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YOUNG RESEARCHERS PRIZE 2015

YOUNG RESEARCHERS PRIZE | ABSTRACTS

CONTENTS

1 | A Comparison of Integration Solutions for a Gas Stirling Micro-cogeneration System in Residential Buildings

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Micro-Combined Heat and Power (µCHP) is a technology allowing to produce decentralized electricity (electrical power below 36 kWel). The main advantage of µCHP is to avoid thermal energy losses while producing and distributing electricity in order to use primary energy rationally. The electricity can be consumed locally in the building or in the neighborhood area while thermal energy can be recovered to satisfy space heating (SH) and domestic hot water (DHW) demands. Stirling engine is one of the various µCHP technologies that can be integrated in individual or small multi-family residential buildings.

The aim of this paper is to study the impact of storage configurations, hydraulic patterns and control strategies on the performance of a µCHP system. This study is carried out on an individual residential building in different climates with various electrical, DHW and SH loads.

A dynamic model developed to represent a 1 kWel gas Stirling µCHP system (producing up to 24 kWth thanks to an auxiliary burner) has been experimentally calibrated and validated. This model and storage, emitter and distribution network models are implemented in DYMOLA/Modelica environment in order to get a dynamic representation of the whole installation coupled to the building.

The comparison between the different cases is shown in terms of primary energy consumption and analysis of operating conditions. The results allow to identify the best SE-µCHP designs according to building conditions.

4 | Application of fractal grids in industrial low-swirl combustion

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Fractal-grid-generated turbulence is a successful technique to significantly improve the mediocre reaction rate in the center of a low-swirl flame. Previous results [Verbeek et al., Comb. Flame 162, 2015] are promising, but the experiments are only performed using natural gas at a single equivalence ratio and flow rate. In industry, the need arises to adapt gas turbines to a wider range of fuels, such as biogas and syngas. To simulate these other fuels, natural gas is enriched with up to 30% hydrogen (molar based). By means of planar OH-LIF, the turbulent flame speed is assessed. It is shown that the beneficial effect of fractal-grid-generated turbulence remains upon hydrogen enrichment. The fractal grids enhance the combustion in an energy effcient way, irrespective of the hydrogen fraction. Moreover, the characteristic linear relation of the normalized local consumption speed versus the normalized rms velocity holds for the investigated range, with an increasing coeffcient upon hydrogen enrichment. For industry, a wide operability range is essential to operate at part load, therefore the lean stability limit is investigated, as well. It is shown that fractal grids increase the lean stability limit, i.e., the equivalence ratio at which blow-off occurs, by 0.03, compared to a standard grid. Increasing the bulk flow significantly increases the lean stability limit and the difference between the two investigated grid types increases upon hydrogen enrichment. Hydrogen addition results in a decrease in the lean stability limit, regardless of the grid. A positive correlation was found between the equivalence ratio at blow-off and the rms velocity at the flame brush. The outcome of the presented study provides, despite a slightly increased lean stability limit, a promising prospect for the application of fractal grids in industrial low-swirl combustion.

5 | Biomass ash fluidized-bed agglomeration: hydrodynamic investigations using high temperature and cold flow lab-scale reactors

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Biomass gasification is a promising way to make renewable energy. It produces a syngas which can be turned into different kinds of energy: CHP (Combined Heat Power), bio-fuel or combined biomethane fuel (or BioSNG: a green Substitute Natural Gas) and heat. Combined biomethane/ heat is environmentfriendly (high energetic and chemical yields, local heat valorization, reasonable biomass supply volume and radius) and is complementary to the other renewable energies.

Project "GAYA", started in June 2010, is aiming to develop and prepare industrialization of the combined 2nd generation biomethane pathway with grid injection (2000 to 10000 Nm3/h), through a demonstration operation and an R&D pilot plant to be erected in Lyon (France). The project objective is to develop an efficient and environmental friendly 2nd generation pathway from biomass to biomethane and injection in natural gas grid. The project has identified optimized configurations of each process blocks. Innovations and improvements will be developed in order to reach the highest energetic efficiency and a better environmental balance in comparison with others 2nd generations' pathways.

Fluidized-bed reactors (FBR) constitute a suitable and proven technology for syngas and advanced biomethane production from lignocellulosic biomass feedstock. However, it is well known that some feedstock, in particular ash-rich biomasses (straw, waste wood, paper sludge,…), have a deleterious effect on the process evidenced by agglomeration and defluidization at elevated temperature. Reaction between ash species, and sometimes bed materials, can lead to liquid phase formation (slag or meltedsalt type). The direct consequence is the hydrodynamic disturbance of the bed by agglomerate formation, followed by rapid defluidization when agglomeration becomes severe. Nevertheless, only few studies investigate the influence of the phenomena on the hydrodynamic behavior of a FBR. Moreover, available predicting models of agglomeration/defluidization (A/D) in fluidized-bed reactor exhibit limited physical comprehension.

