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Conceptual Design of a Hythane-based Infrastructure System for Combined Power and District Heat Production

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As the debate on climate change intensifies, interests (from many stakeholders) on possible transition from an energy system based on natural gas to a H2/NG mixture as an initial step for reducing the emission of greenhouse gases to the atmosphere has heightened. H2/NG mixture often christened Hythane is a mixture of about 20%:80% by volume of hydrogen and Natural gas. In line with these, a municipality in the Netherlands has initiated a project (based on a positive technical feasibility study), where part of the city will be redeveloped into a sustainable city – wherein the existing natural gas network will be adapted to accommodate hydrogen. At a higher level of abstraction, this paper looks at the technical conceptual design of the infrastructure system for this Hythane-based power and district heat production. Two systems (the stand alone Hythane-based heat production unit and a combined Hythane-based heat and power production units) have been simulated in ASPEN Plus®. Though the level of CO2 emission is the same for both systems, the steam-turbine based cogeneration case is the most economically attractive amongst the various cogeneration options simulated. The steam-turbine based cogeneration unit has been conceptually designed together with the associated pipeline network.

Keywords: Hythane, District heating, Conceptual Design, Combined Heat and Power

1. Introduction

There are three primary sectors that are sources of carbon dioxide emissions–the power sector, the transportation sector, and the thermal sector (residential and commercial heating and the industrial processes) (Kurtz Waltzer, 2006), as shown in the pie chart below.

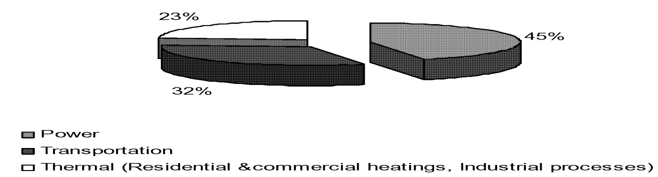

Figure 1: Share of the CO2 budget per sector

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This reveals that residential and commercial as well as other industrial processes contribute a total of 23 percent of the total carbon dioxide emission budget. Furthermore, the emissions of CO_2 from the generation of electricity at natural gas-fired plants as well as the emissions of CO_2 from natural gas based-district heating plants runs into the order of thousand million metric tons annually. According to (IEA, 2001a and 2001b), the current energy supply to the district heating systems is dominated by the use of fossil fuels, mostly in combined heat and power (CHP) plants where natural gas constitutes about 45 % of such supply. With these statistics in mind, CO_2 emission could be reduced by the use of less green house gases or the partial mixture of natural gas with hydrogen. This 20% mixture of hydrogen with 80% by volume natural gas often termed Hythane, capable of having a significant reduction in the CO_2 emission is gradually finding reported positive remarks in terms of technical feasibility, as feedstock for space and water heating. It is also possible to transport hydrogen in the natural gas network with relatively little modification, and this may be the best option if it can be brought about. Adding hydrogen to natural gas is an effective way of improving the combustion properties and cleanliness of the fuel. From the exploratory feasibility study of mixing and transporting hydrogen through the existing natural gas network conducted (van de Beld et.al. 2003) it has been shown that it is technically feasible. Though its technical feasibility has been established, however, in the open literature, work on the conceptual design of such process is still grossly lacking. In this work, an attempt has been made towards having a technical conceptual design of the process. Two systems (the stand alone Hythane-based heat production unit and a CHP-Combined Hythane based-heat and power production units) have been simulated in ASPEN plus. In the Cogeneration case (combined heat and power) three different simulations were conducted- a steam turbine, gas turbine and combined gas/steam turbine cases to determine the most efficient one. The combined cycle is a combination of a gas-turbine cycle and a steam-turbine cycle, and has a higher thermal efficiency than either of the cycles operated individually. In a combined cycle power plant there are two generators producing electric power.

