of 75% N_2, 15% CO_2 and 10% O_2 (all by volume). It is led to a gas cleaning section downstream where the CO_2 is separated by a carbon capture system with chemical solvent. Simultaneously, an electrolysis is producing H_2 by splitting H_2O into H_2

[1] VGB PowerTech e.V. is the international technical association for generation and storage of power and heat.