This work aims to improve the knowledge on hydrodynamic disturbance inside bubbling fluidized beds caused by A/D, and in parallel, to develop a simple physical model of agglomeration dedicated to biomass gasification and/or combustion. The identification and influence of the main parameters involved in the A/D process is carried out inside both a laboratory fluidized-bed operating at high temperature (700-1000°C) and a cold flow fluidized bed (ambient temperature). The influence of the liquid fraction, liquid properties (viscosity, wettability…) and of the operating parameters (temperature, atmosphere, fluidization velocity, H/D…) on the agglomeration process and on the fluidized-bed hydrodynamic is investigated. Modeling criteria concern liquid fraction (estimated from thermodynamic calculation using biomass composition) and its properties (wettability of the bed materials), and address the work of adhesion of liquid phase on bed materials and the interparticle forces (liquid bridges formation and breaking).

This work would provide a physical model to predict formation of aggregates in the reactor and will help operator in anticipate production rupture on the industrial demonstrator for 2nd generation biomethane injection in gas grid.

6 | Carbon steel corrosion in dense phase CO2: Above and below the water solubility limit

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CCS entails to capture waste CO2 from large point sources and transport it to a permanently deposit, usually in geological formations. The captured CO2 is likely to contain impurities like water, oxygen, nitrogen dioxide, sulfur dioxide and hydrogen sulfide. These impurities are known to cause corrosion, dust and/or solid formations, and may lead to operational difficulties. The present study examine how water content above and below the solubility limit in dense phase CO2, affects the corrosion of carbon steel.

There are few experimental studies that have examined corrosion under CO2 transport conditions, and these have shown very different corrosion rates (CR) in experiments where the water content in the CO2 were the same. These discrepancies may reflect short-comings in the experimental methodology in some of these studies, where formation of free water may have contributed to high corrosion rates. In the present work, the experimental equipment was designed to allow complete control of the water concentration in CO2, without the risk of droplet formation. This provides a more realistic condition mimicing the situation in the operating pipelines.

Two different corrosion experiments were conducted. In the first experiment the dissolved water concentration in CO2 was increased stepwise from 500 ppmv to 2400 ppmv, which is slightly under the solubility limit for water (25 °C and 95 bar). The general corrosion rate was below 1.0 µm/y and no localized attacks were found. In the second experiment the water concentration in the CO2 feed where held at 2500 ppmv and the temperature was ramped between 8 °C and 14 °C to ensure that the water solubility was exceeded (95 bar). The corrosion rate was still at 1.0 µm/y, with no localized attacks.

7 | Comparison of GERG-2008 and Soave-BWR in PVT Modeling and Thermal Properties Calculation of Natural Gas Systems

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1. Introduction

Accurate description of thermodynamic properties of natural gas systems is of great significance in the oil and gas industry. For this application, non-cubic equations of state (EoSs) are advantageous due to their better density description. Among these non-cubic models, GERG-2008 [1] is a new wide-range EoS for natural gases and other mixtures of 21 natural gas components. It is considered as a standard reference equation suitable for natural gas applications where highly accurate thermodynamic properties are required.

Soave's modification of Benedict-Webb-Rubin (Soave-BWR) EoS [2] is another model that despite its empirical nature, provides accurate density description even around the critical point. It is much simpler than GERG-2008 and easier to handle and generalize to reservoir oil fluids.

2. Comprehensive comparison between GERG-2008 and Soave-BWR

This study presents a comprehensive comparison between GERG-2008 and Soave-BWR in description of pure component densities in a wide temperature and pressure range, calculation of binary Vapor-Liquid-Equilibria (VLE), and prediction of multicomponent phase envelopes. In addition, the two models are compared in calculation of thermal properties such as Heat Capacity and Joule-Thomson coefficients for both pure components and mixtures. The results are compared with available experimental data in the literature and special focus has been given to the reverse Joule-Thomson effects at high pressure high temperature (HPHT) conditions.

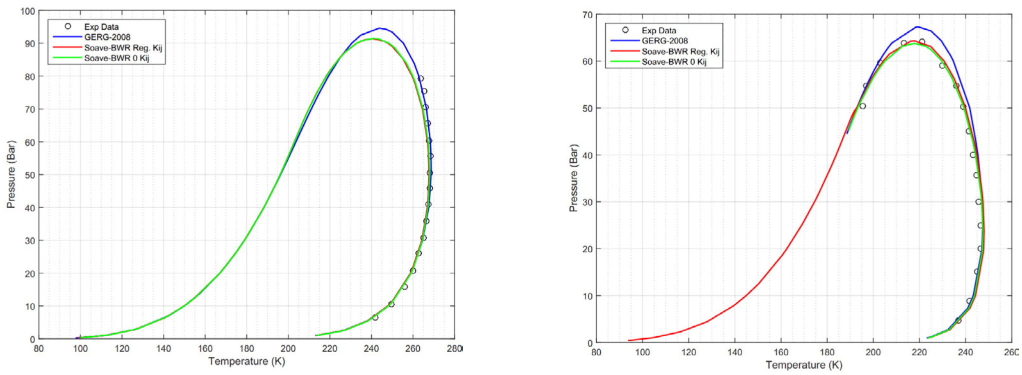

Figure 1. Phase Envelope Calculation a) Morch et al. 2006 Gas mixture 3 and b) Avila et al. 2002a Gas mixture 3

3. Conclusion

It is found that Soave-BWR is largely comparable to GERG-2008, although not as good, in density description. The two models are very similar in phase equilibrium calculation whereas Soave-BWR has some challenges in highly asymmetric systems. The comparison shows the potential of Soave-BWR as a light-weight alternative to GERG-2008 although further development of Soave-BWR, e.g., modification of its mixing rules, seems to be needed.

