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Design and Development of Sand Bed Filter for Upgrading Producer Gas to IC Engine Quality Fuel

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Abstract *- Engine quality producer gas must be almost free of solid particulate matters (SPM) and organic contaminants (Tar) to minimize engine wear and maintenance. Except for the catalytic tar crackers, none of the gas cleaning systems commercially available can securely meet a tar removal exceeding 90 % and hence new concepts for tar removal are required. This paper presents a design and development work of sand filter for upgrading producer gas to IC engine quality fuel. The developed sand filter was tested for its performance with SPRERI'S 20* kW_e *down draft circular throat type gasifier with engine set up. The experimental investigations show that the percentage reduction in tar and particulate matters is above 90 %. The total amount of tar and particulate matters was 319* $mg\ N^{-1}m^{-3}$ *and* $53 mg\ N^{-1}m^{-3}$ *before and after filter respectively.*

Keywords **- IC engine application, Producer gas cleaning, Regenerative sand bed filter, Tar and particulate matters.**

1. INTRODUCTION

The present study was carried out under quality improvement programme of thermo-chemical conversion division of SPRERI. The organics produced under thermal or partial-oxidation regimes (gasification) of any organic material are called tar and are generally assumed to be largely aromatic [1]. The producer gas must be free from tar and particulate matters and it should be cooled up to the ambient temperature for IC engine application.

The gas quality requirement for the power generators is very strict. However, the postulated gas quality given in the literature should be interpreted carefully as it depends on the type of engine used and the methods of contaminant sampling and analysis procedures used during experiment. Gas cleaning systems are expected to reduce particles and tar content from the raw producer gas to the postulated levels. Typical values of particulates and tar content are given in Table 1 [1]. Table shows that the amount of tar is much higher in countercurrent than cocurrent gasifiers. Therefore in the present investigation cocurrent throat type gasifier with IC engine for power generation was used to evaluate newly developed sand filter. Gas quality requirements for the power generation are very strict (*see* Table 2)[1]. Numerous methods of contaminant sampling and analysis procedures are in use, which may lead to results, which are not strictly comparable. Large differences can be expected, especially, for the sampling and analysis of tar. In the present study, the field type tar and particulate sampling unit designed by IIT Bombay was used for filter evaluation.

Table 1. Gas quality of raw producer gas from atmospheric air blown biomass gasifier [1]

	Fixed bed cocurrent gasifier	Fixed bed countercurrent gasifier	CFB gasifier
Particles, $mg\ N^{-1}m^{-3}$	100 - 8000	100 - 3000	8000 – 100,000
Tar, $mg\ N^{-1}m^{-3}$	10 - 6000	10,000 – 150,000	2000 – 30,000

Note: Some tar values are indicative since definitions are not specified

Table 2. Gas quality requirements for power generators [1]

	IC engine	Gas turbine
Particles, $mg\ N^{-1}m^{-3}$	< 50	< 30
Particle size, µm	< 10	< 5
Tar, $mg\ N^{-1}m^{-3}$	< 100	
Alkali metals, $mg\ N^{-1}m^{-3}$		0.24

Mukunda et al. developed sand bed filter to remove the particulates collected by the cooling water in spray tower. The filter is separated in to coarse and fine sections. The coarse filter is filled with sand of 0.5 – 2 mm size particles and the fine sand bed filled with 0.2 – 0.6 mm size sand. The size of the filter area is so chosen that the gas velocities through the filter bed do not exceed 0.1 $m\ s^{-1}$. This low velocity coupled with the tortuous path causes the removal of a large part of the dust from the gas. The results indicated that the hot-end tar is about 100 $mg\ m^{-3}$ and comes down to 20 +/- 10 $mg\ m^{-3}$ at the end of the fine filter (cold end). The particulates level also comes down to 50 $mg\ m^{-3}$ at the cold end from about 700 $mg\ m^{-3}$ at the hot end [2]. Hasler et al. showed that a 90% particle removal is easier than a 90% tar removal. Based on experimental data for the removal of particles and tar, none of the investigated gas cleaning systems can safely meet the gas quality requirements for

