International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-3, Issue-3, May-2016

Evaluation of the Effectiveness of Super Absorbent Polymers (SAPs) In Air Dehumidification for Maize Drying

Odero Shadrack O.
Department of Environmental and Biosystems Engineering, University of Nairobi, School of Engineering, P.O Box 30197-00100, Nairobi, Kenya,

Eng. Dr. Mbuge D. Onyango
Department of Environmental and Biosystems Engineering, University of Nairobi, School of Engineering, P.O Box 30197-00100, Nairobi, Kenya,

Emmanuel K. Mutai
Department of Agricultural and Biosystems Engineering, School of Engineering, University of Eldoret, P. OBox 1125 - 30100, Eldoret, Kenya

Mutuli Gibson Peter
Department of Environmental and Biosystems Engineering, University of Nairobi, School of Engineering, P.O Box 30197-00100, Nairobi, Kenya,

ABSTRACT
Major maize grain losses have been experienced in various parts of the World as a result of infection by aflatoxin producing moulds called *Aspergillus flavus*. Aflatoxin infection is caused by high temperature, high relative humidity of the surrounding air and high moisture content of the grain as a result of ineffective drying of maize. Aflatoxin infection leads to losses of human lives from consumption of contaminated as well as loss of animals. Most farmers depend on direct sunlight drying. This research aimed to determine the effectiveness of Super Absorbent Polymers in air drying by studying some of its basic properties in air drying in order to find out its suitability to curb these problems of aflatoxin infection in maize grain. In particular, this project explored the possibility of using super absorbent polymers to pre-dry air to be used in drying grain. Dry desiccant drying reduces the use of electricity and fossil fuels and promotes the viability of seed that are sensitive to high temperatures. In an experiment set up to dry maize grains using desiccated air using super adsorbent polymer (SAP), a single layer of the Super Absorbent Polymer effectively dried flowing air between 20°C and 60°C with an optimum drying temperature of 23°C and reduced relative humidity of air by approximately 8% at 80% relative humidity at room temperature. Moisture absorption rate of SAP was found to increase with increase in air velocity and relative humidity with an optimum absorption at 0.5m/s and 100% relative humidity.

Index Terms: Aflatoxin, Super Absorbent Polymer, Maize, Desiccant, Drying, moisture content

1.0 INTRODUCTION
Desiccant drying is a viable and attractive option to hot air drying in a number of instances including seed (planting material) drying which requires to be done at low temperature, since the viability of seed diminishes with increase in temperature, [1] and [2]. Desiccant drying may also be useful in places where the supply of grid power and fossil fuel is scarce such as in developing countries. For very heat-sensitive products like mushroom, a study found desiccant drying to be the most appropriate compared to freeze dryers which are expensive and time consuming technique. The structure and chemical constituents of the mushroom were maintained [3]. In Morocco [4] found improved quality and reduced drying time, from 52 to 4h, for the drying of apricots. [5], in combining a rotary desiccant wheel system with a solar-powered adsorption refrigeration system for the cooling of grain, found better performance in terms of energy savings and lower operating costs for this hybrid system compared to a purely adsorption refrigeration system. *S*orption drying (adsorption and absorptions) removes the water from the air by absorbing it using hygroscopic substances such as water solution of calcium chloride and magnesium chloride, a solution of lithium chloride, a silica gel, potassium chloride, activated aluminium, calcium chloride, salts of lithium chloride and lithium bromide or super absorbent polymer [6], [7].

Past researchers carried out investigations on sorption drying of mustard, sunflower, soybean and groundnut oilseeds in fluidized bed of seeds and silica gel under different conditions. They varied different air drying conditions such as air temperature, bed height, feed rate, initial moisture content and flow rate of hot air. Desiccants are materials that have a strong affinity for water. They are classified according to their physical sates as either solid desiccants or liquid desiccants.

