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Sawdust: From wood waste to pore-former in the fabrication of ceramic membrane

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Abstract

The extensive uses of pore-formers are considered to be a major factor for determining morphology in ceramic membrane fabrication, but the behavior of pore-formers during membrane fabrication remains unverified. Five different size ranges of sawdust screened through 30, 44, 60, 72 and 100 B.S.S. meshes (500, 355, 250, 212, and 150 μm) are utilized as a pore-former and are believed to influence on membrane porosity, pore size and surface texture. Two series of experiments have been conducted; the first set of experiment is planned to determine thermal behavior and particle size of sawdust as well as the change in physical properties of sawdust when burnt in the presence of air and the sustainability of raw and burnt-sawdust in acid and alkali media. The second set of experiment is the selection of appropriate sized sawdust particle for the fabrication of ceramic membrane based on first set of experiments for understanding the behavior of sawdust during membrane fabrication. Sawdust samples are characterized by thermogravimetric analysis (TGA), Fourier-transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM), field-emission scanning electron microscopy (FESEM) and energy dispersive x-ray (EDX). Chemical sustainability of sawdust is verified using acid–alkali test. Based on the experimental data, it is concluded that there is an obvious effect of sawdust on the morphology of fabricated membrane and the sawdust screened through 44 B.S.S. mesh is selected for the fabrication of membrane for our purpose. The mechanical strength of the membrane is also noteworthy.

Keywords: A. Precursors: organic; B. Microstructure-final; B. Microstructure-prefiring; E. Membranes

1. Introduction

Understanding the use of pore-former in membrane fabrication is a major issue in all times. Indeed, the use of pore-formers has long been cited as a possibly important factor in the manufacturing of ceramic membranes by cheap raw materials such as kaolin [1], dolomite [2], red-clay [3], apatite powder [4] and fly ash [5], etc. These cheap materials are widely used in developing several types of ceramic membranes in terms of separation efficiency and manufacturing cost.

Morphological properties (porosity and pore size) of a ceramic membrane depend on the topographies of pore-formers and removal of pore-former particle in different sintering steps. Microstructure and porosity of ceramics can be controlled by quantity, chemical and thermal properties of the pore-former. Calcium carbonate is used widely as a pore-former for preparing kaolin-based ceramic membranes and can provide porosity in the range of 30–42% [1,6]. Porous texture in the ceramic is controlled by calcium carbonate which under sintering conditions releases carbon dioxide (CO_2) gas. The path taken by the released CO_2 gas thereby creates the porous texture of the inorganic membrane and contributes to the membrane porosity. Though calcium carbonate is appreciably used in laboratory scale, it is difficult to control cost during industrial scale manufacturing.

In order to overcome this problem, several researchers have reported alternative raw material as pore-formers, like sawdust for different purposes, such as, the construction of ceramic bricks. A ceramic brick have been prepared with 9 wt% of sawdust of eucalyptus at 950 °C whose mechanical properties are appropriate for use as secondary raw material in ceramic brick production. The effect of sawdust addition on the

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technological behavior, such as, drying and firing shrinkage, porosity, water absorption, bulk density and compressive strength of the brick are also verified [7]. Another attempt has been made to incorporate sawdust in the manufacturing of ceramic brick with rubber to increase the insulating capacity of brick [8]. In another literature, it is reported that viable bricks can also be manufactured with a combination of different percentages of sawdust and organic–inorganic wastes or marble residue and clay mix. Their results indicate the preparation of ceramic bricks using sawdust along with other raw materials that fulfill the technological standards for traditional bricks and hold mechanical properties similar to those of clay bricks without these raw materials [9]. A laboratory test has been carried out on highly porous ceramic brick firing at temperatures up to 920 °C, made of clay with up to 30% volume of sawdust and/or papermaking sludge as pore-formers [10]. In addition, sawdust has been used as a replacement for cement in concrete mixes for their pozzolanic properties which provide good performance with desired workability and strength [11,12].

Wood, the cheapest ligno-cellulosic material, is the source of the inexpensive wood precursor sawdust [13,14]. Wood has already been used as a natural composite material consists of cellulose, hemicellulose and lignin, forms a cellular microstructure of high porosity, good strength, stiffness and toughness [15,16]. Sawdust can be used in a variety of applications including filters, ceramic bricks and catalytic membrane reactor support, etc. under a controlled manufacturing cost. The advantage of using sawdust over conventional pore-formers is the achievement of high porous structure economically.