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satisfactory IC engine applications. The sand bed filter and wash tower have already been successfully tested in fixed bed biomass gasifier coupled to IC engines. The results show that particle collection is less critical than tar separation. The highest particle separation efficiency was observed in sand bed filters, rotational atomizers and in wet electrostatics precipitators (ESP). The highest tar reduction was also found in high temperature catalytic tar crackers, in venturi scrubbers and in sand bed filters. [3]. The gas quality for successful IC engine operation has been postulated as below 50 $mg\ N^{-1}m^{-3}$ for the particle and less than 100 $mg\ N^{-1}m^{-3}$ for the tar [4]. Wet packed bed scrubber, spray towers or venturi scrubbers are often used for tar and particulates removal from producer gas. These commercialized cleaning devices make use of water for gas cleaning and cooling. For large-scale gasifier systems, water requirement would be in huge amount. In addition, there are several environmental regulations restricting disposal of polluted wastewater in the environment. The tar is present in vapor form at the gasifier exit where the temperature of the producer gas ranges from 350 ºC to 450 ºC. But as the gas cools to less than 150 ºC, the tar condenses and solidifies. For IC Engine application, the gas needs to be cooled to around 40 ºC i.e. ambient temperature. As stated earlier cooling of producer gas to this temperature will condense tar which affect the engine operation [5]. The aim of the present work is to design, develop and evaluate performance of sand bed filter.

2. EXPERIMENTAL METHODS

Design of Sand Bed Filter

The design philosophy behind the sand filter is as follows:

1. The sand is neutral and non-reactive material.
2. It is inexpensive and easily available.
3. It is easily available in different grain size grades.
4. It can withstand high gas temperature
5. It is easy to clean and recycle i.e. regenerative material.

The sand bed filter was designed, developed and tested with the existing 20 kW_e down draft throat type gasifier with IC engine set up for power generation. The area of sand bed filter was designed for superficial velocity of 0.1 m s^{-1} [2] and gas flow rate of 60 Nm^3h^{-1} i.e. the designed flow rate of the gasifier**.** The sand bed filter rectangular was fabricated from 3 mm thick mild steel sheet and wire meshes fabricated from stainless steel 304 were used to separate filter bed.

SPRERI had conducted an experimental study on effect of bed height on pressure drop across the bed on dry packed bed filter. Experimental investigations suggest a liner relationship between bed height and the pressure drop across the bed. This in turn, increases power consumption of the blower. Literature and our experience shows that most of the gas contaminants (SPM and tar) were deposited in the initial 20 to 30 mm layers of bed height. Therefore, to be on safe side the bed height of each bed in the present filter was taken as 85 mm.

The filter consists of following five compartments:

First compartment : Raw producer gas collection
Second compartment : Sun dried wood shaves
Third compartment : Φ 0.60 mm coarse sand
Fourth compartment : Φ 0.15 - Φ 0.35 mm fine sand
Fifth compartment : Clean producer gas collection

The second, third and fourth compartment were filled with wood shaves, coarse sand and fine sand respectively and each bed having bed height of 85 mm. The sun dried wood shave was used to remove the moisture from the producer gas. The coarse sand was used to remove coarse particulates and tar while the fine sand was used to remove fine particulates and tar. Wire meshes having size equivalent to that of respective sand size was used to separate the beds. The three beds of wood shaves, coarse sand and fine sand can be removed by opening flange provided at the bottom of the filter. The filter has facility to measure pressure drop at each bed and also across the filter. Two sampling port were also provided on the top of the filter in the raw gas collector and clean gas collector for measurement of tar and particulate in raw and clean gas. The schematic diagram of the regenerative sand bed filter is shown in Fig. 1.