[1] O. Kunz and W. Wagner, "The GERG-2008 Wide-Range Equation of State for Natural Gases and Other Mixtures: An Expansion of GERG-2004," J. Chem. Eng. Data, vol. 57, no. 11, pp. 3032–3091 (2012)
[2] G. S. Soave, "An effective modification of the Benedict–Webb–Rubin equation of state," Fluid Phase Equilib., vol. 164, no. 2, pp. 157–172 (1999)

9 | Development of an Accurate, Modern, Adaptable, Isothermal Gas Calorimeter

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Non commercial current calorimeters measure directly the enthalpy combustion but inferred from the values of the Wobee number or the index of oxygen of combustion. These commercial calorimeters require calibration bay electrical heater or using reference gases and they are hard to control by a computer and require high maintenance, like the Cutler-Hammer calorimeter. Isothermal calorimeters based on Alexandrov design are more accurate, do not require calibration or very much maintenance and can be controlled easily by a computer, also they can be adjusted to measure biogas mixtures.

Alexandrov's calorimeter works by burning the flammable gas (methane, natural gas, biogas, bio-methane...) in a combustion chamber. The heat produced in the combustion is used to evaporate a certain amount of a refrigerant or another kind of fluid that can be used as heat carrier. Then the heat is removed from the system thanks to several peltier elements making the refrigerant to condensate again. To measure the heat flux an electrical heater was placed inside the combustion chamber used to keep the temperature of the refrigerant at 25°C in steady state. The heat provided by this electric compensation heater will be different when gas is being burnt from when it is not, and this difference will be used to calculate the heat power of the gas used.

There is a lack of study in calorimetry using this kind of device, some of the last studies were done many years ago and they required to be updated. With that purpose, PTB in collaboration with University of Valladolid is performing this study, where the work of this isothermal gas calorimeter is deeply analysed seeking possible weaknesses and who to improve its performance and to enhance accuracy of the measurements. This includes accuracy of the mass flow controllers, reducing noise in electrical heating, humidity measurements in the outlet stream, etc.

This work takes part in the European project EMRP-ENG54 Metrology for Biogas supported by EURAMET and the European Union.

10 | Duel-fuel CNG-diesel Light Duty Engine

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Natural gas is a promising fuel for transport applications due to its large availability and low cost compared to conventional transportation fuels. In the last decades, emission legislation on pollutant emissions generated by road transportation has become the main driving force for internal combustion engine development, and due to its lower carbon content, natural gas is also perceived as a way to reduce carbon dioxide emissions emitted per kilometer.

Light-duty gas engines are usually spark-ignited due to similar combustion characteristics for methane gas and gasoline. Since spark ignition requires a low compression ratio to avoid knock problems, gas engines have lower efficiency than diesel engines. A combustion concept that has been successfully applied on large stationary engines and to some extent on heavy-duty engines is dual-fuel combustion, where a compression-ignited diesel pilot injection is used to ignite a homogeneous charge of compressed natural gas (CNG) and air. This dual-fuel combustion concept is well established for large stationary engines and exists as an after-market solution for heavy-duty engines but does not exist at all for light-duty engines. This concept offers a high degree of flexibility for the engine operation because dual fuel combustion does not require heavy modifications of the original diesel engine architecture so diesel operation could remain unaltered.

Therefore, a light-duty engine located at the laboratories of the Division of Combustion Engines at Lund University (Sweden) has been rebuilt for dual-fuel operation. The engine admits a mixture of air and CNG which is later ignited by a pilot injection of diesel. That event triggers the main combustion and controls combustion phasing. The main limitations of this concept are related to methane oxidation in the aftertreatment system and preignition at high load. Low load conditions are challenging due to lean combustion. However, intake air heating has been proved as an effective way to extend the operating range at low loads by means of an improvement of the flame propagation process and consequently remarkable efficiencies at low loads compared to conventional sparkignition gas engines have been recorded during experiments. At mid loads, alternative combustion modes like reactivity controlled compression ignition (RCCI) showed high potential for low nitrogen oxides emissions. Finally, exhaust gas recirculation (EGR) could be used at high loads in order to control preignition events, allowing the use of CNG during full load operation. Under these conditions, up to 95% of the total fuel energy supplied could be provided by CNG, therefore maximizing the use and emission reduction potential of natural gas in automotive applications.

12 | Global Gas Market Simulation Model

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The natural gas sector is facing huge uncertainties related to technological advances, geopolitical changes, and strategic policy shifts. Therefore the supply and demand picture has become an enigma. A combination of factors lies behind: 1) the ongoing liberalization process; 2) the security of supply concerns due to the concentration of suppliers and Europe's dependency in these imports; 3) the globalization of the natural gas markets through the LNG, its recent convergence in global gas prices and its sustainability over time; 4) the evolving framework of long-term contracts based on the cost of alternative fuels (oil price) and big take-or-pay commitments to liquid markets with transparent gas index prices; 5) the production of shale gas in North America, its global present and future output and possible shale gas developments in other areas; 6) the role of natural gas in a low carbon Europe.