The strength of a desiccant is measured by its equilibrium vapour pressure. The solid desiccants considered in this study was Superabsorbent Polymer (SAP). Super Absorbent Polymers (SAPs) are polymers that can absorb and retain very large amounts of a liquid relative to their own mass. In distilled water, a Super Absorbent Polymer may absorb 500 times its weight. The ability of SAP to absorb moisture is affected by the type and the degree of cross-linking. The lower the cross-linking, the higher the absorption capacity and swelling. Low cross-linking also results in soft and stickier gel formation on absorption of water. Higher cross-linking will give low absorption capacities but will give gels that are firm and maintain particle shape after absorbing water even under modest pressure. The swelling of cross-linked SAP is based on the concept of osmotic pressure, where SAP becomes the semi-permeable membrane retains absorbed fluid and does not allow it to leave the polymer into the surrounding solution. Because of the ionic differences on either side of the polymer, osmotic pressure exerted by the gradient causes the polymer chain to swell as further ions diffuse in [8], [9], [10]).

Unheated air drying depends on the ambient air having moisture content less than saturated air. The relationship between the volumes of air passed, specific volume, initial moisture content and final moisture content is given by Equation 1 [11].

$$Q = \frac{v}{mi - mf} \qquad (1)$$

Where Q = volume of air passed.
v = specific volume of air.
mi = initial moisture content at a given temperature.
mf = final moisture content at a given temperature.

The concept of using SAP for dehumidification has been applied to the desiccant wheel where the performance of the wheel is determined by the moisture removal capacity (MRC), and regeneration specific heat input (RSHI). MRC is presented as mass of moisture removed per hour, (lbs/hr or kg/hr), and RSHI as hourly regeneration energy supplied to the device, normalized by MRC, (kBtu/lb or kJ/kg) [12].

$$MRC = \rho_{std} * 60Q * \frac{1}{7000} \Delta GPP \qquad (2)$$

$$RSHI = \dot{E}_{regen} / MRC \qquad (3)$$

Where:
MRC = moisture removal capacity, lb/hr
ρ_{std} = standard density of air, 0.075 lb/ft^3
Q = process air volume flow rate, (ft^3/min)
ΔGPP = absolute humidity depression of the process, grains/lb
RSHI = regeneration specific heat input, kBtu/lb
$\dot{E}_{regen}$=thermal energy input rate, kBtu/hr.
Equation 3 rates the test itself rather than the device being tested: Moisture Mass Balance, defined as:
Moisture mass balance = MRC/MRR, (4)

Where MRR, Moisture Removal Regeneration, is analogous to MRC, however it is calculated using regeneration flow rate and grain pickup across the wheel. It confirms that the measured adsorption on the process side matches the measured desorption during regeneration, and it must fall in the range of 0.95-1.05 for a test to be considered valid. This does not imply that the MRC is known to within five percent; the acceptable range is empirical, based on decades of collective industry experience. It is a tough standard to satisfy because of the inherent difficulty in psychrometric measurement, but a balance outside this range indicates a condition in the system that must be corrected [12].

In this study air was forced through desiccant to reduce the ambient relative humidity and the dry air would be passed through wet maize grain to dry it as shown in Figure 1.

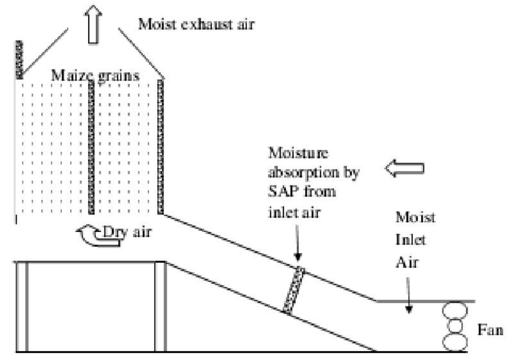

Figure 1: Drying method using SAP to dehumidify ambient air for grain drying

The main objective of the study was to determine effectiveness of Super Absorbent Polymers on air drying to dry maize. The specific objectives were to determine the effect of ambient air temperatures, velocity and relative humidity on absorptive rate and capacity of Super Absorbent Polymers (SAP).