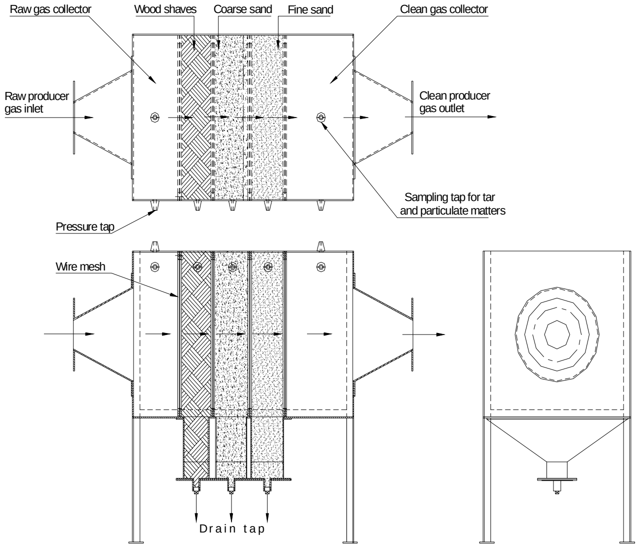

Fig. 1. Schematic diagram of regenerative sand bed filter to clean producer gas.

Fig. 2. Comparative photographic view of wood shaves, coarse sand and fine sand before and after test.

