Synthesis and Optimization of a New Starch-Based Adsorbent for Dehumidification of Air in a Pressure-Swing Dryer

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Corn grits selectively adsorb water from many types of organic vapors and are used commercially to dry 2.8 billion L of fuel-grade fermentation ethanol annually. Evaluation of grits in a pressure-swing dryer at 308 kPa, combined with analyses of their physical properties, showed that the specific surface of the grits (0.5 m²/g) limited steady-state drying of air to a dewpoint of −20 °C. By selectively taking advantage of the best features of the natural material, a new class of natural adsorbents with a higher affinity for water was then synthesized using materials derived from corn: starch and cob flour. The chemical composition of the synthesized adsorbent was determined, as well as specific physical properties. Scanning electron microscopy showed the synthesized adsorbent surface had a large number of macropores (10–25 μm in diameter) unlike corn grits which have limited porosity. This material gave reasonable and reproducible results, similar to those obtained with molecular sieves using a commercially available pressure-swing air dryer. After 70 h of operation at 30 psi, the new adsorbent provided air at a dewpoint of −63 °C. The methods for preparing this material and an explanation of its performance in terms of macroscopic and microscopic structural characteristics are described.

Introduction

Cellulose and starch-containing materials have been shown to remove water from a wide range of organics since 1979 when Ladasch and Dyck demonstrated the separation of ethanol—water vapor mixtures over cracked corn, starch, and carboxymethyl cellulose. Other biomass materials including corn grits, corn meal, corn cob, xylan, crystalline cellulose (Avicel), and wood chips have shown to separate water from ethanol (Hong et al., 1981; Robertson et al., 1983; Ladasch et al., 1984; Rebar et al., 1984), and water was removed from the alcohols, methanol, isopropyl alcohol, and tert-butyl alcohol (Bienkowski et al., 1986). More recently, the gas-phase drying of propionaldehyde, MEK, acetone, organic acids (acetic, propionic, butyric), and ethers (ethyl ether, MTBE, ETBE) over starch was carried out (Westgate and Ladasch, 1993a). Corn grits are currently used in large-scale fermentation alcohol plants to dry approximately 2.8 billion L/y of fuel-grade ethanol.

Corn grits with 2.3 mm average particle size have been used in our laboratory to dry moist air to a dewpoint of −42 °C in a pressure-swing adsorber operated between 300 and 101 kPa pressure (Westgate and Ladasch, 1993b). Pressure-swing air drying utilizing molecular sieves as the desiccant is common in many industrial applications such as ozone generation, paint spraying, microwave antenna and telephone cable pressurization, environmental chamber testing, and continuous emissions monitoring. Usage of inorganic desiccants is estimated at 30–50 million kg/yr, with drying of gases being a historically important unit operation (Yang, 1987, King, 1971). When molecular sieves were initially replaced with corn grits in a pressure-swing adsorber it was found that the grits are physically stable but that their operational drying capacity is less than that of molecular sieves (Westgate and Ladasch, 1993b). Hence, there was incentive to try to improve the performance of the grits or to synthesize an adsorbent from natural materials that is as effective as the sieves.

Corn grits have both the advantages and disadvantages of a natural material. Grits are easily available, an order of magnitude less expensive than the molecular sieves, mechanically stable, biodegradable, and easily disposable. The greatest disadvantage is that the specific surface area for adsorption is limited. While the surface area can be increased by reducing the particle size, i.e., by more finely grinding the corn, a limit is quickly reached, below which the pressure drop for flow through a packed bed of fine particles is excessive. Therefore, a mechanically stable, robust material having a higher surface area than corn grits is needed.

Starch particles (2–10 μm in size) have an equilibrum capacity of 158 mg of water/g with respect to saturated air, measured at 28 °C and 30 psi in gas chromatograph studies (Westgate et al., 1992). The operational capacity of corn grits, such as for a pressure-swing air dryer, however, is only 0.45 mg/g, which is less than 1% of the equilibrium loading. This indicates that only a small fraction of the available sorption sites of corn grits is being accessed or utilized (Westgate and Ladasch, 1993b).