2. Process Simulations

2.1 Process Description Stand alone Heat production (base case) unit

The condensed water returning from the households to the central collection unit of the districts, DHIN, enters the plant at 66.5°C and 9 bar, where it is first preheated in the flue gas heat-exchanger to 80°C. The desired temperature (137.2ºC) of the hot tap water, DHOUT, which is sent to the districts through the pipeline network, is achieved after heating up the preheated tap water stream, FGHXOUT, in an atmospheric fired heater using a mixture of natural gas and hydrogen, HYTHANE. Natural gas, NGSTD, is mixed with a hydrogen stream, HYDROGEN, at 15°C and 1 bar and then fed into the fired heater to be burnt with air generating the required heat to heat up the preheated cold tap water, FGHXOUT, from 80ºC to 137.2ºC. Combustion air, AIRIN, is sucked from the atmosphere and feeds a blower. The discharge of the blower, AIROUT, is fed into the fired heater at 1.3 bar and 20°C. The off-gas, EMISSIONS, from the fired heater is released to the atmosphere through the stack at 80ºC and 1.3 bar. The hot tap water, FURNOUT, is then sent to a pump that delivers hot tap water, DHOUT, at 13 bar to the distribution system. The condensed water returning from the households is collected and then recirculated to the furnace as feed water.

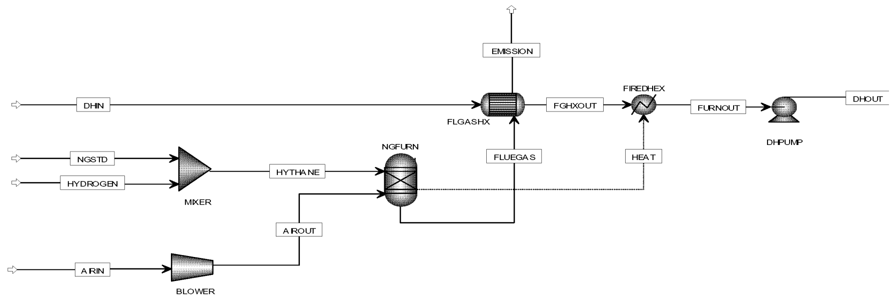


Figure 2. ASPEN flow diagram for Stand alone Hythane based heat production unit

2.2 Process Description of Steam-turbine CHP (ST-CHP) Unit:

In the steam-turbine CHP unit the heat provided by the flue gas heat-exchanger and the fired heater is utilized to evaporate the water stream circulating in the closed-loop, FLGHXIN, and converts it to a high-pressure steam at 421ºC and 45 bar, STEAM. This stream is then split into two streams, namely TURBIN and HEX2IN. TURBIN passes through the steam-turbine where it does some work in rotating the turbine blades thus producing electricity. The turbine discharge stream TURBOUT at a pressure and temperature of 8 bar and 206ºC respectively is subsequently used in preheating the cold tap water returning for the districts, DHIN, to 70ºC in a heat-exchanger. For electricity generation, the turbine is connected to a generator. The preheated cold tap water, HEX1OUT, is then sent to the second heat exchanger where it is heated to 137.2 ºC, HEX2OUT. The steam streams condense to water streams in the heat-exchangers are mixed together, WATER, and pumped to the flue gas heat-exchanger, FLGHXIN.

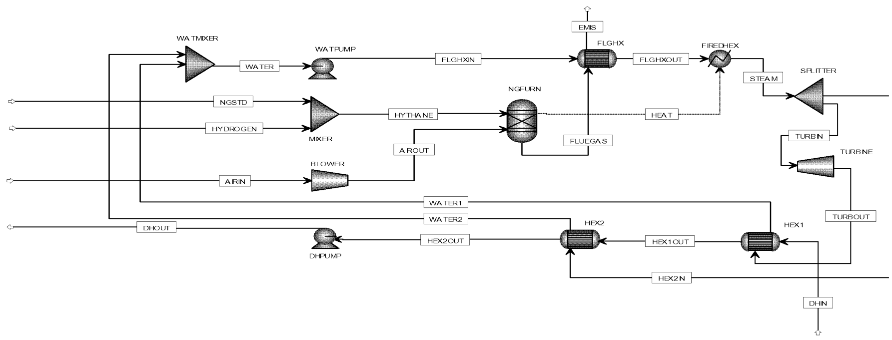


Figure 3. ASPEN flow diagram for Steam-turbine CHP

2.3 Process Description of Gas-Turbine CHP (GT-CHP) Unit

In the gas-turbine CHP (GT-CHP) unit, the flue gas stream, FURNOUT, produced in the fired heater at 523ºC and 25 bar, as a result of the hydrogen/natural gas mixture, HYTHANE combustion, is split into two streams i.e. TURBIN and HEX2IN. TURBIN at 25 bar and 523ºC passes through the gas-turbine where it does some work in rotating the turbine blades thus producing electricity. The turbine discharge pressure and temperature reduce to 5 bar and 277ºC, respectively. The turbine is connected to a generator, for electricity generation. Afterwards, the cold tap water returning from the districts is preheated by the turbine outlet stream, TURBOUT, to 70ºC in a heat-exchanger. The preheated tap water is, subsequently, fed to another heat-exchanger where it is heated to 137.2ºC. The flue gas streams emitted from the first heat-exchanger, EMIS1, and the second heat-exchanger, EMIS2, through a stack are at 80ºC.

