**ADREM: Benchmarking new modular reactor technologies**

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**Highlights**

* Methane conversion to liquid chemicals in one-step process has been benchmarked.
* Microwave technology replaces thermal methods for benzene with energy savings of 40%.
* C2 mixtures are produced with plasma technology with the minimum environmental impact. (a significant decrease of GHG emissions)
* OCM in gas solid vortex reactor is scalable and outperforms fixed bed reactors.

**1. Introduction**

The aim of the ADREM project is to develop new modular and flexible reactor technologies, that can accommodate different methane-rich sources, such as flared gas, associated gas from oil extraction, or biogas, and valorize it directly to chemicals. Some examples of key candidates that could be used on that concept are flared gas (which for 2017 was approximately 141 bcm), and the biogas that has reached 50 bcm in 2017. The impact of the flared gas to the environment is huge, since only for 2017, approximately 140 bcm were flared, equivalent to approximately 400Mt CO2 and enough to provide the annual gas consumption of Germany and France.

In this work we focused on the integration of new reactor concepts, developed during the ADREM project, in the overall process design and on the evaluation of the feasibility for the technology upscale from an engineering point of view. The aim was modular, flexible units, that can be easily transported to remote locations, or to methane sources with small gas production.

**2. Methods**

Lab-scale results from the ADREM partners were used for the reactor performance evaluation, while for the pretreatment and downstream of the products state-of-the-art was used. Two cases of throughput were considered for the process design: i) associated gas and, ii) biogas. Liquid products (e.g. mixture or low purity products) that are easily transportable to a centralized purification unit were defined as process output. For each chemistry a flow scheme was developed, based on the product and on the reactor’s requirements. The mini-methanol plant (commercially available) was used as a benchmark. The ADREM novel reactor concepts that were evaluated were: i) microwave assisted non-oxidative methane coupling, ii) plasma non-oxidative methane coupling, iii) oxidative coupling of methane (OCM) in gas solid vortex reactor with and, iv) plasma dry reforming. The performance indicators of each concept were the productivity, the total energy consumption and the specific energy consumption of each scenario, the CO2 emissions and the carbon formation rates. Based on these numbers, the two “most promising” reactor concepts were selected for TRL5 demonstration.

**3. Results and discussion**

The process design revealed interesting results for the four different reactor concepts, when considering that electricity is decarbonized. The microwave non-oxidative methane coupling for benzene production showed low energy consumption. Compared to the benchmark case, the energy demand decreased by 40% in the case of associated gas. With respect to the CO2 emissions, there is up to 50% reduction compared to flaring, depending on the throughput. Plasma coupling of methane to C2 mixtures showed operational flexibility, reducing significantly the CO2 emissions. However, the energy requirements when the plasma technology was implemented, were increased two-fold in the best-case scenario (with associated gas as the feedstock) compared to the benchmark case. This reactor concept resulted in a decrease of CO2 emissions by 50-80% compared to direct flaring. Plasma technology in the dry reforming for syngas (and subsequently methanol) production had a similar performance; the energy requirements of the plasma technology were on the high side, with a four-fold increase compared to the benchmark case, while the CO2 emissions had a tremendous reduction of 70%. Finally, the gas solid vortex reactor had quite a unique setup, easily scalable, compact and yet able to handle large throughput, with relatively low energy consumption. In this concept, the energy requirements of the entire process were comparable to the benchmark case, with a 10% energy savings when associated gas was used. In this reactor concept, CO2 emissions were reduced between 20-40% compared to direct flaring. Based on the comparison of the performance indicators, the microwave assisted methane coupling and the plasma coupling were selected for TRL5 demonstration.

**4. Conclusions**

The present work shows the potential of the ADREM new reactor technologies on the integrated overall process scheme. This work gives more insights on the modular and flexible reactor technology that can accommodate methane-rich sources and convert them to a liquid product. For all the evaluated reactor technologies, the CO2 emission profile was low compared to flaring, while some of them showed competitive energy requirements compared to the conventional thermal methods.

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