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# Moving bed syngas conditioning: Modelling

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## HIGHLIGHTS

- A 2D, 2 phase, adiabatic, steady-state model for simulating tars and dust removal is proposed.
- The MBHEF has been proven as feasible for syngas conditioning in end-use syngas applications.
- Tars removal efficiencies of 88–94% can be achieved in compact size equipment.
- Low gas velocities (0.5–1 m/s) and high particle size (400–700 μm) are the most suitable operating conditions.

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## ABSTRACT

This paper presents a modelling approach for simulating tars and particulate (dust) removal in a moving bed heat exchange filter (MBHEF) in order to satisfy gas requirements of end-use syngas applications: engines and turbines. The two-dimension, adiabatic, steady-state proposed model accounts for two-phase (gas and solid) and neglects conduction and mass diffusion. Tars condensation is modelled through representative tar class lumps: phenol (class 2), naphthalene (class 4), pyrene (class 5). The model also considers tar concentration influence on the tar dew point. The filtration model is taken from literature. A sensitivity analysis is performed varying the particle size and the superficial gas velocity. Maps of temperature and tars abatement efficiency are presented. The simulation results indicate the feasibility of the use a MBHEF as tars removal equipment benefiting its advantages against others gas-cleaning methods with acceptable pollutant removal efficiencies, ranging 88–94% for ranges studied. Results also point out low gas velocities (0.5-1 m/s) and high particle size (400–700 μm) for reducing operational costs in MBHEFs with compact size.



## 1. Introduction

From some time past, there is an increasing concern about global warming and its effects due to Green House Gas (GHG) emissions of anthropologic origin since fossil fuels are still the dominant source of global primary energy supply [1]. Then, much effort has been addressed in research and development of less polluting fuel-to-energy processes such biomass conversion technologies [2], sustainable renewable energy systems such as solar-based, ground source-based and day-lighting [3] and solar energy, wind energy and bioenergy [4], methods and tools to evaluate the availability of renewable energy sources [5] and investigation of $CO_2$ capture and storage techniques [6,7]. Additionally, in the present days, there seems still to be a long way to improve the efficiency of every step in power production process.

In the way to improve process efficiency and lower pollutant emissions many attention is focused on biomass gasification (BG). The interest in biomass as fuel mainly lays in the very low net GHG emissions compared to others fuels when it is processed by some thermal technology conversion [8]. Among all existing conversion routes, biomass gasification in fluidized beds (BGFB's) has been proven as a feasible and eco-friendly fuel-to-energy thermal conversion method [2]. However, this type of fuel conversion presents several drawbacks. One of the most important disadvantages of BGFB's is the unacceptable tar content in the raw syngas for power production in internal combustion engines, combined cycle gas turbine, fuel cells, chemical synthesis, etc [9]. The tar problem in BG underlie in its physical properties: a low dew point yielding the condensation of sticky and refractory slurries that can lead to operational problems as blockage and attrition in filters, heat exchangers, exit pipes, etc [10]. Thus, tar removal is key for a successful application of biomass-derived producer gas though is still a challenge that has to be solved [11].

Gas cleaning systems for conditioning syngas produced by BG reactors have been extensively studied and reviewed along the

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time since gas quality requirements for different gas application changes with the technology development and improvement [9]. As for example, the NREL of Colorado [9] and the ECN Institution [12] have reviewed the state-of-the-art of tar removal technologies. The current work proposes the use of a Moving Bed Heat Exchanger Filter (MBHEF) as hot gas clean-up system for removing tar and particulate material. The choice of a MBHEF as hot gas cleaning equipment is justified by: the possibility of operating at high temperatures (up to 700–800 °C, the exhaust gas temperature from the gasifier) in contrast to problems presented by others devices such as ceramic filters over 400 °C [13], no-clogging and non-pressure increase during operation [14]. All these advantages offered by the MBHEF system would avoid shut-down and its associated costs in comparison with traditional hot gas clean-up devices.

To date, MBHEF's have been studied because of offering particular advantages when cleaning hot gas exhaust from reactors such BFBG's in contrast to traditional equipment: ceramic filters, scrubbers, electrostatic precipitators or bag filters in order to remove particulate material. This paper is aimed at evaluating the use of a MBHEF for conditioning syngas from BG processes in order to give a usable gas for power production applications. The purpose of the model proposed is to provide a predictive tool for simulating such steady MBHEF operation and to give tars and particles reduction level maps. The MBHEF will be optimised [15] in order to improve the tars and particulate removal efficiency ($\eta_{tars}$ and $\eta_{dust}$ respectively) as well as the heat transfer and pressure drop.