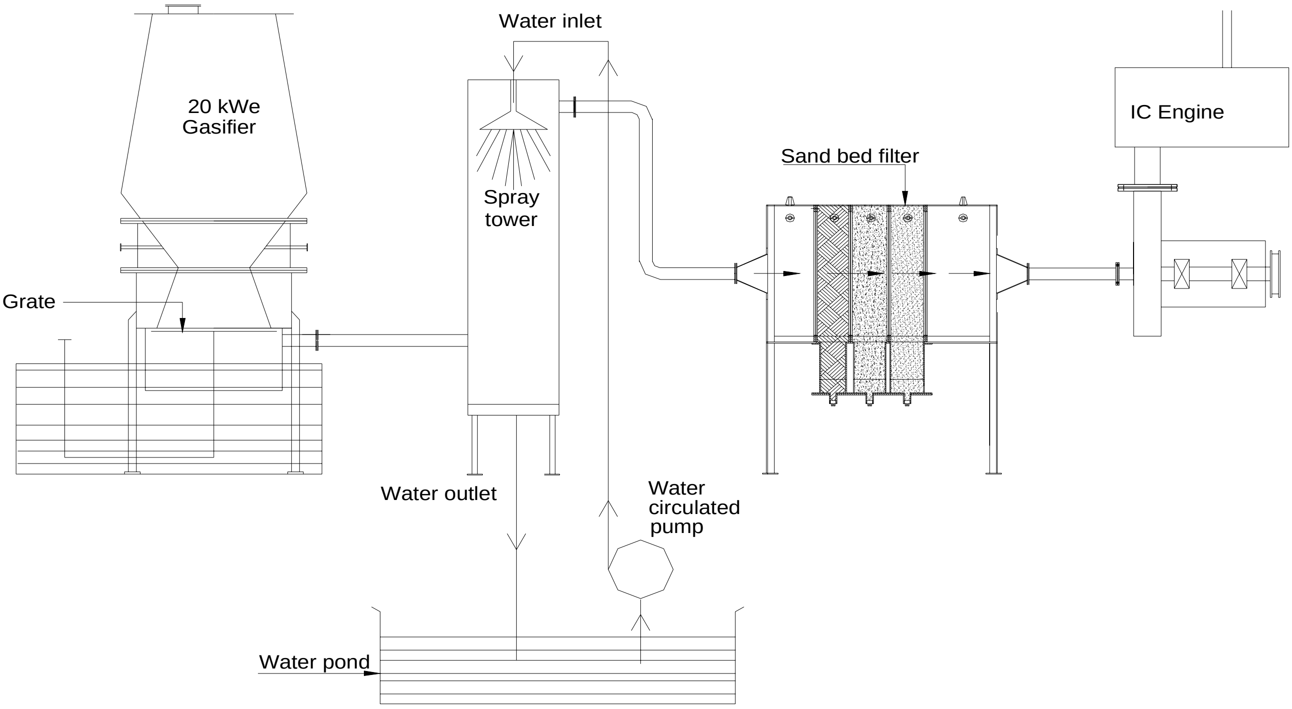

Fig. 3. Schematic diagram of experimental setup of the sand bed filter.

The properties of sun dried wood shaves, coarse and fine sand were measured at thermo-chemical conversion laboratory of SPRERI. The density of wood shaves was 68 kg m^{-3} at 9.5 moisture content (w.b.). The density and void fraction of fine sand (ϕ 0.15 – 0.35 ìm) is 1399 kg m^{-3} and 43 % respectively. The density and void fraction of coarse sand (ϕ 0.6 ìm) is 1450 kg m^{-3} and 46 % respectively. The comparative photographic view of wood shaves, coarse sand and fine sand before and after test is shown in Fig. 2.

Experimental Setup

The instrumented experimental set up was developed to evaluate the performance of the filter in terms of tar and particulates removal efficiency. The schematic diagram of the experimental set up is shown in Fig. 3. The experimental set up consists of 20 kW$_e$ down draft gasifier, spray tower, sand bed filter and IC engine. The details of gasifier and spray tower were the same as described in Patel et al [6].

System Operation and Measurements

The gasifier was charged with charcoal up to the nozzles and then with woody biomass, is ignited by starting blower and using lighting torch at the ignition port. After 15 minutes a good quality of producer gas is generated which is flared at the burner. Then the producer gas was introduced to IC engine through the sand filter. The gas flow rate of producer gas of 60 Nm^{3}h^{-1} was maintained constant throughout the experimental investigations. The performance of the sand filter was evaluated by measuring the following parameters.

1. Tar and particulate matters
2. Producer gas temperature at inlet and outlet of the filter.
3. Pressure drop across the filter.
4. Water temperature at inlet and outlet of spray tower.

Chromel-Alumel (K type) thermocouples and a digital multichannel temperature indicator were used to measure various temperatures. Water-filled U tube manometers were used to measure the pressure drop across the filter and at the orifice meter. The field type tar and particulates measurement set up was used to measure tar and particulates of raw and clean producer gas. This unit measures total tar and particulate (TTP) contents of producer gas. It has the piston cylinder assembly, Non-return suction valve, and filter – paper holder assembly, stroke counter and pedal and base. A Whatman glass micro fiber filter, grade: GF/C cat. No 1822 047 having 47 mm diameter was used in the field type tar sampler.

3. RESULTS AND DISCUSSIONS

The system was extensively tested to evaluate filter performance. The performance parameters like pressure drop across the filter, temperature of the producer gas at the inlet and outlet of the filter and inlet and outlet temperature of the spray tower, tar and particulate matters in the producer gas before and after the filter were measured. The readings were taken at an interval of 15 minutes. The experimental results of tar and particulate matters measured by using field type tar sampler are shown in Table 3. Table 3 shows that the cleaning efficiency of the sand filter obtained in the range of 83 – 97 %. Table 3-shows significant reduction in collection efficiency with time because the filter area was reduced due to deposition of tar and particulate in the filter media. To avoid this problem water shower can be provided on the top of each bed and collect the contaminated water from the bottom of the filter, which continuously removes the tar and particulates from the filter media.