Grits contain 78% starch (Table 1) and have two visually distinct regions, the smooth and yellow vitreous regions interspersed with opaque regions consisting of tightly packed spheroidal starch particles. The operational capacity of the corn grits was postulated to be primarily associated with the starch particles in the opaque regions (Westgate and Ladasch, 1993b). The adsorption of water is hypothesized to include transport of water molecules between the adjacent starch polymers which make up the small spherical bodies in...
Table I. Typical Composition of Corn Grits, as Is Basis

<table>
<thead>
<tr>
<th>Component</th>
<th>% weight</th>
</tr>
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<tbody>
<tr>
<td>starch</td>
<td>78.0</td>
</tr>
<tr>
<td>protein</td>
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</tr>
<tr>
<td>fat</td>
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</tr>
<tr>
<td>ash</td>
<td>0.3</td>
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<tr>
<td>oil</td>
<td>2.0</td>
</tr>
<tr>
<td>moisture</td>
<td>11.5</td>
</tr>
<tr>
<td>total</td>
<td>100.0</td>
</tr>
</tbody>
</table>

mobilized on the surface of the corn grit (Bienkowski et al., 1986).

The low porosity of the grits results in a low surface area per unit bed volume. This led to the hypothesis that agglomerates of starch particles with large macropores and a high internal surface area would have an improved performance over grits. The objective of this research was to increase the operational capacity by increasing the accessible surface area of the starch at a molecular level while avoiding the high-pressure drop of 2–10 μm starch particles. For corn grits with an average diameter of 900 μm the estimated external surface area is 0.0065 m²/g, which is equivalent to 0.0045 m²/mL column volume. Starch particles, in comparison, have an average particle size of 10 μm and a surface area of 0.72 m²/g, or 0.41 m²/cm³. An ideal adsorbent was postulated to be a macroreticular material coated with starch, which would have the same accessible surface area as starch particles alone.

This paper describes our first work in the design and synthesis of polysaccharide sorbents from starch and corn cobs. The physical attribute of corn grits (i.e., small starch spheres immobilized on a supporting scaffold of a much larger solid surface were reproduced, while the surface area was increased through a network of internal pores). Starch particles were immobilized on a mechanically stable, macroscopic supporting matrix of a cob flour. These materials were examined using scanning electron microscopy (SEM), and desirable structural organizations were selected for testing in a pressure-awing drying system. A material capable of drying air to −63 °C dewpoint was developed through this research.

Materials and Methods

Starch and Cob Materials. The corn starch (Lot 46F-0312, No. S-4126) was obtained from Sigma Chemical Co. and was found by SEM to be almost spherical with an average diameter of 10 μm. Cob flour was used for control studies obtained from Short Milling Co. (Kankakee, IL). The average particle sizes used for this study were 0.72, 1.75, 2.3, and 5.2 mm. These materials were screened before use. The small amount of fines which passed a 25 mesh screen were discarded. The composition of grits is given in Table 1.

Three types of cob flour (Grit-0′coys 30, Grit-0′coys 60 and Grit-0′cobs 1420) were a gift of the Andersons' Corncob Products Inc., Delphi, IN. Cob flour is derived from corn cobs and has a composition of 60% hemicellulose, 30% cellulose, 8% lignin, and 2% ash. All particles and pore sizes were estimated from SEM examination. Cobs are resistant to attrition, and both the xylan and cellulose contained in them have sorptive properties (Hong et al., 1981). Consequently, cob flour could complement the moisture-adsorbing properties of starch.

The cob 1420 material, with an average size of 1.06 mm, was used to confirm the intrinsic capability of cobs to act as a sorbent since it had a particle size close to the 0.9 mm corn grits used in this work.

Scanning Electron Microscopy. The basic materials, cob flour and corn starch, from which the adsorbent was to be synthesized, as well as the particles derived from the synthesis procedure were examined using a scanning electron microscope (SEM). The JEOL T800 SEM was used at an operating voltage of 5 kV. Samples were conductor-coated using an Anatech LTD Hummer 6.2 sputter coater or an Edwards vacuum coater, E306A. SEM photomicrographs were used to select the size of the cob flour matrices as an aid for developing methods for fixing starch on the surface of the cobs.

