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Recent developments in dry hot syngas cleaning processes

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ABSTRACT

The dry hot syngas cleaning process appears to be potentially more efficient and cleaner than the proven wet cleaning or semi-wet cleaning processes but it is still far from commercialisation. There are several technological barriers responsible such as poor availability factor, degeneration of sorbent and several stages of separation. This paper summarises the reported current status of dry hot cleaning of syngas from coal gasification processes along with the shortcomings of reporting of dry hot syngas cleaning performance results. The paper also proposes and discusses a rational method of performance reporting, a novel pulse less filtration concept and a system to prevent failure of filter elements.

1. Introduction

The reliability and efficiency of dry hot syngas cleaning processes could be considered as the most important factors for the success of coal gasification based zero emission power generation and fuel production technologies. Conventional wet gas cleaning is a proven technology with an almost 100% availability factor but is thermally inefficient and produces waste water sludge, an environmental nuisance [1]. Dry hot gas cleaning, on the other hand, has a potential to be very efficient, clean and reliable although the performance of sorbents and particulate filters has yet to be proven at higher temperatures especially above 400 °C [2–5]. A rigorous examination of published literature reveals that some of the results are also presented with incomplete background information that may be essential to enable the evaluation of the actual performance of filter and sorbent. For instance, many of the performance results for filters do not describe whether the same component has been used continuously over thousands of hours of operation or whether the total number of operating hours achieved is the cumulative sum of several short campaigns, shut downs and element replacement. The assessment of availability factors on the basis of this information could be misleading to technology purchasers and delay the focus of research providers on the key issues. This paper provides information on filter performance and presents a method for rational reporting. Some novel concepts to further improve the existing dry hot gas cleaning process are also presented.

2. Current shortcoming with reporting of filter performance

An acceptable availability factor of >95% for a commercial power plant requires a reliable gas cleaning process. At present a number of demonstration scale syngas cleaning systems are operational [6–9] with an objective to test and improve the performance of various components. The quality of syngas and levels of impurities significantly varies depending on type of fuel, gasifier and oxidant used [10,6,8]. Therefore a proven component for a gas cleaning process with one quality of syngas from a particular type of gasifier and fuel may not perform equally well with another type of gasifier and fuel. Therefore the maximum operating period or availability of any component are valid only for the conditions of its exposure. Any performance data without detailed *operational background variables* (OBV) such as (1) composition of all impurities and fuels, (2) annual maintenance schedule, (3) component replacement record, (4) period and number of campaigns etc., could be misleading if used as a basis for performance evaluation, design and scale up of the gas cleaning process. Although qualitative illustrations of some of these conditions have been included in some of the publication [6,8], there is no systematic method to quantify these variables and the performance of the filters. As shown in Table 1, different types of filters have been tested in different environments (*operational background variables*) and their performance could not be compared or used for different applications. There is no method to normalise the *operational background variables* to draw a comparison and rate the filters according to their performance. For example, Table 1 shows that a variety of filter elements have been tested in a coal-derived syngas at 400 °C, 1.5 MPa at the Power Systems Development Facility (PSDF), USA [3] for over 2700 h and the iron aluminide filter has achieved over 8547 h [11]. This is an extensive database of test work but

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Table 1
Current reported status of particulate filter performance.

Operating variables	Filters					
	Various[a]	Ceramic and metal[b]	Asahi glass CTF	Schumacher ceramic filter	Dia-Schumalith	Reinforced calcium silicate
Filter compositions	SiC, FeAl	Monolithic & composite ceramic, FeAl haymes	–	–	–	–
Technology	Gasification, EERC, USA	Gasification, PSDF	PFBC	IGCC, Buggenum	Waste incineration	Industrial exhaust
Operating conditions	–	–	Oxidising	–	–	–
Temperature (°C)	540–650	399	650–850	250–285	400–550	>350
Pressure (MPa)	1.0	Stable ΔP	$\Delta P = 0.0029-0.0039$	2.6	$\Delta P = 0.0027$	$\Delta P = 2.5$
Face velocity (m/min)	0.76–1.37	~1.06	–	–	1–1.4	–
Reverse pulse pressure	1.7–2.38 MPa (N_2)	–	1.5 MPa + operating pressure	–	0.05–0.1 MPa + operating pressure	–
Particulate loading (ppm)	4500–45,000	4000–10,000 <0.1 at filter exist	–	1000–5000	–	–
Particle size (μm)	7–22	>100 (pipe debris)	–	–	–	–
Separation efficiency (%)	–	99.999	–	–	99.9 for particles <1 μm	–
Operating period (h)	1800	2700 (other) 8547 (Fe_3Al)	8000	2675	–	–
Reference	[1]	[2,10]	[3]	[4]	[5]	[6]