2.0 MATERIALS AND METHODS

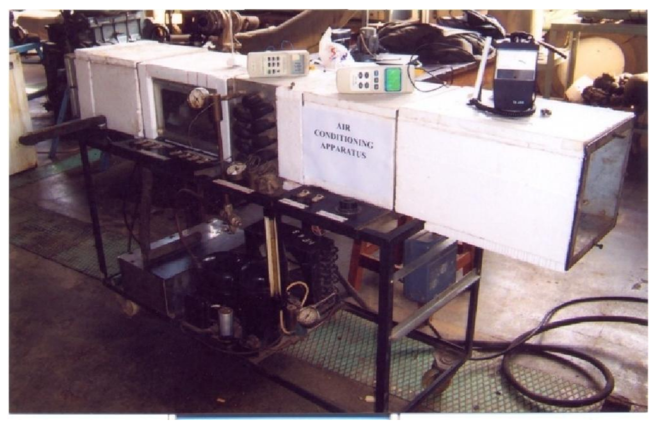

Plate 1: Pictorial view of experimental set-up

The experimental set up was as presented in plate 1 and Figure 2.

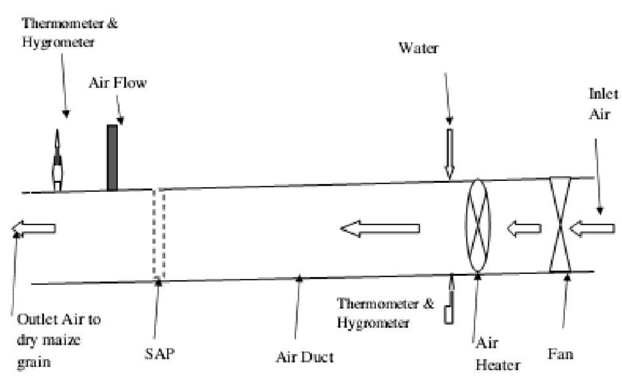

Figure 2: Experimental setup

The air duct in Figure 2 was a square 200mm by 200mm cross sectional area and 2000mm long. It was insulated to minimize heat losses as well as external heat effects. The fan had an auto step down transformer for air speed control. Air heaters used were coils with controls to vary air temperature from 20°C to above 100°C. A water heater steam supplied into the duct through the nozzle to vary the relative humidity of the air. The system had compartments for attaching/ inserting equipment for measuring various air parameters of importance to the researcher such as temperature, humidity and velocity.
The SAP used has the brand name Luquafleece® supplied by BASF in Germany. In this product, sodium polyacrylate is embedded in fabric and is white in colour. It was supplied in roll of 40m long, 1m wide and 0.003m thick sheets of fabric. For all the experiments, SAP pre-dried to 0% moisture content was placed perpendicular to the direction of the air flow, covering the entire duct area of dimensions 200mm × 200 mm. Only one layer of SAP was used.

To determine effect of temperature on moisture absorption rate and capacity of SAP, the air velocity and the relative humidity were maintained at 0.5m/s and 66% respectively. The air temperature was varied from 20°C through 60°C in steps of 10°C. Inlet and outlet RH measured and recorded until the inlet and outlet RH remained constant, meaning that the SAP had stopped absorbing moisture. For each temperature level, the final mass and moisture content of the SAP were determined. A curve of moisture content versus temperature was plotted in Figure 3.

The effect of velocity was determined by maintaining air temperature at an average value of 22°C and inlet relative humidity at an average value of 76%. The air velocity was varied from 0.1m/s to 5m/s in steps of 0.1m/s. The final SAP moisture content was determined for each air velocity and the results plotted in Figure 4.
To determine the range of relative humidity at which the SAP functions, air temperature was maintained at a constant value of 26°C and air velocity kept constant at 0.5m/s. Humid air was then blown through the SAP and the moisture content of the SAPs determined when equilibrium was reached. The inlet average relative humidity of air used were 42%, 48.71%, 69.63%, 79%, 88.31% and 100%. The results obtained were plotted in Figure 5.

3.0 RESULTS AND DISCUSSION

The variation in absorption rate with respect to change in temperature is presented in Figure 3.