Moisture Determination. The moisture content was determined by drying the samples in a convection oven for 16 h at 103 °C. The loss in weight was used to calculate the moisture content.

Elemental Analysis. Selected samples of corn grits, corn starch, cob, and synthesized adsorbent were analyzed for carbon, hydrogen, nitrogen, oxygen, and sulfur with a Perkin-Elmer 240 C elemental analyzer (Norwalk, CT) using acetonitrile as a standard. The analysis was provided by Dr. Daniel Lee of the Chemistry Department.

Coating Procedures. The coating of starch on the cob particles was studied using a 2.1 weight ratio of starch to cob mixed together at ambient temperature for 5, 10, 20, 30, 40, 50, and 60 min and 2 days in a glass jar that was placed on rollers. The preferred method ultimately involved addition of 40 mM NaOH at a liquid to solid ratio of 1:1.5. The blended mixture consisted of the proportions of 1 g of starch, 0.5 g of cob 60, and 1 mL of 0.04 M NaOH. The resulting adsorbent agglomerates were subjected to heat treatment to fix the starch onto the cob matrix.

Heat Treatment (Remobilization/Aggregation) Procedure. The adsorbent agglomerates were fixed by spreading an agglomerated mixture of 4 g of starch, 2 g of cob 60, and 4 mL of 0.04 M NaOH in a 10-cm-diameter Petri dish with another Petri dish pressing down on it. The resulting sheet was then baked in a Blue M single-wall gravity convection laboratory oven for 15 min at 160 °C. A sheet of material having a thickness of 1.5 mm was obtained.

Particle Formation. Sheets from either method were broken into smaller pieces and ground using a mortar and pestle. The agglomerates were examined under the SEM. The average particle size of the adsorbent particles (1.15 mm) was measured by sieving analysis using 14, 16, 18, 20, and 25 mesh sieves whose openings corresponded to 1.40, 1.18, 1.00, 0.85, and 0.71 mm, respectively. The synthesized adsorbents were characterized with respect to surface area, crystallinity, and resistance to attrition.

Specific Surface Area (Porosity) by Mercury Porosimetry. The specific surface area of the adsorbent material was found by mercury intrusion using a mercury porosimeter. A powder sample was placed in the porosimeter container, and the chamber was evacuated to remove gases and vapors. The chamber was then filled with mercury. Mercury first filled the pores between particles. As the pressure in the chamber was increased, mercury entered the pores in the particles. The volume of mercury forced into the chamber was recorded as a function of pressure (Somasundaran, 1980). The specific surface area of the material was directly proportional to the unit area work, defined as the pressure applied over an incremental penetration.
volume:

$$A = \frac{\int P \, dV}{\gamma \cos \phi} \tag{1}$$

where $P$ is the external pressure forcing a volume of mercury, $dV$, into the pores, $\gamma$ is the surface free energy of liquid mercury, and $\phi$ is the contact angle between mercury and the surface of the material. The integral term in eq 1 was graphically evaluated from a plot of intruded volume versus pressure (Roottare, 1967).

**External Specific Surface Area.** The external specific surface area was found by assuming the grits to be spherical and using their average particle size. The volume of grits was found by noting the volume of ethanol displaced in a graduate cylinder (25 mL capacity) at 23 °C when a measured weight of dry grits of 2–8 g was added. Ethanol was used because its adsorption on starch is much slower than water. About 15 mL of ethanol was taken in each case and the volume of grits measured varied from 2 to 8 mL. The contact time was less than 2 min, with the rise in level noted as soon as the grits were fully immersed. The specific surface areas of the grits are summarized in Table 2.

**Crystallinity (X-ray Diffraction).** The percent crystallinity of the starch granule plays a role in the adsorption properties of the material. In a starch granule, the crystalline regions are held together by hydrogen bonds which cannot be utilized as adsorption sites. Therefore, changing the crystallinity of the starch adsorbents would alter the adsorption properties. X-ray diffraction was used to determine if the crystallinity of the materials was modified during processing and drying.