EERC = Energy Environment & Research Centre (gasifier tested in transport reactor development unit (TRDU)).
[a] Industrial Filter & Pump (IF&P), Fibrosic and REECER™ candles, silicon carbon fibre and silicon oxide ceramic fibre candles from 3 M company, sintered metal (iron aluminide) and vitropore silicon carbide ceramic candles from Pall, advanced separation systems corporation ceramic fibre filter from both Mc Dermott and DuPont Lanaxide, granular SiC candles from US Filter/Schumacher, candle filter failsafe from westinghouse science and technology centre
[b] Monolithic ceramic, composite ceramic with iron aluminide and haynes fail safes.

quantitative information about the *operational background variables* is not presented.

Over 29,000 h operation of Dia-Schumalith F40 and 10–20 filters at Nuon Power in Buggenum has been reported [4,8] but this also seems to exclude the *operational background variables*. The particulate filters used in the IGCC plant at Buggenum appears to be exposed to less severe condition [12] and therefore filter performance could not be compared with the conditions at PSDF.

Similarly the performance results of several hundred hours of operation with syngas from the Transport Reactor Development Unit (TRDU) at the Energy & Environment Research Centre (EERC), does not present the detailed operational information [2].

It is also likely that in these publications, the detailed operational information might have been curtailed due to the space constraints; however these operational background variables could be presented in the form of a set of parameters associated with the performance of the filter.

3. Proposed rational rating of filter performance

Rational rating of candle filters may need the following detailed operating variables for the full operating period: (1) Filter material, gasifier design, fuel composition and oxidation media; (2) Record of temperature, pressure, flow and concentration of syngas impurities; (3) Filtration face velocity, number and length of filter elements; (4) Start-up and shut down schedules; (5) Annual operating pattern including continuous operating period, shut down period, number of campaigns; (6) History of each filter element or each group of filter elements, i.e. record time and date of installation and replacement of each filter element or each group of filter elements; (7) Reasons for filter shut down and replacement of filter elements; (8) Cumulative total operating period.

All this information is required to determine: (1) the number of filter elements that survived the full operating period every year, (2) the period of continuous exposure of filters in a single non stop run, (3) the cumulative exposure period, and (4) the extent of exposure to heating–cooling cycles resulting from start-up and shut down. On the basis of these variables the following parameters could be derived for rational reporting and comparison of the performance of any type of filter in any environment.

Filter Survival Factor (f_{sf}) for a given type of filter, vessel size, gas quality, gas flow rate, operating temperature and pressure could be defined as:

$$f_s = \frac{a_{fi} - a_{fr}}{a_{fc}} \quad (1)$$

Where, a_{fi} is the filtration area initially installed, a_{fr} is the filtration area replaced at least once any time during the test, and a_{fc} is the total filtration area currently available In the case where the new filters have same geometric shape and size, $a_{fi} = a_{fc}$. The filter survival factor could also be expressed as a fraction or% of filter media survived or successful.

Another important factor could be the maximum exposure period ($E_{\max}$) of filter elements during an operation

$$E_{\max} = f_s t \quad (2)$$

where, t is the total operating period in hours between the installation of the filter elements and the last shut down. The availability factor (f_a) of the filter will be expressed as:

$$f_a = \frac{E_{\max}}{8760} \quad (3)$$

The availability factor of the filter also depends on the operating condition therefore comparing the availability factor without considering the influence of the operating conditions may not be considered as a rational comparison. Some description of relative severities of the operating conditions along with the availability factors would be a logical way to compare the performance of different filter media exposed to different conditions. Besides operating temperature and pressure, the following factors could be used to approximately describe the relative severity of the operating conditions.

Intensity of exposure with respect to a syngas impurity could be defined as a relative cumulative exposure to that impurity in a year