Finally, concerning the particulate removal, the optimisation of MBHEF study focuses on the tar removal point of view since very high particle collection efficiencies can be easily achieved in comparison to tar reduction levels [16].

### 1.1. Gas quality requirements

The performance, investment and operational costs of a hot gas cleaning system depend on the syngas quality demanded and the reactor performance whereas the quality of the gas produced is determined by the end-use of the gas. The need of tar and particulate removal depends basically on the syngas application. For instance, the acceptable limit of tar concentration in a syngas for engine applications varies according to the author [9]. In this study, the limits adopted were those proposed by Refs. [9,17,18] (Table 1).

The tars nature, but not the tars concentration, is key for successful assessment of the suitability of syngas end-use as Gómez-Barea and Leckner [19] reported, since it has been demonstrated that gas containing 100 mg/Nm$^3$ of tars with a dew point of 70 °C causes mechanical problems in engines but a gas with 5000 mg/Nm$^3$ of tars and a dew point of 20 °C has been used without engines problems. Here, for the sake of simplicity, the tar removal analysis is conducted from a concentration point of view, not exclusively focused on the tar nature. Furthermore, gas derived from biomass and wastes contain others pollutant species such as sulphur compounds, alkaline metals and dust. All these contaminants can be removed by means of conventional devices downstream of the gasifier before condensing tars. Thus, tar conversion is of interest since it increases the heating value of syngas. For instance, the low heating value (LHV) of tars is estimated to be around 26–40 MJ/kg [20].

**Table 1**
Fuel requirements for internal combustion engines and gas turbines [9,17,18].

| Contaminant | Allowable concentration | |
|---|---|---|
| | IC engine | Gas turbine |
| Tar (mg/Nm$^3$) | <50 | <5 |
| Particles (mg/Nm$^3$) | <50 | <30 |
| Particle size (μm) | <10 | <5 |

## 2. Tar removal methods review

To accomplish the objectives of tar removal, tars behaviour in reactors should be understood. This involves knowing tars nature and its formation mechanisms (out of the scope of this paper). As follows, tar removal technologies are briefly presented, pointing out their main strong and weak points. Finally, the MBHEF is chosen as technology solution for tar elimination in order to give syngas with tars content levels acceptable for end-use applications: gas turbines (GT's) and internal combustion engines (ICE's).

### 2.1. Tar definition

Milne and Evans [9] and Li and Suzuki [10] have reviewed tars issues related to cracking, removal, definition and its characterization. Tars or tar fraction in biomass, representing up to half of primary pyrolysis products from devolatilization, is a very complex mixture of chemical species with a heavier molecular weight than permanent gases and the so-called $C_2$ and $C_3$ fraction. Tars comprise a broad range of chemical species tending to be refractory and difficult of being removed by means of thermal, catalytic and physical processes. This fraction of condensable hydrocarbons includes from single ring compounds as benzene to 5-ring aromatic compounds with others oxygenated compounds and polycyclic aromatic hydrocarbons (PAH).

The importance of tar class concentration and even tar lumping when estimating the temperature at which tars condensation can take place has been recently evidenced [21]. Tars behaviour has a great impact in the right design of devices managing gases with non-negligible tar content. Thus, this property is a useful and valuable parameter to design tar removal equipment and choose operating conditions of reactors for producing syngas.

### 2.2. Tar removal methods

The tar removal technologies can be sort out in two categories: primary and secondary methods depending on the location in the BGFB process where tars are removed [22].

Primary methods are addressed to prevent or convert tar formed inside the gasifier so that these types of technologies would save the use of secondary methods downstream. Three types of measures can be taken as primary methods: the proper design of reactor [11], the right selection of operating: use and location of secondary air, equivalence ratio and biomass moisture [23]; steam and $N_2$ (pyrolysis) as gasifying agents [24]; co-gasification of high moisture woodchips and shredded rubber waste [25] and the use of proper bed additives/catalysts during gasification: silica sand, calcined limestone, combination of calcined limestone and calcined waste [24]; inert quartzite, olivine, dolomite, Ni–alumina [26]; silica sand, alumina, alumina impregnated with nickel [27].

On the other hand, secondary methods are aimed to treat the hot gas after the gasifier. They consist of chemical or physical treatment: thermal or catalytic cracking and mechanical methods such as use of electrostatic filters, ceramic filters, fabric filters, scrubbers and rotating particle separators.

In spite of the existence of a wide variety of tar removal technologies, not all of them are suitable from an economic point of view. Although secondary methods have been proven and shown as efficient, new trends address to the investigation of primary methods. In fact, recent works are focused on the development and the optimisation of primary tar technologies. These works