The instrument used was a Siemens X-ray diffractometer (Kahrlarube, Germany), and the software package used was Diffrac At, version 3.2 (Siemens Co., 1995). The HT voltage was set at 40 kV and the X-ray tube current at 20 mA. A copper wire source was used to give Kα radiation. The detector slits used were 1°, 1°, 1°, and 0.15°. An aluminum sample holder with a quartz bottom was used to hold the powder samples during examination.

**Particle Attrition Test.** An experimental procedure using a Crescent Wig-L-Bug (Lyons, IL) electric motor (no. 3110B) was created to test the stability of the adsorbent particle and pellets. This device rapidly shook a container holding the adsorbent and was used as an accelerated test to predict the attrition of the materials over many cycles in the pressure-swing dryer. The procedure consisted of placing 1.4 g of corn grits (which had previously been sieved through a 25 mesh screen to remove fines initially present) into the Wig-L-Bug holder and then shaking for 5 s. A small amount of dust was formed on the inside of the holder, but the mass of this dust was not significantly related to the percent and approximately 0.15% fines were formed. The extent of attrition was consistent with the attrition of corn grits, previously tested in the dryer for 88 days (254,000 cycles) which had produced about 0.15% fines (particles

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**Figure 1.** Schematic diagram of dryer used to evaluate synthesized adsorbents.

under 0.7 mm) (Westgate and Ladišich, 1993a). When the grits were shaken for 10 s, 0.6% fines were formed.

**Surface Area Effect on Drying.** Four different sizes of commercially available corn grits (J. R. Short Milling Co., Kankakee, IL) were run in the dryer to test the effect of the surface area on sorption capacity. Their external surface area/mL of column (a) was found by using:

$$a = \frac{s \cdot V}{1 + \frac{m \cdot \rho}{100 \cdot V}} \tag{2}$$

where $s$ = specific surface area based on dry weight (cm$^2$/g), $\rho$ = weight packed in column (g), $m$ = % moisture content, and $V$ = bed volume (cm$^3$).

The percent moisture of the grits was calculated by difference. The grits were dried in an oven for 24 h at 90 °C, and the initial and final weights were measured.

The bed volume ($V$) of the grits was 140 cm$^3$. This was found by calculations from the measured dimensions of the dryer bed (4.1 × 10.6 cm). The total mass of synthesized adsorbent required to fill each chamber was 40–41 g, thus resulting in an apparent packing density on the order of 0.29 g/mL, compared to 96–102 g of the grits which corresponds to a packing density of 0.71 g/mL.

**Evaluation of Adsorbents in a Pressure-Swing Dryer.** The operational sorption capacity of the corn grits and the synthesized adsorbents was tested in a commercially available pressure-swing dryer (Westgate and Ladišich, 1993b). The dryer was a Puregas dryer (Model HF 2000A106-A130, General Cable Co., Westminster, Co.) with two 152 mm desiccant chambers. Each chamber held 135 mL of desiccant, which corresponded to 40 g of synthesized adsorbent, or 100 g of corn grits. The actual bed height in both cases was 125 mm.

The dryer was fitted with other external components to provide a system in which inlet air flow rate and inlet and outlet moisture contents could be controlled and/or monitored. Figure 1 shows a schematic of the complete air dryer system.

Air at approximately 320 kPa and 298 K was humidified to +5 °C dewpoint by bubbling it through 1 L of distilled water. Trace amounts of oil were removed by oil traps along the air line. The flow of air at the outlet was maintained at 1.8 L/min (STP, 273 K, 101.3 kPa) by a flow controller (Matheson, Model 3040). The dry
Figure 2. Correlation of % moisture (by volume) in air as a function of dewpoint temperature.

air flow used for the regeneration cycle was 11.5 L/min (STP), with each of the two sorbent beds cycling between sorption and regeneration every 30 s. The low outlet/purge ratio was used in order to promote rapid equilibration of the bed to steady-state outlet moisture conditions.

The dewpoint of the dry air was measured by a System 580 hygrometer (Panametrics Inc., Waltham, MA) which has a range of -80 to +10 °C dewpoint. This sensor relates the amount of water adsorbed (through the electrical impedance) to the vapor pressure of water in the atmosphere around the gold-coated, anodized aluminum oxide element. The detector was insensitive to temperature and flow rate at these system conditions. Dewpoint temperature was chosen to report the data since it provides a sensitive measure of low moisture levels as shown in Figure 2.

