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DEVELOPMENT OF BIOMASS ASH FILTERS FOR HIGH TEMPERATURE APPLICATIONS

K. Umamaheswaran[1], Vidya S. Batra[2] and D.V.S. Bhagavanulu[1]
[1]*Vellore Institute of Technology, Vellore 632 014, Tamilnadu, India*
[2]*The Energy & Resources Institute, Habitat Place, Lodhi Road, New Delhi 110 003, India.*

ABSTRACT

This study reports an innovative method of utilizing ash as a raw material for fabricating inorganic membrane filters. Biomass ash from five different sources (bagasse, groundnut shell, cashew shell, aracnut shell, and rice husk) was analyzed for particle size distribution, chemical composition and thermal properties (thermogravimetric analysis, differential thermal analysis). Membrane filters from these ash powders were prepared by tape casting and sintering. Porosity of the membrane filters was in the range 30- 70 volume percent and median pore size was in the range 0.2μm - 27μm. Membranes made with bagasse and rice husk ash showed good handling strength with optimum porosity and pore size distribution.

Keywords: Biomass ash, inorganic membranes, pore size distribution

1. INTRODUCTION

Inorganic membrane applications have increased since the early 80's in areas where polymeric membranes failed due to its limitations. Inorganic membranes have process stability, high chemical and physical stability, outstanding separation characteristics, constant filtrate quality and long working life[1]. Inorganic membranes have promising applications in biotechnology, environmental technologies (water treatment) and gas cleaning especially at high temperatures. Inorganic membrane filters with particulate collection efficiencies in the range 99.67 to 99.88% were obtained while firing micronized middle kittannig sea coal which was marginally better than the pulse-jet baghouse[2].

Inorganic membrane geometry is typically tubular or honeycomb in liquid separation and flat sheets in gas cleaning and catalytic process[3, 4]. Flat membranes are prepared by slip casting, dip coating, and tape casting. In slip casting slurry is poured or pumped into a permeable mould and capillary suction concentrates the solids in the cast adjacent to mould wall. In tape casting the slurry is cast on a substrate and dried to produce green tape. In all processes, final step is densification done by sintering.

Inorganic membranes are made with single component of inorganic material. Waste material ash has many of the compounds which are typically used for inorganic membrane. It has been reported that membranes made of coal ash contain micron- sized tortuous pores, which would potentially be suitable in hot gas cleaning applications[5, 6]. In this study biomass ash such as bagasse ash, aracnut ash, groundnut ash, cashew shell ash and rice husk ash have been explored for filter fabrication.

2. EXPERIMENTAL

2.1 Biomass ash characterization

Raw ash from various sources was milled in a ball mill and sieved through 38μm sieve to reduce the particle size distribution and to remove the visible impurities (agglomerates and unburnt material) and analyzed for chemical composition, particle size distribution. Ash behaviour at high temperatures was analysed with thermal analysis involving thermogravimetric analysis (TGA) and differential thermal analysis (DTA).

2.2 Filter development

Main steps in filter development are slurry formulation, green tape preparation and sintering. Sieved ash powders were heated at 450^{O}C to remove the residual carbon and moisture content. Slurry was prepared by mixing water and glycerol with continuous agitation. Binders like water soluble polyvinyl alcohol and carboxy methyl cellulose were added and the slurry was stirred till the binder dissolved completely. Ash was then added in this mixture and stirred for 3 hours to obtain a homogeneous slurry.

Prepared slurry was poured in 5”X5” wooden mould and dried. Dried green tapes were removed from the mould and sintered for 12 h at 800^{O}C in a muffle furnace. Initially the temperature was increased to 350^{O}C at the rate of 4^{O}C/min and held constant for 1 h, then temperature was raised to 800^{O}C at the rate 1 ^{O}C/min.

2.3 Filter Characterization

The filters were characterized by visual observation, pore size distribution, membrane pressure drop and mechanical properties. Sintered tapes were visually observed for appearance and handling strength. Pore size distribution of the sintered membranes was analyzed by the mercury porosimeter (micrometrics pore sizer 9320). The strength of heat-treated membrane was investigated by the ultra sonicator, the observation was done based on the weight loss in membrane after agitation in the ultra sonicator for 30 minutes.