The objective of this research is to present a simulation model that represents the global natural gas market defining the infrastructures and the agents involved, from the wellhead to the consumers.

The model therefore, considers the following agents: producers, traders (which act as interface between producers and marketers), marketers and consumers. About 50 nodes will be considered in the model, including the countries with bigger production, the different consumption zones, and those zones which may be relevant due to the existence of significant gas facilities (as liquefaction or regasification terminals).

Besides, the following infrastructures are modeled: wells, liquefaction plants, pipelines, LNG routes, underground storages and regasification plants. For each infrastructure, technical constraints, congestions, gas balance equations considering losses and operational cost are considered.
The model is formulated as an optimization problem, and is solved by linear or quadratic programming, based on piecewise linear approximations of the nonlinear constraints. The model will be coded in the GAMS language.

The model provides insights on how the natural gas sector might evolve in a medium- to longterm scope. Specifically, the main results provided by the model are: consumption for the different sectors, productions, traded volumes, gas flows by pipelines, LNG trades, regasified gas and prices for the different nodes.

This model constitute a very useful tool for analyzing how different hypothesis (e.g. a raise in the demand or in the production from a specific country) may affect the global operation of the gas sector.

13 | Heating Buildings with a Natural Gas Absorption Heat Pump: performance Analysis of a Small Prototype Designed for Residential Use

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The thesis to be presented has been developed on the basis on the results of the HEAT4U project (1st November 2011-31 October 2014), which was aimed to develop and test an innovative small size prototype (18kW) of Gas Absorption Heat Pump (GAHP), designed for the european residential market, with particular target for mono and bi-familiar users. The aim of the thesis was to find the best application of the GAHP technology for winter air contitionig in Italy, in order to optimize the cost benefit ratio achieved by its better performance.

The thesis is structured in three parts, the first one consists of a deep analysis of the data recorded during the field test campaign, which took place near the ENEA Casaccia research center (Rome) in the heating season 2014, for the HEAT4U project.

The second part consists of the development of a TRNSYS dynamic model based on a hybrid system (GAHP plus back up boiler), providing space heating for multiple users.

In the third part, an economic assessment is made, in order to get the minimum pay back time of the system compared with the classic solution of a single gas boiler for each user.

The HEAT4U project intended to show mainly the performance of GAHP technology in direct retrofits of single user residential applications for both domestic hot water preparation and space heating. Five different locations for the field tests were therefore identified in order to check the performance in different climates all over the Europe (Germany, France, Poland, England, Italy). The field test were carried on in real houses with a specific heat demand, intended to be as close as possible to the heating power supplied by the GAHP at the design temperature of the chosen location. For this reason, due to the difficulties of evaluating the real heat demand of an existing building, ENEA preferred to develop a virtual building simulator instead of using a real house.

The results obtained in Italy were very interesting, the GAHP scored 1.379±0.055 (net calorific value), that is a great improvement with respect to gas boilers which rarely reaches 0,85. The achievements met the minimum desired specifications for a next industrial production.

Considering the air temperature histogram of the Italian location during the heating season, only the 2% of the cases fall into the cell below or equal to the design temperature of the location, as a consequence a heating device rarely operating at or near full power.

This fact makes a GAHP to work in light to heavy part-load running conditions, lowering the expected performance. To overcome this issue, was decided to check the performance of the GAHP utilized to fulfill the base load of a multiple user application in combination with peak load boilers. After the experimental data analysis, because of the exuberant performance of the GAHP in our latitudes, it was implemented a dynamic model in TRNSYS of a residential complex composed by several terraced house sections (of new and old manufacture), heated by a hybrid system GAHP-back up boiler. The terraced houses's sections were located in three different sites:

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Palermo, Rome, Milan, so that it was possible to evaluate how much the different climates can affect the overall system performance. The number of terraced houses was varied from time to time recording the SGUE and an optimal value was finally found. The optimal SGUE, on net calorific value basis, found by the simulations varied in the range 1,32 –1,48 according to the latitude.

In the final economic analysis, the minimum pay back time of two plant solutions was found: one gas boiler for each terraced house to provide domestic hot water and space heating, or a common GAHP-gas boiler hybrid system for space heating combined with an instantaneous gas water heater for each user. The results gave a value of 5-6 years in Rome or Milan with respectively 8 and 5 terraced houses adopting old manufacture houses, and 9-7 years for new houses. The results are slightly better than those achieved for single user applications, and furthermore the investment costs of the GAHP can be shared among all the users, in order to get a better payback time. The results of the simulations in Palermo are more questionable: the sensitivity to the boundary conditions brings to highly oscillating values that require more attention in them handling.

14 | Influence of External Factors on the Share of Power-to-Gas in an Optimal Storage Portfolio

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The share of intermittent renewable energy sources (RES) in the electricity generation mix is increasing worldwide. Since these intermittent RES are not fully dispatchable and electricity demand is variable and unpredictable, there is a need for flexibility instruments to match supply and demand. This flexibility is needed both on the daily and seasonal level.