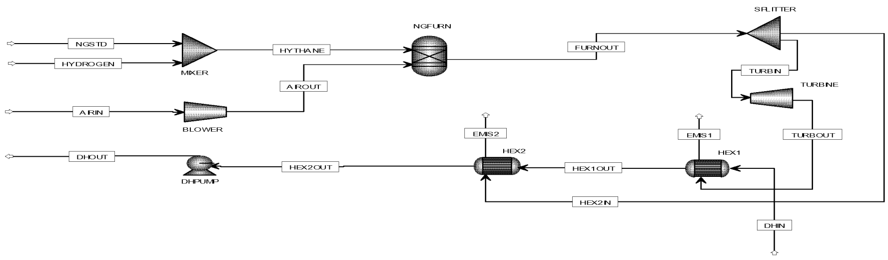


Figure 4. ASPEN flow diagram for Gas-turbine CHP

2.4 Process Description of Combined Gas-Steam Turbine CHP (CGST-CHP) Unit

Like in the gas-turbine CHP plant, in the combined Gas-steam CHP (CGST-CHP), the flue gas stream, FURNOUT, at 523ºC and 25 bar is split into two streams, namely GTURBIN and HEXIN2. However, the gas-turbine outlet stream, GTURBOUT, at 279ºC and 5 bar and HEXIN2 at 523ºC and 25 bar are utilized to preheat and convert the circulating water stream to a high-pressure steam, STEAM, at 340ºC and 55 bar respectively. The flue gas streams form the first heat-exchanger, EMIS1, and the second heat exchanger, EMIS2, are released to the atmosphere by means of a stack at 274ºC and 345ºC respectively. The high-pressure steam, STEAM, is split into two streams i.e. STURBIN and HEX4IN. STURBIN passes through the steam-turbine where its temperature and pressure reduce to 237ºC and 25 bar, accordingly. Afterwards, the cold tap water stream returning form the districts, DHIN, is preheated by the turbine outlet stream, STURBOUT, to 69.5ºC. The preheated tap water, HEX3OUT, is then sent to another heat-exchanger in which the desired temperature of 137.2ºC is achieved. The steam streams condensed to water streams in the heat-exchangers are mixed together, WATER, and pumped, HEXIN, to a heat-exchanger to be heated up by the gas-turbine outlet stream, GTURBOUT.

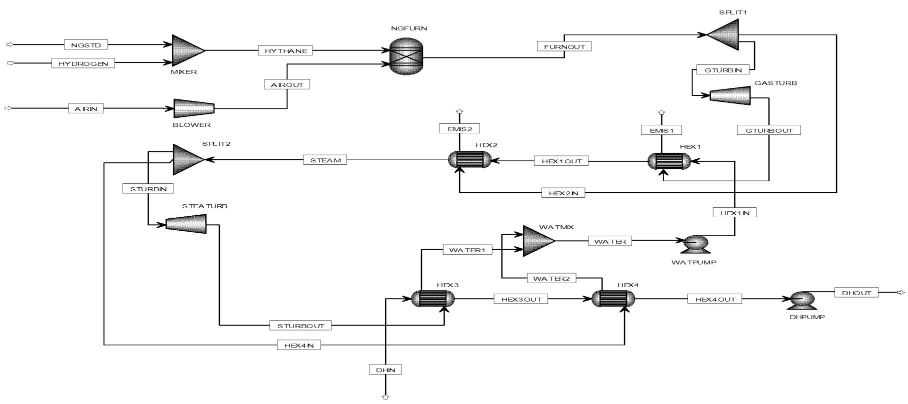


Figure 4. ASPEN flow diagram for Combined Gas- Steam turbine CHP

3. Mass and Energy Balances

The overall mass and energy balance of the steam-turbine CHP processes are depicted in Table 1. Others have been skipped for space constraints.