Table 3. Tar and particulate matters measurement using field type tar sampler

Sr. No.	Time	Sampling	No. of Stroke	Weight of Filter Paper, mg					Tar and Particulate		Cleaning Efficiency, %
				Final Before Drying A	Final After Drying B	Initial C	Diff. A-C	Diff. B-C	Before Drying, mg/m^3	After Drying, mg/m^3	
1	3.00 PM	Filter Inlet	40	0.185	0.123	0.094	0.091	0.029	4840	1542	97
2	3.00 PM	Filter Outlet	40	0.096	0.095	0.094	0.002	0.001	106	53	----
3	4.15 PM	Filter Inlet	40	0.109	0.100	0.094	0.015	0.006	798	319	83
4	4.15 PM	Filter Outlet	40	0.096	0.095	0.094	0.002	0.001	106	53	----

However, this techniques leads to another two problems first, requirement of large quantity of water and second, disposal of contaminated water to the environment.

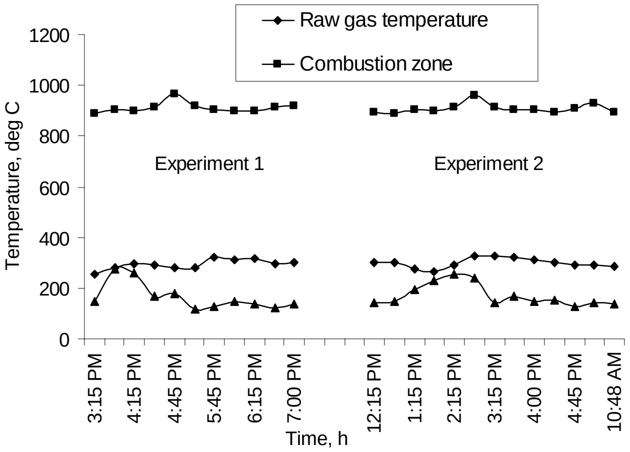

Fig. 4. Variation of raw gas temperature, combustion zone temperature and drying zone temperature with time.

Figure 4 shows the variation of raw gas temperature, combustion zone temperature and drying zone temperature of 20 kW$_e$ down draft gasifier with time, which shows that the variation of temperature is almost constant, which indicates the steady and smooth operation of gasifier.

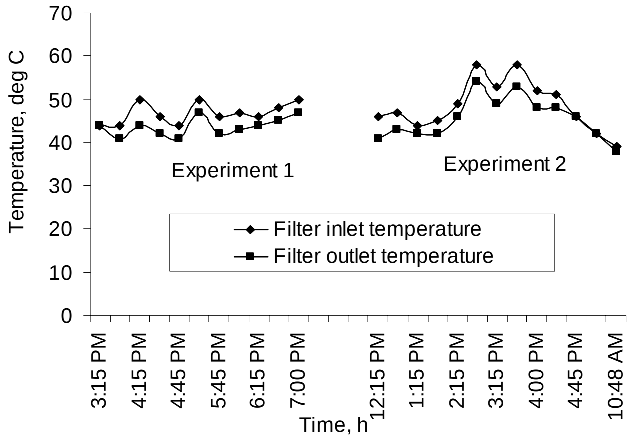

Fig. 5. Variation of gas temperature at inlet and outlet of filter with time.

Figure 5 shows the variation of gas temperature at filter inlet and outlet with time. It is observed that the slight variation in the gas temperature at filter inlet and outlet which is due to variation in raw gas temperature. It is also observed that there is small temperature drop of producer gas in the filter.

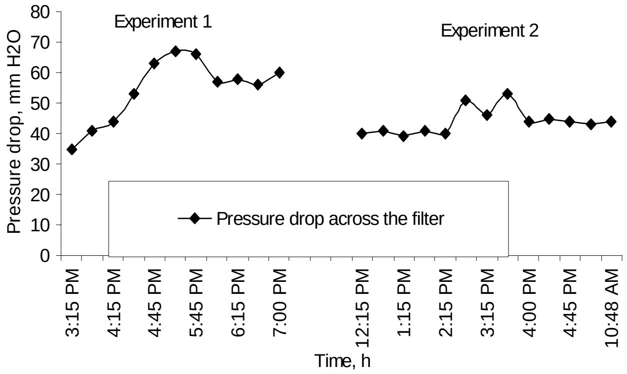

Fig. 6. Variation of pressure drop across the filter with time.