Several flexibility options exist in the electricity system, e.g. dynamic operation of conventional power plants, expansion of the electricity grid, active demand response, curtailment of RES and storage of electricity [1]. Storage is an interesting source of flexibility as it can both absorb excess electric power and "generate" electric power when other generation capacity is insufficient.
Hydrogen and synthetic methane (SM) are two energy carriers that can store surplus electricity indirectly through electrolysis for H2 and possibly further methanation to get methane. This can be done on a large scale (up to several weeks of electric energy consumption) and for longer term purposes (seasonal storage). The technology used to produce hydrogen or methane from electricity is called power-to-gas (P2G) [2].

The conversion efficiency of P2G is reported to be between 30% and 40%. Although other storage technologies have higher reported efficiencies, simulation results show that in future high-RES scenarios the need for large amounts of energy storage presents possible opportunities for P2G [3].

In this work, the influence of external factors on the share of P2G in an optimal storage portfolio is investigated. Towards this end, an investment model is developed. The model objective is to minimize total system cost while meeting the instantaneous electric power demand at all times and assuring an imposed minimum share of renewable end-electric energy.

The total system cost is equal to the cost of all installed generation and storage capacity, fixed operating and maintenance cost and the cost of consumed natural gas. Synthetic methane can only be produced endogenously. The cost of SM is taken into account through the installation cost of electricity generation technologies. Curtailment is free.

Electricity is generated by RES and combined cycle gas turbine power plants (CCGTs) fueled with synthetic methane or natural gas. Electricity can be stored as SM by P2G or in batteries. The energy storage capacity for batteries is limited by their energy-to-power ratio. No energy-to-power ratio is imposed for SM storage. The electric (P2G) power capacity and methane storage capacity are not coupled and can be installed independently.

The Belgian electric power demand and RES generation profiles are used as a test case to quantitatively address the opportunities for P2G. Demand data of the Belgian electric power system from 2013 are obtained from the Belgian transmission system operator (TSO). Renewable generation profiles are obtained separately (solar, onshore and offshore wind) from the TSO. The time horizon of the model is 1 year, with hourly resolution.
Several scenarios are created where a different renewable end-electric energy target is imposed

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and where a different RES source can be used (onshore wind, offshore wind, solar or a mix of all three). To assess the influence of external factors, the parameters shown in Table 1 are varied in each scenario.

Table 1: Sensitivity parameters in each scenario.

Sensitivity parameters
Battery cost
P2G cost
Battery efficiency
P2G efficiency
Energy-to-Power ratio.

Results show that the cost of battery capacity and the battery efficiency have the biggest impact on both the amount of P2G and the battery capacity in the storage portfolio. Furthermore, the battery capacity is relatively more sensitive to changes in external factors than P2G capacity. Only when the electricity is produced by solar power, P2G is more sensitive than batteries.

[1] E. Delarue and J. Morris, Renewables intermittency: implications for long-term energy system models, TME-Working Paper, WP EN2014-22, unpublished. [Online] Available at: http://www.mech.kuleuven.be/en/tme/research/energy_environment/PublicationsEnergyandenvir onme nt/Journalpapers.
[2] M. Sterner, Bioenergy and renewable power methane in integrated 100% renewable energy systems, PhD. dissertation, Univ. Kassel, 2009.
[3] A. Belderbos, E. Delarue and W. D'haeseleer, "Possible role of Power-to-Gas in future energy systems," in 12th Conference on the European Energy Markets (EEM), Lisbon, 2015.

15 | Interchangeability of Different Natural Gas Blends Containing Hydrogen and Biogas Based On The European Norm Draft PR EN 16726

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1. Introduction The addition of different mixtures of biogas and hydrogen to a reference natural gas is studied in order to establish interchangeable mixtures that can be injected directly into the gas grid with the final aim of direct combustion in internal combustion engines or domestic gas appliances. One of the main issues to consider when changing the basic composition of the natural gas is its knock properties characterized by the Methane Number (MN). Hitherto there is not a common international accepted method to calculate precisely the methane number of a gas mixture, particularly when hydrogen is included. Moreover, the recent European standard draft PR EN 16726 [1] has been prepared with the aim of establishing a unique method to calculate the methane number, including the presence of hydrogen.

2. Objectives In this work the interchangeability of different gas blends containing conventional natural gas, hydrogen and non-upgraded biogas is studied by analyzing the knock properties through the value of the methane number calculated with the AVL-based method described in the norm PR EN 16726. A new computational program has been developed to calculate that value by following the iterative process described in the norm. In addition, the combustion properties of the different blends are analyzed by means of the existing widespread interchangeability standards of Delbourg (France), A.G.A. (U.S.A), Weaver (U.S.A.) and Dutton (U.K.) so that any problem like light-back or flame detachment is prevented.

3. Preliminary results and conclusions These studies have indicated the possibility of simultaneous addition of hydrogen and nonhighly purified biogas to the conventional natural gas. They have demonstrated the synergistic effect of the two additions; i. e., mixtures of NG with biogas that initially are not interchangeable, they become interchangeable when adding a certain amount of hydrogen. Furthermore, mixtures with a content of hydrogen up to 15% and of biogas up to 17% by volume have been demonstrated to be interchangeable with the conventional natural gas, under the criteria imposed by all the aforementioned interchangeability standards. These mixtures show a possible content in CO2 up to 6 % by volume.

