3D-CFD simulation of catalytic filter candles for particulate abatement and tar and methane steam reforming inside the freeboard of a gasifier

Elisa Savuto[1]*, Andrea Di Carlo[2], Katia Gallucci[2], Domenico Borello[3], Sergio Rapagnà[4]

1 Tuscia University, Via S. M. in Gradi 4, Viterbo, Italy; 2 University of L'Aquila, Via Campo di Pile, L'Aquila, Italy; 3 Sapienza University of Rome, Via Eudossiana 18, Rome, Italy; 4 University of Teramo, Via R. Balzarini 1, 64100 Teramo, Italy

**Corresponding author: savuto@unitus.it; elisa.savuto@gmail.com*

Highlights

- A 3D-CFD model of catalytic filters inside the freeboard of a gasifier was developed
- The model was validated with experimental data collected in a bench scale gasifier
- Simulations of tar and methane steam reforming through the filters were carried out
- The influence of the main process parameters on the efficiency of the filters was studied

1. Introduction

Biomass gasification is a very promising process to produce energy from agricultural waste, but tar and particulate have to be removed in order to make the gas exploitable. Catalytic filter candles are an innovative solution for hot gas cleaning&conditioning: these components, inserted in the freeboard of a fluidized bed gasifier, allow the removal of particulate by means of their porous filtering structure, and furthermore act as catalyst thanks to their Ni active phase content. A 2D-CFD model of a catalytic candle in the freeboard of a gasifier has been previously developed and used for simulations of the candle activity at different operating conditions [1]. In this work a 3D-CFD model has been developed, reproducing 6 ceramic catalytic filters inserted in the freeboard of a pilot scale steam gasifier (100 kWth as biomass input), to verify their behavior in the conversion of tar in a real case application.

2. Methods

The gasification reactor reproduced in the model is a dual bubbling fluidized bed, consisting in an internal cylindrical combustion reactor, surrounded by the steam gasification reactor. In the gasification reactor six catalytic candles (6 cm O.D., 1.5 m length) are placed, for the filtration and conditioning of the syngas generated. The gasification reactor is surrounded by ceramic blanket as insulation material.

The 3D-CFD model was developed with the FLUENT software. The symmetrical control volume, represented in **Figure 1 a)**, is half of the cylindrical reactor. More details about the characteristics of the catalytic ceramic candles can be found in [2]. The chemical species considered are H_2, CO, CO_2, CH_4, H_2O, and benzene (C_6H_6), toluene (C_7H_8) and naphthalene ($C_{10}H_8$), as representatives of the tar mixture. The reaction rates given by Depner and Jess [3] and Li [4] are used for the steam reforming of benzene, naphthalene and toluene respectively. For the conversion of methane and the water gas shift reaction, the model of Xu and Froment [5] was used.

3. Results and discussion

The model was validated with experimental values obtained in a bench scale gasifier equipped with a catalytic candle in its freeboard. The reaction rates were tuned by the use of correction factors in order to calibrate the model with the experimental values.

Errore. L'origine riferimento non è stata trovata. **b)** shows the temperature profile in the control volume. The catalytic candles are in a temperature range of 930 – 1080 K; in particular the portion of the candles closer to the internal cylinder are characterized by a higher temperature, probably due to the heat exchange from the combustion to the gasification reactor. Simulations of steam reforming through the catalytic candles have been carried out using, as input, the gas composition and tar content obtained for steam gasification, at 800°C and SB = 0.5.

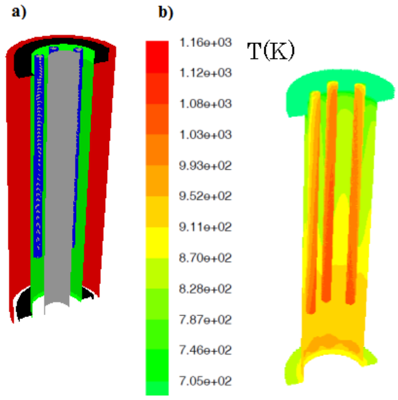

Figure 1. - a) Control volume of the 3D-CFD model; b) Temperature profile on the control volume

The conversion rates of tar compounds are displayed in **Figure 2** and residual content after the catalytic filters is reported in **Table** 3.

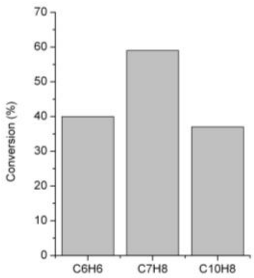

Figure 2 – Tar conversion rates

	g/Nm^3
C_6H_6	6.6
C_7H_8	3.3
$C_{10}H_8$	2.9

Table 1 – Residual tar content

The diagrams show that the tar conversions are consistent even if not complete, the H_2 content in the syngas increased of 11% indeed. Toluene had a higher conversion compared to benzene and naphthalene, but their residual concentration is still too high. The low efficiency of the catalytic candles in the tar removal is due to their low temperature; as shown in **Figure 1 b)**, the average temperature of the filters is around 730°C, which is definitely lower than the optimal temperature for tar steam reforming.

4. Conclusions

A 3D-CFD model of a freeboard equipped with catalytic candles was developed and validated. The simulations carried out with the model showed that there is a consistent temperature drop along the height of the freeboard (due to thermal dispersions), which is probably the cause of the low temperature of the filter candles and the low conversion of tar. The model allowed to identify this issue, that could be solved by increasing the temperature in the upper part of the freeboard by means of small oxygen/air injections; further studies will focus on the simulation of this configuration with the CFD model.

References

[1] E. Savuto, A. Di Carlo, E. Bocci, A. D'Orazio, M. Villarini, M. Carlini, and P. U. Foscolo, "Development of a CFD model for the simulation of tar and methane steam reforming through a ceramic catalytic filter," *Int. J. Hydrogen Energy*, vol. 40, no. 25, pp. 7991–8004, 2015.

[2] S. Rapagnà, K. Gallucci, and P. U. Foscolo, "Olivine, dolomite and ceramic filters in one vessel to produce clean gas from biomass," *Waste Manag.*, 2017.

[3] H. Depner and a. Jess, "Kinetics of nickel-catalyzed purification of tarry fuel gases from gasification and pyrolysis of solid fuels," *Fuel*, vol. 78, no. 12, pp. 1369–1377, Oct. 1999.

[4] C. Li, D. Hirabayashi, and K. Suzuki, "Development of new nickel based catalyst for biomass tar steam reforming producing H< sub> 2</sub>-rich syngas," *Fuel Process. Technol.*, vol. 90, no. 6, pp. 790–796, 2009.

[5] J. Xu and G. F. Froment, "Methane steam reforming, methanation and water-gas shift: I. Intrinsic kinetics," *AIChE J.*, vol. 35, no. 1, pp. 88–96, 1989.

Keywords
Catalytic candles, CFD model, tar conversion, steam reforming.