Pressure drop across the sintered membrane filters were tested by fixing the 2” square membrane in a stainless steel filter holder with pressure taps 2.5 inches upstream and 2.5 inches downstream of the center of the membrane filter using a digital manometer. Zero air from a pressurized cylinder was passed initially to check the air leak. Airflow rate from the pressurized cylinder was controlled by the flowmeter (rotameter). Figure 1 shows the pressure drop test rig.

3. RESULTS AND DISCUSSION

3.1 Biomass ash characterization

Chemical composition analysis of ash powders by X-ray Fluorescence (XRF) technique is shown in Table 1. It can be observed that bagasse, groundnut shell and arcanut shell ash have more SiO_2 content compared with the cashew shell ash. SiO_2, Al_2O_3, and Fe_2O_3 content are relatively high in the bagasse ash and rice husk ash and low in the cashew shell ash. Both these compounds are found high in groundnut shell ash. Loss of ignition (L.O.I) due to unburnt residual carbon particles is high in bagasse, cashew shell, and arcanut shell ashes compared to the groundnut shell ash.

The particle size distribution data for the ash powders was obtained from the laser particle size analysis technique. It was observed that arcanut shell ash has largest mean diameter of 57.9 µm and the lowest mean diameter was in cashew shell ash with 17.7 µm. Groundnut shell ash, rice husk ash and bagasse ash had median diameter size of 19.6µm, 28.3µm and 26.4µm respectively. Particle size distribution of the ashes is given in figure 2.

Thermal analysis results (DTA and TGA) of ashes shows weight loss in all the ash powders. Significant weight loss occurs in the temperature $300^{O}C$ to $500^{O}C$ due to volatile compounds and residual carbon content removal. Cashew shell ash has high weight loss in this temperature range (70%). The weight loss for bagasse ash, groundnut shell ash, arcanut shell ash, rice husk ash, and cashew shell ash was 25%, 6.5%, 30%, 0.5% and 80% respectively. Arcanut shell and cashew shell ashes shows a significant endothermic heat flow in temperature range $350^{O}C$ to $600^{O}C$ associated with the volatile content removal, initial peaks observed in these two are due to SO_3 vaporizing effect.

3.2 Filter development

Slurry formulation trials revealed that the slurry prepared with polyvinyl alcohol had significant air bubbles trapped inside. The green tapes prepared with this slurry broke easily and had a rough surface. The green tapes prepared with carboxymethyl cellulose as binder was smooth and flexible with sufficient handling strength. Based on the trials, the optimum composition was identified for making the slurry as shown in Table 2.

3.3 Filter Characterization

Visual observation of the tapes shows sintered bagasse ash and ricehusk ash membranes were grey in colour with good handling strength, sintered arcanut shell ash and cashew shell ash membranes were yellow in colour whereas groundnut shell ash membrane was brown in colour. Both bagasse ash and ricehusk ash membranes have good handling strength compared to other ash membranes.

3.3.1.Pore Size Distribution

Figure 3 and table 3 gives the results of porosity analysis of sintered membranes. It can been seen that bagasse ash filter has lower porosity compared to others with 37.06 volume percent pores and median pore diameter of 7.36 m. Groundnut shell ash filter has high porosity 67.74 volume percent and median pore diameter of 0.3 m Cashew shell ash filter has porosity of 44.10 volume percent and median pore diameter of 2.231 m, rice husk ash filter has porosity of 33.4 volume percent and median pore diameter 8.22 m, arcanut shell ash filter has porosity of 59.11 volume percent and median pore diameter 15.32 m.

Pore area for filters are given in Table 3. Cashew shell ash filter has high pore area of 11.52 m^2/gm, arcanut shell filters had a low pore area of 7.14 m^2/gm. Filters of groundnut shell ash, bagasse ash and rice husk ash have surface area of 10.01 m^2/gm, 8.67 m^2/gm and 8.76 m^2/gm respectively.

Based on the above results, bagasse and rice husk ash filters were found to have most suitable properties and were characterized further.