With this proposal the cost of the biogas depuration processes prior to grid injection could be reduced with the consequent economical save. Moreover, due to the use of two renewable energy sources (biogas and hydrogen) the contribution to a lower environmental impact is noticeable. Consequently, it would be highly recommendable to establish more flexible national policies in relation to hydrogen and oxygen dioxide contents in the natural gas type fuel transportation. As an example, Spanish legislation [2] allows a maximum of 2.5% in CO2 content and a maximum of 5% in hydrogen content, which is below the real capacity of transport and consumption in the natural gas pipe network according to this study and in the same direction as indicated in the NATURALHY project [3].

[1] European Standard DRAFT prEN 16726 "Gas infrastructure - Quality of gas - Group H". May 2014. Ref. No. prEN 16726:2014 E.
[2] Spanish Legislation: Boletín Oficial del Estado (BOE). Nº 6, Lunes 7 de enero de 2013, Sec. I. Pag. 889. I. Disposiciones Generales, Ministerio de Industria Energía y Turismo. Resolución de 21 de diciembre de 2012, de la Dirección General de Política Energética y Minas, por la que se modifica el protocolo de detalle PD-01 «Medición, Calidad y Odorización de Gas» de las normas de gestión técnica del sistema gasista.
[3] O. Florisson, N. V. Nederlandse Gasunie, in "NATURALHY, Preparing for the hydrogen economy by using the existing natural gas system as a catalyst", SES6/CT/2004/502661, 2010.

16 | Optimization of Pre-chamber Ignition system for highly efficient Natural Gas Engines

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The Gas Engine Project at Lund University aims to explore and understand the combustion phenomenon in engine operating on gaseous fuels and develop technologies as an alternative to present day diesel operated heavy duty engines which are facing severe challenges like stringent emissions norms, high technology cost and unsustainable fuel supply. The two main goals are to increase the maximum load and improve fuel efficiency of natural gas engines. The current phase of the project focuses on prechamber ignition system to achieve these goals in heavy duty natural gas engines.

Initial experiments using pre-chamber spark plug without auxiliary fueling showed improvement in combustion stability (low coefficient of variation of IMEPg), which was due mainly to the spatially distributed ignition source provided by a pre-chamber; but only marginal extension in dilution limit with excess air and EGR, which is believed to be due to over-leaning of mixture in the pre-chamber by residual gasses in absence of any scavenging mechanism to flush the pre-chamber in the beginning of every cycle.

Following these observations, a literature survey was conducted and it was soon identified that additional fueling to the pre-chamber will help scavenge the residual gasses and will also lead to formation of a easily combustible mixture in the pre-chamber while the main chamber is extremely lean. Experiments were conducted on a single cylinder engine setup and a custom made pre-chamber capable of fuel injection, spark ignition and pressure measurement. First set of experiments performed were to study the effect of relative excess air ratio between the pre- and main chamber and also to evaluate the lean limit of operation with excess air. It was observed that the lean limit of combustion extended considerably from excess air ratio of about 1.7 (with un-fueled pre-chamber) to 2.6 (fueled prechamber). The maximum indicated efficiency observed at operating load of 10 bar IMEPg was 47.5% at a combination of main chamber excess air ratio of 2.4 and pre-chamber excess air ratio of 0.2, with engine-out NOx emission below EURO 6 levels (for heavy duty natural gas engines).

Following these finding, experiments to study the effect of pre-chamber volume and nozzle diameter on resulting main chamber ignition were conducted, where pre-chamber volume fraction of 2.4% and nozzle diameter ratio in the range 0.025-0.035 cm-1 were found to be optimal. CFD simulations were then conducted to study the fluid dynamic aspects of interaction between pre-chamber jets and main chamber charge during all experimental conditions which revealed the importance of main chamber charge motion and jets-wall interaction in main chamber ignition. Current and future studies are planned to study scalability aspects of pre-chamber ignition by conducting experiments on a marine engine setup.

19 | Power-to-Gas – The quest for the most beneficial location

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For the implementation of the energy transition and the associated fundamental transformation of the energy system alternative storage options for the use of excess electric energy produced by volatile renewable sources are required for the future power supply. Flexible and technically feasible long-term energy storage in the relevant dimension is offered by power-to-gas (P2G) technologies e.g. by the production of synthetic natural gas (SNG). The infrastructure necessary for the effective operation of such storage facilities on an industrial scale poses questions concerning the local electricity supply as well as the availability of carbon dioxide (CO2) required for the methanation process. These questions shall be answered based on the development of technical criteria aimed at determining predestined locations.

To determine these criteria, virtual infrastructure models are created which represent the German electricity transmission grid with voltage levels of 380 and 220 kV as well as the approved grid expansions by the Electricity Grid Expansion Act (EnLAG 2014) and Law for the National Requirements Plan (BBPlG 2014). In addition, the natural gas transmission system of various size ranges is included for the distribution of SNG and it is complemented by conventional and renewable energy sources of defined sizes in North Rhine-Westphalia. Furthermore, selected industrial CO2 sources and conventional power plants are incorporated and based on these, first theoretical P2G and SNG potentials are calculated for defined balancing zones. On the basis of the model and the conservative assumptions made, criteria are defined for the infrastructural analysis carried out by an evaluative classification of potential P2G locations.