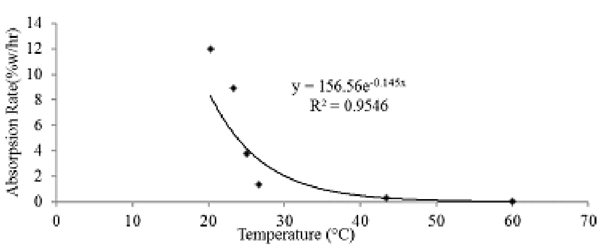

Figure 3: Curve of temperature versus absorption rate at 66% RH and 0.5m/s of air

From Figure 3, it is clear that super absorbent polymers moisture absorption rate decreases exponentially with increase in temperature from 20 ^{0}C up to 60 ^{0}C when it absorption stops and instead the polymer starts releasing its own moisture to the flowing air/environment due to vaporization at the considerably high temperature. The results in Figure 3 imply very strongly that the SAP is best applied for moisture absorption in moving air between air temperature of 20^{0}C and 30^{0}C. Therefore this result indicates that SAP can be used optimally at temperatures lower than 30°C and that desiccant drying with SAP can be used to pre-drying of air before heating it in case heating is required to raise its enthalpy.

The results in Figure 4 represent the relationship between air velocity and absorption rate at constant relative humidity and temperature.

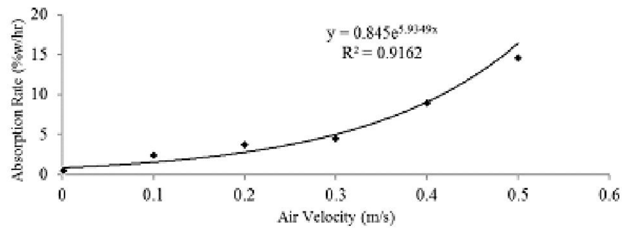

Figure 4: Air Velocity Versus Absorption rate at 76% RH and temperature of 22°C

From Figure 4, the rate of absorption increases exponentially with increase in air velocity within the range of velocities studied. It can be deduced that the rate of absorption increases as the velocity increases since, with increase in velocity, there are more moisture particles interacting with the SAP per unit time.
When the relative humidity was varied at constant temperature (room temperature) and air velocity (0.5m/s), Figure 5 was constructed.

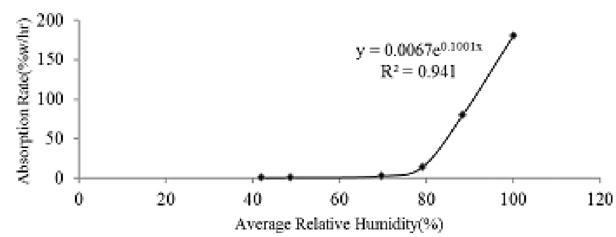

Figure 5: Effectiveness of SAPs in reducing relative humidity of air at average temperature of 26°C and velocity of 0.5m/s

From Figure 5, it was deduced that the absorption rate of super absorbent polymers absorption rate increases exponentially with increase in relative humidity when temperature and air velocity are kept constant. At low values of relative humidity up to 60%, there is very little absorption of moisture. However, the absorption rate increases exponentially as the relative humidity approaches saturation point. These results show that air drying efficiency by SAP is only viable for air with relative humidity above 80%. For most climates, the typical relative humidity values are above this value and therefore air drying by SAP would find wide application in such areas.

Figure 6 shows the absorption of moisture by SAP over time. From Figure 6, it is clear that the absorptive capacity of SAPs is greatest in the first minutes and diminishes over time following a decay curve. The average change of relative humidity for air with an initial relative humidity of about 80% passing through the SAP at about 0.4% m/s is 8%. This result presents a good case for the use of SAP in air drying considering that only one layer of SAP was responsible for the 8% decrease in relative humidity.

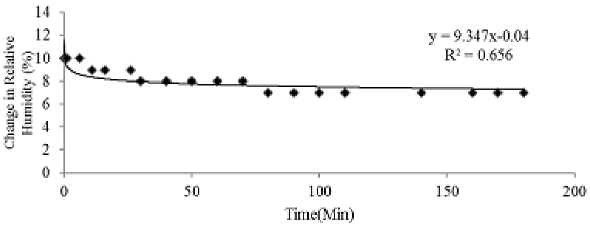

Figure 6: Change in Relative humidity versus time at constant temperature, relative humidity and air velocity of 21.6°C, 69.60% and 0.5m/s.