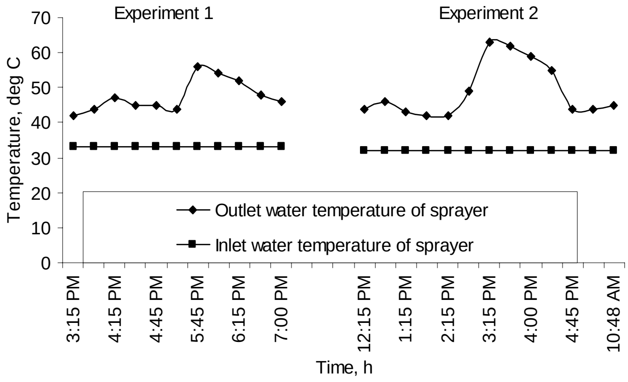

Fig. 7. Variation of water temperature at inlet and outlet of spray tower with time.

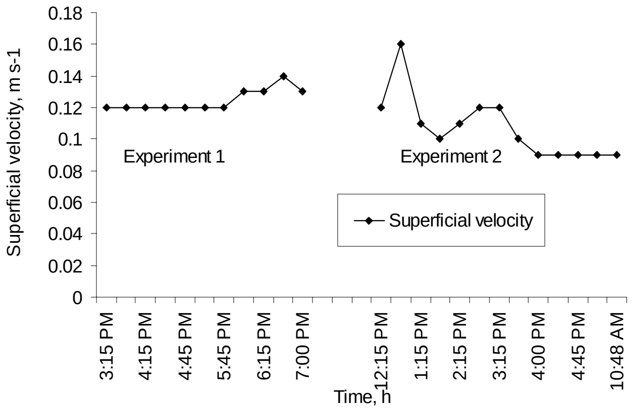

Fig. 8. Variation of superficial velocity with time.

Fig. 6 shows the variation of pressure drop across the filter. It was observed that the pressure drop across the filter is increased with time, which shows blockage of cleaning area of the filter, which shows deposition of tar and particulates in to the filter medium. It was also observed that the pressure drop was low in the bed of wood shaves and coarse sand bed while pressure drop was high in the bed of fine sand. Fig. 7 shows the variation of water temperature at inlet and outlet of water spray tower. It is observed that the inlet temperature of water to spray tower remains constant while the outlet temperature decreases as raw gas outlet temperature decreases and increases as raw gas outlet temperature increases. Fig. 8 shows variation of superficial velocity with time. It is shown that during the first experiment superficial velocity is maintained constant as per designed value and in the second experiment it varies due to variation in flow rate of producer gas as superficial velocity is function of producer gas flow rate.

Fig. 2 shows that the coloure of coarse and fine sand present in the third and final compartment has changed to black colour from yellow, which proves that the tar and particulate matter have been trapped. It is also observed that the fine sand of size of ϕ 0.15 – ϕ 0.35 (fine sand) are more darker in colour than the sand of ϕ 0.60 mm (coarse sand) which shows that the fine sand are more effective for cleaning than coarse sand. The cooling water washes part of the tar and the rest is deposited in the sand bed filter. Experiments have shown that the moisture carries over from the cooler causes slight wetting of the sand bed. It was observed that the percentage reduction of moisture content by the filter was around 10 – 18 %.

4. CONCLUSIONS

1. The developed sand filter worked satisfactorily and the tar and particulates removal efficiency was in the range of 83 – 97 %.
2. The pressure drop across the filter was increased with the duration of test, which indicates that the moisture, tar and particulates being filtered out from the producer gas.

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