The dryer system was set up prior to each run. The water reservoir was emptied of any remaining water by slowly pressurizing the system with the feed line open. The system was then vented, and the reservoir was refilled with 600 mL of deionized water. Finally, the feed valve was closed, the system pressure turned on, and the vent closed (in that order). The computer program used to record the dewpoint data from the hygrometer was Lablog2, version 3.52 (Quin-Curtis, Computer Boards, Inc.).

Air flow rates for both the product air and the purge air were measured by recording the time required for a 2 L graduated cylinder to fill with product or purge air. The 2 L cylinder was completely filled with water and inverted into a bucket of water (the small amount of water lost during the inversion was estimated). Output air was transported into the cylinder by a tube. The time to fill the cylinder was recorded three times for each run, and the average value was taken as the flow rate. The ideal gas law was then used to calculate the volume displaced at standard conditions of 293 K and atmospheric pressure.

Results and Discussion

Surface Area Effects and Operational Characteristics of Corn Grits. The separation of water from air or organic vapor occurs because of different rates of adsorption and the strength of the solute—starch bonds at the starch's surface. Vapor-phase water molecules have a much greater attraction to starch than do organic molecules. In a mixture of water and ethanol, the rate of vapor-phase adsorption of water on starch is 100−1000 times faster than that of ethanol (Lee et al., 1991). Mass transfer can control the rate of adsorption, limited by the diffusion of the molecules through the carrier gas to the surface of the starch (Westgate and Ladesch, 1993b). Since the starch matrix attracts the polar water molecules, the water can quickly form strong hydrogen bonds with the hydroxyl groups on the surface of the starch. If the contact time of water vapor with the starch is sufficiently long, the water may penetrate the intrastarch hydrogen bonds in the starch matrix. This results in a depletion of water near the surface and establishment of a diffusion gradient in the vapor, allowing kinetic adsorption.

A short contact time minimizes such diffusional effects, and the specific surface area becomes a dominant factor in water adsorption on starch. A series of experiments carried out in the pressure-swing dryer using four particle sizes of corn grits show that, as the particle size decreases, the external surface area of the sorbent per unit bed volume increases (Table 2) and the extent of drying of the gas at steady-state conditions is enhanced (Figure 3). The lowest dewpoint corresponded to the smallest particle size. The conditions of short contact time, low loading, and low inlet moisture content favored adsorption at the external surface of particle and minimized penetration of water into the interior portions of the grits. The decrease in dewpoint temperature with an increase in specific surface area follows a logarithmic function:

$$ T_D = 22.1 - 56 \log a \quad (3) $$

where $T_D$ is the dewpoint temperature and $a$ is the specific surface area (Figure 4). The data clearly show that surface area is a dominant parameter in determining the operational sorption capacity of the grits in a pressure-swing dryer.

Operational Characteristics of Corn Cob Flour. Cob 1420 material was evaluated in the air dryer to examine the adsorption capabilities of the cob flour alone, without the addition of starch granules. The large particle size of cob (1.05 mm) was selected as the control because it was comparable in size to the synthesized adsorbent particles. This material also had a surface area of 5.86 m²/g. At a pressure of 208 kPa and a controlled air flow rate of 1.3 SLPM, a steady-state dewpoint of −63 °C was achieved after 40 h. This dewpoint was maintained through 25 000 cycles, after which the run was discontinued, and the material was
removed from the chambers. Even though the final average particle size was found to be 1.04 mm after this run, there was about a 5% increase in the particles which were 0.85 mm or smaller, and several percent fines were present. This was significantly higher than the fines observed for corn grits after 254,000 cycles. While the outlet dewpoint is comparable to that of the smallest grits, the tendency for these cobs to form dust was undesirable. Nonetheless, the results showed that the cobs would, themselves, adsorb water to the same degree as starch. Hence, they provided a useful scaffold upon which the starch particles could be immobilized.