Before applying these criteria on the example of the German federal state North Rhine-Westphalia (NRW), the current energy system is introduced and discussed. Subsequently, available CO2 sources are considered as potential P2G locations, which are then grouped into evaluative classes based on available infrastructural connections to assess the feasibility of P2G, and lastly, the realisable SNG quantities and P2G capacities for each location and balancing zone are calculated. Finally, ten predestined locations are able to fulfil the conservative criteria for the feasibility of P2G plants in NRW, reducing the theoretical potential to particularly synergetic locations.

25 | Combination of Methanation and Membrane GasPermeation in a Power-to-Gas-Concept

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The further development of PV and wind power as renewable energies with their production rate fluctuations both on short- and medium-time-scale result in the necessity of smarter grids and higher energy storage capacities. One very prominent and promising technology for meeting this future electric energy storage demand is the concept of Power-to-Gas. Here, the excess electric energy is converted to hydrogen using alkaline or PEM electrolysis. Most concepts incorporate an immediate subsequent conversion to methane using a local carbon dioxide source and a process of thermo-catalytic or biological methanation. After a final gas upgrading mainly comprising the separation of H2, CO2 and H2O the thereby produced SNG can be fed to the natural gas grid owning a huge potential for energy storage and distribution.

The current work presents the joint research efforts undertaken by Vienna University of Technology and the Montanuniversitaet Leoben in the field of Power-to-Gas-Processes. A process chain consisting of a catalytic methanation step and product gas upgrading applying membrane-based gas-permeation is developed and demonstrated on laboratory scale. Hydrogen and carbon dioxide are fed from gas cylinders in different mixture ratios and converted to methane using commercial packed bed catalyst as well as novel honeycomb catalyst based on nickel as active catalytic material. The gas upgrading consists of an initial drying step by condensation (gas temperature 5 °C) and a subsequent membrane stage separating residual H2O, H2 and CO2. The remaining methane-rich gas stream is thoroughly analysed and compliance to Austrian gas grid standards is verified (ÖVGW G31/G33). A multistage membrane step is envisaged to produce separate H2-rich and CO2-rich streams to allow for a controlled recycle of non reacted educts. Process simulation is extensively used for basic engineering and process optimisation steps. For this purpose, in-house-modelling algorithms have been implemented in the well-known commercial software environment ASPEN© Plus©. This package can be used for the analysis of complex plant layouts and the optimisation of recycle options.

Beginning mid October 2015 this process chain will be coupled with a combined biogas and hydrogen dark fermentation step for the supply of ´real-world´ educt gases. An additional adsorptive fine removal of H2S, NH3 and volatile organic components as well as a piston gas compressor will be applied to the system. Thus, the complete Power-to-Gas-Concept from biomass and excess electric energy to natural-gas-grid-compliant SNG-methane will be demonstrated at a scale of roughly 0.5 m^3(STP)/h.

26 | Solutions for Advanced Biogas Upgrading

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The upgrading of biogas for the production of biomethane to be injected to the natural gas grid has gained significant importance in recent years. It is often considered to be superior to the production of electricity and district heat with internal combustion engines (CHP) mainly because of the better energy utilisation and the higher flexibility of applying a natural gas substitute. A considerable number of small and industrial scale plants have been commissioned to date representing the current portfolio of currently available upgrading technologies. Although supposed to be state-of-the-art, academic research demonstrates that biogas upgrading still provides huge potential for optimisation and development.

High capabilities towards biogas upgrading is ascribed to membrane-based gas-permeation technology due to its flexibility and adaptability. Different membrane materials, membrane module configurations and plant topologies allow for the design of a tailor-made upgrading plant according to the needs of the customer and the application. Furthermore, gaspermeation stands out for low specific energy demand, high process simplicity and plant safety.

To fully exploit the potentials of gas-permeation for biogas upgrading a thorough analysis and design of the process is inevitable. Process simulation has proved to be a valuable tool for this investigation provided that capable and validated model algorithms are utilised. This is especially true during the design of processes incorporating different membrane materials for the selective and individual separation of different biogas constituents like CO2, H2S and CH4.

Frequently, the most challenging upgrading step is not the separation of the bulk component CO2 but the one of certain trace components like H2S, NH3 or various hydrocarbons (terpenes, thiophenes, mercaptans). A novel process of short-time-contacted chemical-oxidative scrubbing has recently been commercialized and serves well for the removal of high and strongly fluctuating sulphur contents in the raw biogas. The combination of this technique with an adsorptive precision cleaning step using oxides of iron, zinc or copper facilitates the safe and constant compliance with the strict gas grid regulations even for highly loaded biogas and at reasonable costs.

Current work provides an insight to the authors' research undertaken in the field of biogas upgrading. The application of commercial as well as innovative membrane materials e.g. for the separation of CO2 and H2S from methane-rich gas streams is presented by means of numerical and experimental approaches. Additionally, the novel process for desulphurization of carbon dioxide- and methane-rich gaseous energy carriers will be illustrated using results from field-tests of a pilot plant and an industrial scale reference plant. A prospect of optimization potential and future research pathways in the field of biogas upgrading shall be given in a summary.