3.3.2 Mechanical Stability

Mechanical stability results are obtained as a function of sample weight loss after 30 minutes of sonication. Results shows that weight loss in bagasse ash and rice husk ash filters are 0.53% and 1.04% respectively after 30 minutes of sonication. Most of the weight loss in the samples is found in the initial 5 minutes, after that there is no significant weight loss in the sample.

3.3.3. Pressure drop

The results of the pressure drop measurements are shown in figure 4. It can be observes that in both the cases pressure drop increases with the increasing flow rate. The pressure drop gradient was highest in bagasse ash filter (0.13 Kpa $l^{-1}min^{-1}$) and is lowest in rice husk ash filter (0.03 Kpa l^{-1} min^{-1}).

4. CONCLUSIONS

An alternative method for utilizing biomass ash as a starting material in filter fabrication applicable to high temperature environments was studied. Among the five-biomass ashes tested for its physical and chemical properties bagasse and ricehusk are found to be most suitable in terms of handling strength, porosity and pore size distribution. Chemical composition of ash powders reveals that silica is the primary compound in most of the ash powders, Cashew shell ash, arcanut shell ash and groundnut shell ash also has other oxides. Rice husk and bagasse ashes having high silica and alumina content may be more appropriate. Analysis of sintered membranes shows porosity was in the range of 30- 70 volume percentage with median pore size of 0.2 m-27 m with membrane thickness from 3-4mm. Filter characterization showed the preparation procedure is reproducible and applicable in filtration systems of potentially high temperature environments. The product developed provides the utilization of the waste ash as a filtering medium.

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TABLES

Table 1. Chemical composition analysis of ashes as determined by the XRF analysis

Compound	% Weight				
	Bagasse	Groundnut shell	Arcanut shell	Cashew shell	Rice husk
SiO_2	65.03	43.13	42.43	8.16	93.50
Al_2O_3	0.49	10.71	3.85	3.05	0.01
Fe_2O_3	0.49	3.96	4.20	2.05	0.51
TiO_2	0.08	0.55	0.07	0.12	0.04
P_2O_5	1.14	4.19	7.29	14.63	1.06
CaO	2.75	10.81	1.23	7.50	0.68
MgO	3.26	6.10	0.48	10.63	0.47
Na_2O	0.06	5.60	0.20	5.24	0.40
K_2O	1.73	9.61	18.90	21.6	2.40
Cl	0.12	1.44	3.70	1.98	0.11
MnO	0.00	0.00	0.02	0.20	-
SO_3	0.00	0.00	5.09	4.06	-
LOI	24.84	3.90	12.50	20.5	0.80

Table 2. Optimum slurry composition for green tape preparation

Constituent	**Amount**
Carboxy methyl cellulose, CMC	1 g
Glycerol	2 cc
Flyash	10 g
Water	60 cc

Table 3. Porosity data of sintered filters

ASH	Parameters		
	Porosity (%)	Median pore size (m)	Total pore area (m^2/g)
Bagasse	30.91	7.36	8.67
Groundnut shell	67.74	2.866	10.01
Arcanut shell	59.11	15.32	7.14
Rice husk	33.40	8.22	8.76
Cashew shell	44.21	2.23	11.52