Surface Properties of Starch and Cobs. Corn starch is nearly spherical with an average diameter of 10 μm (Figure 5), while the cob 30 and cob 60 materials were 300 and 150 μm, respectively. The cobs 30 material has elongated pores of 50 × 20 μm (Figure 6) while cobs 60 particles had round pores with a size on the order of 10 μm (Figure 7). The cob 60 particle was chosen based on the SEM photomicrographs, since the pores were thought to be most likely to retain a high surface density of starch particles which could lodge into the holes.

Mixing of Starch with Cobs. The photomicrographs showed that the greatest amount of starch adhered to the cob after a mixing time of 60 min, when dry conditions were used. Extended periods of mixing did not result in an increase in the starch coating. The photomicrographs of the cob surface after 5 and 60 min of mixing are shown in Figures 8 and 9. Figure 9 shows how the starch particles assembled in the macropores of the cobs during the mixing process.

Selection of a Heat Treatment Method. The side away from the heat source became more smooth (Figure 10) compared to the side closest to the heat source which remained rough (Figure 11). It was hypothesized that heat forced the water vapor to the other side, where it condensed with starch to form a smooth film (Figure 10). The film is a likely contributor to the structural integrity of the starch cob matrix while the rough side contributed surface area through a dense and uniform coating of immobilized starch (Figure 11).
Characterization of Physical Properties and Operational Characteristics of Synthesized Adsorbent. The resulting materials were ground, giving an average particle size of 1.09 mm. The polysaccharide adsorbent gave a steady-state dewpoint of -63 °C compared to -70 °C for molecular sieves. The particle size distribution of the adsorbent particles after a 24-day (27 600-cycle) run showed some attrition of larger sized particles was noted. The masses of synthesized adsorbents packed initially in the two columns were 43.2712 and 42.4730 g, and 5.0% fines were generated in both chambers. The fines generated are similar to the attrition test where 0.50 g of the synthesized adsorbent generated 4.0% fines in 5 s. The same test performed on 0.53 g of molecular sieves gave 2.1% fines, thus indicating that the sieves are more resistant to attrition. Further improvement in the stability of the synthesized adsorbent is needed, which might be obtained by increasing the starch to cob ratio because the basis for adhesion is a starch hydrate which forms a viscous gel. The starch gel wets the surfaces to be joined (Williams, 1986; Kennedy, 1989). When the water is removed, such as occurs when the material is heated in the oven, a solid noncrystalline film forms between the surfaces (Satterwaite and Iwinski, 1973), holding them together. It is to be noted that NaOH lowers the gelatinization temperature of starch by disrupting the hydrogen bonds in the granules (Radley, 1954; Leach, 1965) and heating results in the formation of a viscous gel, producing the glue to hold the mixture together. Although the gelled starch provides much of the structural strength to the cob, there is an optimum concentration for this form of the starch since it forms a coating on the surface and blocks the pores, thereby decreasing accessible surface area.

Porosity of Synthesized Adsorbent. Mercury intrusion results showed that the porosity of the adsorbents (5.21 m²/g) was nearly 10 times greater than the corn grits (0.51 m²/g) of the same size. Density estimates showed that while the solid density was nearly the same as the starting material (1.4 g/cm³), the bulk density of the synthesized adsorbents (0.63 g/cm³) was less than half of that of the corn grits. This difference is also reflected by the packing densities of the corn grits and synthesized adsorbent which had 0.74 and 0.30 g/mL bed volume. The lower bulk density reflects the higher internal porosity of the synthesized adsorbent.

Crystallinity. X-ray diffraction patterns of corn starch, a 2:1 mixture of corn starch and cob flour, adsorbent particles before use in the dryer, and adsorbent pasteurization temperature of starch by disrupting the hydrogen bonds in the granules (Radley, 1954; Leach, 1965) and heating results in the formation of a viscous gel, producing the glue to hold the mixture together. Although the gelled starch provides much of the structural strength to the cob, there is an optimum concentration for this form of the starch since it forms a coating on the surface and blocks the pores, thereby decreasing accessible surface area.

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Figure 12. X-ray diffraction pattern for (a) corn starch, (b) corn starch and cob flour, (c) adsorbent particles (never used in air dryer), and (d) synthesized adsorbents after 86 400 cycles. Note: spike at Theta = 44 in (b) is due to the sample holder.