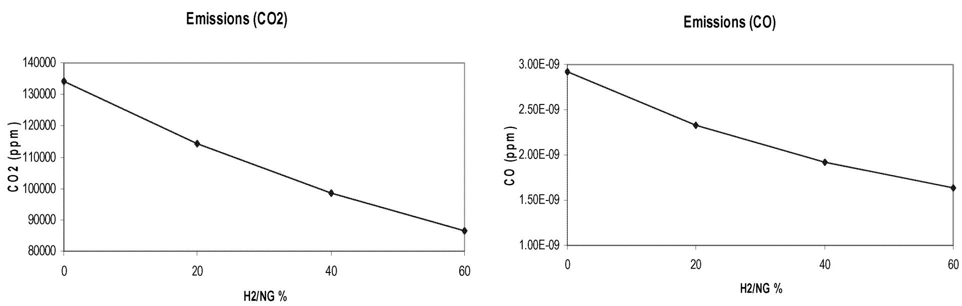
Table 1: The overall mass and energy balance of the steam-turbine CHP plant.

Stream/Equipment	In		Out	
	Mass (kg/s)	Heat (kW)	Mass (kg/s)	Heat (kW)
DHIN	97.39	-1.54E6		
DHOUT			97.39	-1.51E6
NGSTD	0.98	-3.56E3		
HYDROGEN	0.02	-2.85		
AIRIN	16.03	-85.65		
EMIS			17.03	-3.58E4
BLOWER		568.98		
DHPUMP		101.65		
TURBINE				-265.70*
WATPUMP		110.71		
Total	**114.42**	**1.54E6**	**114.42**	**-1.54E6**

* This value corresponds to the case in which the heat consumption is at its highest rate in the district.

4. Emission Analysis

Figure 5 shows the CO_2 reduction potentials of mixing hydrogen to natural gas. The result of the simulation shows that a 20/80 H_2/NG mixture will result in about 15% and 25% reduction in CO_2 and CO respectively. As more hydrogen is introduced, the resultant emission also decreases. However, any mixture more that the 20/80 ratio may not be currently possible as that may aggravate the embrittling of the current NG pipeline by hydrogen.



(a) (b)

Figure 5. Emission reductions (a) CO2, (b) CO

5. System Components Design

Based on the Aspen Plus simulation, the major pieces of equipment used in the process was designed. The equipment costs, their specifications and/or sizes are listed in Table 2 for the selected most economically attractive case, the steam CHP plant. From the cost list, the combined gas-steam CHP plants seems to have the greatest equipment cost, however, the amount of electricity it produces is by a factor of 3, greater than the amount of electricity from a single gas or steam turbine CHP system.

Table 2: List of the main equipments – Steam-turbine CHP (GT-CHP) Plant.

	Main Specification	Cost10^3xUS$
BLOWER	569 kW	105
NGFURN	124821 kW	5941
FLGASHX	975 m^2	98
TURBINE	23913* kW	2253
HEX1	26 m^2	18
HEX2	247 m^2	39
WATPUMP	111 kW	22
DHPUMP	92 kW	21
Total	**-**	**8497**

* This value corresponds to the case in which the heat consumption is at its lowest rate in the district.

6. Economic Assessment

The economic evaluation of the various options shows that though all the options are technically feasible, only the steam-turbine CHP process is economically viable. Other options have negative cash flows and tremendously high pay out time as depicted in Table 5. Based on the economic analysis, the ST-CHP system has been selected.

Table 5 : Economic performance of the various options (all costs and revenues in Million $US)

Economic Indicators	Base case	ST- CHP	GT- CHP	CGST- CHP
Total Investment	21.7	31.3	57.3	146
Total Production Cost	16.0	19.4	80.0	216
Annual Revenue	14.2	29.4	70.2	168
Cash Flow	**-1.8**	**10.0**	**-9.8**	**-48**

7. Conclusions

CO_2 emissions from natural gas based-district heating systems have been identified as on of the contributor to the overall fugitive green house emission budget. An innovative way in the form of using Hythane-based processes instead of natural gas in reducing this emission is receiving a lot of attention in recent time. In contributing to this effort, we have undertaken a conceptual design of a Hythane based cogeneration system. Two systems (the heat alone Hythane-based unit and a combined Hythane-based heat and power production units) have been simulated in ASPEN Plus®. The simulation reveals that about 15% and 25% CO_2 and CO emission reduction could be obtained using the new Hythane process in lieu of the conventional natural gas based cogeneration system.

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