FIGURES

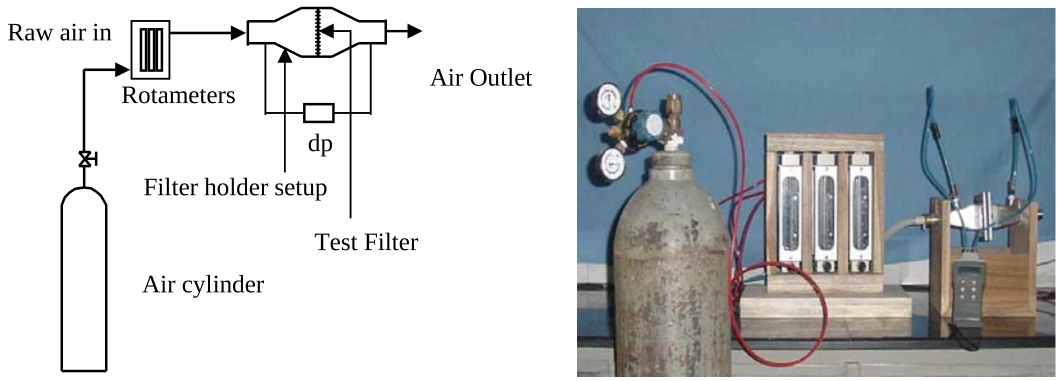

Figure. 1 Test rig setup to measure pressure drop across the membrane

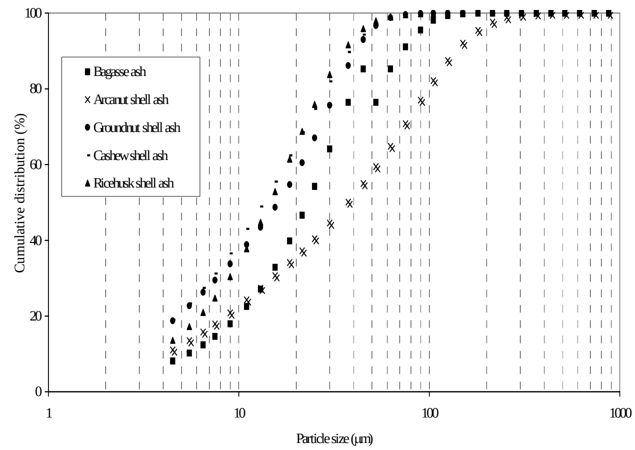

Fig 2. Particle size distribution of ash powders

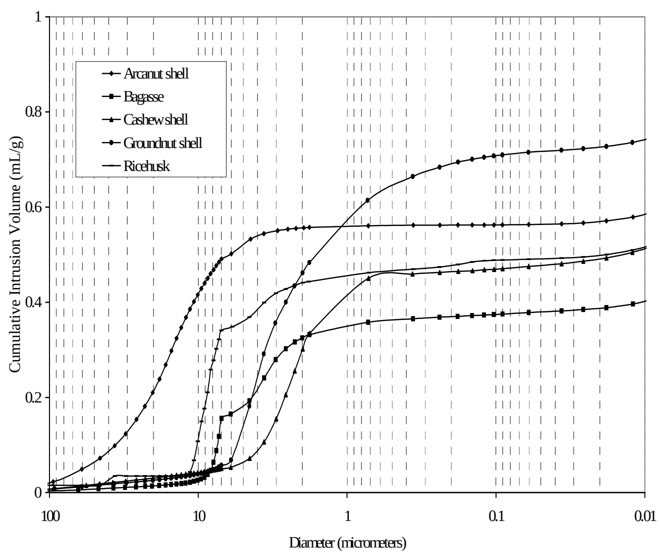

Fig 3. Pore size distribution of ash filters

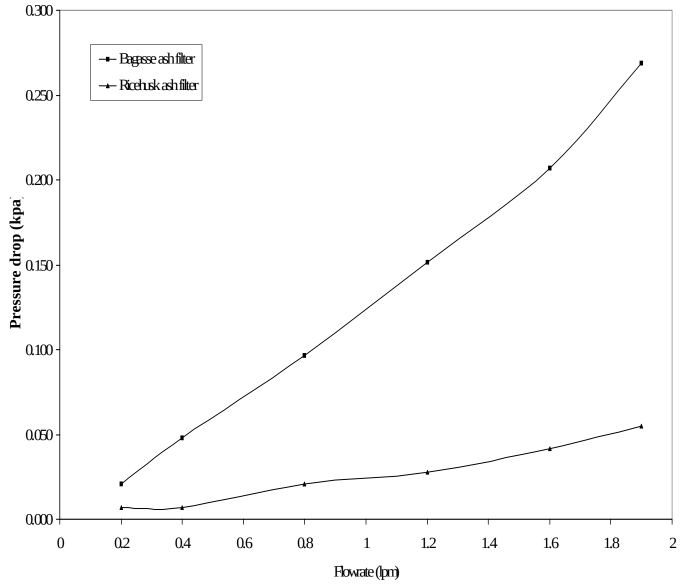

Figure 4. Pressure drop versus air flowrate for the filter