So far, sawdust is used only in ceramic brick and cement manufacturing. However, there is no report on the use of sawdust as pore-former in ceramic membrane fabrication and its behavior, especially, the change of physical properties and control on the morphology of membranes during sintering. In our recent study, on the fabrication of low-cost tubular ceramic support membrane, sawdust has been used as a pore-former to reduce the manufacturing cost of the membrane [16,17] considering the role of the sawdust in the membrane fabrication.

This present study differs from the others works mainly because of two significant points. Firstly, the use of sawdust as pore-former for the manufacturing of ceramic membrane is not even tried before by any researcher to the best of the knowledge. Secondly, the manufacturing cost of the membrane is substantially lower compared to any tubular ceramic membrane available in the market.

Hence, the use of sawdust as a pore-former in ceramic membrane manufacturing for controlling membrane morphology and demonstrating the change in physical behavior during entire sintering steps are the significance and originality of the present work.

Here, firstly, five different size ranges of sawdust screened through 30, 44, 60, 72 and 100 B.S.S. have been considered to determine the particle size distribution of sawdust by laser particle size analyzer (LPSA) and then the change in physical properties of sawdust when burnt in the presence of air using thermogravimetric analysis (TGA) and Fourier-transformation infrared (FTIR) spectroscopy, respectively. The chemical sustainibility of raw and burnt-sawdust in acid and alkali media is verified by acid–alkali test and the residual part after acid–alkali test is collected to confirm the surface structure and any variation in composition by scanning electron microscopy (SEM) and energy dispersive X-ray, respectively. Secondly, based on particle size analysis, membranes made of three different size ranges of sawdust particles (30, 44 and 100 B.S.S.) have been considered to ensure the change in membrane porosity and pore size with change in particle size of sawdust. The change in surface morphology of the fabricated membrane is also verified using field-emission scanning electron microscopy (FESEM). Based on the behavior of sawdust observed from the characterization techniques of raw and thermally–chemically modified sawdust, the morphological and chemical stability of the fabricated membrane are recognized. At last, on the basis of porosity value, sawdust has been selected screened through 44 B.S.S. mesh for the desired membrane characteristics.

2. Experimental

2.1. Materials and methods

Sawdust, a ligno-cellulosic material contains cellulose, hemicellulose and lignin compounds. Sawdust is unique as a pore-former for the fabrication of ceramic membrane because it easily forms pore by removing cellulose, hemicellulose and lignin compounds during heating and is cheap. Sawdust is taken from a local sawmill and the change in physical and chemical properties while heated at different temperatures and kept in acid and alkali media for 7 days, respectively, is verified. Sawdust samples are screened through gyratory sieve shaker using five different mesh sizes i.e., B.S.S. 30, 44, 60, 72 and 100 for fabricating ceramic membrane to understand the effect of particle size of sawdust material on the morphology (porosity and pore size) of the fabricated membrane. Concentrated HCl (1 N) and NaOH pellets for acid–alkali test are purchased from M/s Merck India Pvt. Ltd.

2.1.1. Thermal modification of sawdust

Thermal modification of sawdust has been performed to realize the change in physical properties of sawdust which is the significant factor for understanding the pathway of making pores in ceramic membranes. The raw sawdust particles undergo three heat treatment steps. Firstly, the raw sawdust is dried at room temperature for 24 h. After that, it is dehydrated at 100 °C for 12 h using α-alumina crucible in a muffle furnace followed by heating at 250 °C for 24 h. Secondly, it is sintered from 250 °C to desired sintering temperature (550, 700 and 850 °C) at a heating rate of 2 °C/min for 5 h. Then the thermally modified sawdust is cooled by an atmospheric cooling process implemented by switching off the muffle furnace. The entire heating step is considered as it is stated in the fabrication of ceramic membrane in our previous study to understand the behavior of sawdust inside the ceramic body during sintering of membrane in a better way [16].

2.1.2. Acid–alkali test

The raw sawdust and burnt samples are separately dipped into acid (concentrated hydrochloric acid, pH 2) and alkali

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