27 | Cost-efficient transportation of green hydrogen and extraction at arbitrary locations

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The storage of fluctuating electrical excess energy from renewable sources (e.g. wind, solar power) is a key challenge of our energy transition and has gained significant importance during the last few years. Various Power-to-Gas concepts offer a promising approach in this context. Excess electric energy can be used to produce storable green hydrogen with alkaline or PEM electrolysis. Afterwards, hydrogen can be further converted to methane and stored in the natural gas grid. Contrariwise, hydrogen can also directly be fed to the gas grid up to certain limits (in Austria currently 4 vol%). Thus, the well-developed existing natural gas grid can act as storage or as transportation device for the renewable hydrogen.

In a further step, hydrogen could be extracted at arbitrary locations along the gas grid for decentralized utilization. Thus, it would be possible to supply fueling stations or other applications with delocalized renewable hydrogen. The current work presents a concept of extracting hydrogen from mixtures with natural gas (1-10 vol% hydrogen) and provide this hydrogen in fuel cell quality (purity of 99,97 % according to ISO 146782:2012) for further utilization. The developed concept incorporates a first pre-concentration step applying membrane-based gaspermeation for an energy-efficient enrichment to approx. 40 vol% hydrogen and a drastic mass flow reduction. Subsequently, hydrogen is purified to the desired quality using pressure swing adsorption (PSA) as a second process step. Finally, the gas quality is thoroughly analyzed to verify the compliance for the desired application (i.e. fuel cell in the current work). Both process steps, gaspemeation and PSA, provide enough degrees of freedom to allow for a proper and efficient control of the product gas quality.

To demonstrate the concept a lab-scale gas separation plant is currently built at Vienna University of Technology. The developed process must be highly flexible regarding pressure due to different levels in the Austrian gas grid (lowest level 6 bar, highest level up to 100 bar) and hydrogen content in the natural gas. Therefore, extensive experimental analysis will be performed in order to design an adequate process layout. Experimental investigation of the separation process and the individual steps will be performed with pure gases, synthetic gas mixtures and finally with real gases obtained from a real-world hydrogen injection facility (wind2hydrogen project in Auersthal). Additionally, rigorous and experimentally validated process simulation will be used to characterize and further optimize the developed hydrogen extraction concept towards maximum energy efficiency.

28 | Automatic Localisation of Gas Pipes Thanks to GPR Device

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Introduction

While road works and civil engineering work operate near networkpipes,an inaccurate mapping of pipe networks can cause damages which lead to human and economical damages. In France, 156 damages on gas pipelines have been counted during the 2012 year ([Mdl]). Precise location of buried gas networks in a non-destructive manner becomes primordial for all network system operators. Several technologies have been developed to update maps of subground network or to localize pipes in real time before works which could affect them. In our work, we are interested in using the GPR technology to get the position of the gas pipes. However this device doesn't directly provide a position in the 3 dimensions but an image which offers an high degree of freedom in interpretation of results. Operators need experience to understand this particular image. In order to help the nonexpert users of GPR to detect and find the position of buried pipes, a novel method to automatically localize them in the subground has been developed. This device is equipped with a transmitting and receiving antenna placed some centimeters from soil surface. An electromagnetic wave is sent in the subground and backscattered when it encounters an heterogeneity. The shape of the impulse signal looks like a Ricker wavelet. Then the receiving antenna records the backscattered wave at each position as function of time. On a GPR image (also called B-scan), the response of echoes from a pipe will have an hyperbolic shape. Therefore in order to localize the pipes, we have to detect hyperbolas in the B-scan. The automatic detection of hyperbolas offers several advantages. First of all, it simplifies the interpretation for the user. Indeed, the GPR records a lot of information from the soil which makes reading the B-scans hard for a non-expert operator. The overprint of an hyperbola on the GPR image can help him to better understand the B-scan and to work faster. Then it directly allowsusconvertingthetimescaleindepthscale. Afterscanningthesubground,a3Dpositionisn'tdirectlyobtained but a 2D position according to the position of the GPR and a back and forth time travel of the wave. In order to get a depth scale, we must estimate the wave speed in the soil. This can be done with the shape of the hyperbola. Finally, the users will automatically obtain a 3D position of pipes. Several studies addressed the automatic detection issue in GPR images. Most of them used supervised learning algorithms. Thereby, in the article [MS13] the authors applied the algorithm Viola Jones. Whereas the authors of the articles [Bir10] and [ANHN+00] used Neural Network algorithm. In the article [SBP13], the authors proposed a classification method from an adaptive dictionary of gabor wavelets to compute a sparse decomposition of A-scans coupled with the Suport Vector Machine (SVM) algorithm.

Conclusion

In this work, we proposed a method to automatically detect hyperbolas in B-scan and thus localize pipes in the subground. For this purpose, we chose to use a dictionary of simple theoretical measure of pipes. We used the coefficients obtained with the correlation between a B-scan and the dictionary as feature in input of a supervised learning method split into two steps. Our method helps to separate the blobs from the background and so to get the position of pipes and also the shape of the hyperbolas which allows convert the time scale in a depth scale. In future works, an extension of the study on the dictionary could be done. Others supervised algorithm should also be tested.

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