Table 3. Comparison of Synthesized Polysaccharide Adsorbent to Corn Grits

<table>
<thead>
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<th>Adsorbent</th>
<th>synthesized adsorbent</th>
<th>corn grits</th>
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</thead>
<tbody>
<tr>
<td>Pressure-Swing Dryer Runs (at 30 psig)</td>
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<td>11 600</td>
</tr>
<tr>
<td>steady-static dewpoint (°C)</td>
<td>-65</td>
<td>-63</td>
</tr>
<tr>
<td>Physical Properties</td>
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</tr>
<tr>
<td>bulk density (g/cm³)</td>
<td>0.63</td>
<td>1.27</td>
</tr>
<tr>
<td>solid density (g/mL bed volume)</td>
<td>1.39</td>
<td>1.40</td>
</tr>
<tr>
<td>packing density (g/mL bed volume)</td>
<td>0.50</td>
<td>0.74</td>
</tr>
<tr>
<td>particle size (µm)</td>
<td>1100</td>
<td>900</td>
</tr>
<tr>
<td>specific surface area (total) (m²/g)</td>
<td>5.21</td>
<td>0.51</td>
</tr>
<tr>
<td>external specific surface area (m²/g)</td>
<td>N/A</td>
<td>0.0065</td>
</tr>
<tr>
<td>% moisture at ambient conditions</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>material attrition (% of initial weight)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 s accelerated attrition test</td>
<td>4.0</td>
<td>N/A</td>
</tr>
<tr>
<td>operational attrition</td>
<td>3.0</td>
<td>N/A</td>
</tr>
<tr>
<td>(number of cycles)</td>
<td>(86 400)</td>
<td>N/A</td>
</tr>
<tr>
<td>Elemental Analysis (%)</td>
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<td></td>
</tr>
<tr>
<td>carbon</td>
<td>45.0</td>
<td>46.0</td>
</tr>
<tr>
<td>hydrogen</td>
<td>6.0</td>
<td>7.0</td>
</tr>
<tr>
<td>nitrogen</td>
<td>0.5</td>
<td>3.0</td>
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<tr>
<td>sodium</td>
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<tr>
<td>oxygen</td>
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<td>42.0</td>
</tr>
<tr>
<td>ash</td>
<td>2.0</td>
<td>2.0</td>
</tr>
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</table>

* N/A = not available.

The physical stability to more closely approach that of the natural material. The results clearly show that the specific (total) area is the key determinant of the adsorption characteristic of a polysaccharide material in a pressure-swing dryer.

Conclusions

Corn grits show an inverse correlation between the external surface area/mL of column and the moisture content of the outlet air when the grits are used in place of molecular sieves in a pressure-swing dryer. Study of the structural features of the corn grits by SEM, combined with their operational drying performance, resulted in the hypothesis that synthesis of high surface area agglomerates from natural materials, similar to those present in corn grits, may result in a superior adsorbent. This work shows that polysaccharide sorbents with surface area on the order of 5 m²/g give drying capacities which are superior to the natural material, corn grits.

Acknowledgment

The material on the synthesis and evaluation of polysaccharide sorbents was supported through NSF Grant BCS-9202702. The evaluation of surface area effects for corn grits was supported by USDA Contract 92-37500-8013. We thank Dr. Janet Lovell of the Civil Engineering Department at Purdue University for running the surface area tests, Dr. Daniel Lee of the Chemistry Department for performing the elemental analyses reported in this paper, The Andersons for donating cobs, and Short Milling Company for the grits. We also thank Kyle Beery and Subir Basak for helpful comments during the preparation of the manuscript.

Nomenclature

\( A \) = specific surface area, m²/g
\( a \) = external surface area/mL of column volume
\( d_v \) = volume of mercury
\( m \) = % moisture content, weight of water/weight of total mass \( \times 100 \)
\( P \) = external pressure
\( T_b \) = dewpoint temperature, °C
\( V \) = bed volume, cm³
\( W \) = weight of sorbent packed into the column, g

Greek Symbols

\( \phi \) = contact angle
\( \gamma \) = surface free energy of liquid mercury
Literature Cited


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