4.0 CONCLUSIONS

SAP effectively dried flowing air within a large range of temperature between 0°C and 60°C. Beyond 60°C, the SAP starts to lose moisture to the hot air, with an optimum drying temperature of 23°C.

SAP was found to reduce relative humidity of air by approximately 8% working with average conditions of 80% relative humidity, at room temperature and with an air velocity of 0.4 m/s.

Moisture absorption rate of SAPs in drying air increases with increase in air velocity. It was minimum at no flow (0m/s) but optimum at 0.5m/s after which it started to decline.
Moisture absorption rate of superabsorbent polymers in drying air increases with increase in relative humidity of flowing air up to 100% relative humidity.

ACKNOWLEDGMENTS

We would like to express our appreciation to the School of Engineering, University of Nairobi, staff of the Department of Environmental and Biosystems Engineering through the Head of Department Eng. Prof. Ayub Gitau for allowing us unlimited use of their laboratory and equipment and laboratories for research. We would also like to extend our sincere appreciation to Kenya Technical Teachers College for financial and technical support in realizing the completion of this project.

REFERENCES

[1] Zulhisyam A.K., C. T. Seng, A. A. Ismail, N.N. Azwanida, S. Shazani and M.H. Jamaludin (2013). Effect of Storage Temperature and Seed Moisture Contents on Papaya (Carica papaya L.) Seed Viability and Germination, Journal of Sustainability Science and Management, Volume 8 Number 1, June 2013: 87-92.

[2] Mukhopadhyay, D., S.S. Parihar, J. S. Chauhan and S.C.J. Preeti (2010). Effect of Temperature and Desiccation on Seed Viability of Lepidium sativum L., New York Science Journal 2010; 3(5)

[3] Gurtas Seyhan, F., & Evranuz, O. (2000). Low temperature mushroom drying with desiccant dehumidifiers. Drying Technology, 18, 433–446.

[4] Hodali, R., & Bougard, J. (2001). Integration of a desiccant unit in crops solar drying installation: optimization by numerical simulation. Energy Conversion and Management, 42, 1543–1558.

[5] Dai, Y. J., Wang, R. Z., & Xu, Y. X. (2001). Study of a solar powered solid adsorption desiccant cooling system used for grain storage. Renewable Energy, 25, 417–430.

[6] Chua, K.J. and S.K. Chou (2003). Low-cost drying methods for developing countries, Trends in Food Science & Technology, Volume 14, Issue 12, December 2003, Pages 519–528, Elsevier.

[7] Rane, M.V. and Easow, R.R. (2005). Liquid Desiccant-Based Air-Conditioning. India Institute of Technology, Mumbai, India.

[8] Dutkiewicz, J.K. (2002). Superabsorbent Polymers and Waste Solidification. Journal of Biomedical Material Research. Volume 63.

[9] Kuruwita-Mudiyanselage, T. D., (2008). Smart Polymer Materials. Ph.D. Thesis, Graduate College, Bowling Green State University, Ohio, USA.

[10] Zohuriaan-Mehr, Mohamed J. and Kourosh Kabiri (2008). Superabsorbent Polymer Materials: A Review. Iranian Polymer Journal 17 (6), 2008, 466-468.

[11] Donnel, H., (2013). Farm power and machinery management. Scientific International Pvt. Ltd. New Delhi, India.

[12] Slayzak S.J. and Ryan J.P. Desiccant Dehumidification Wheel Test Guide December 2000 NREL/TP-550-26131

BIOGRAPHY

Odero Shadrack O. holds a B.sc. in Agricultural Engineering from Egerton University and a Masters from University of Nairobi. He is a graduate Engineer and a graduate member of institution of Engineers of Kenya. Currently he is a Lecturer in the department of Mechanical Engineering at Kenya Technical Teachers College Nairobi.

Eng. Dr. Mbuge Onyango D. is a graduate of Egerton University and holds both masters and PhD from University of Nairobi. He is a registered Engineer with Engineering registration Board of Kenya and a Cooperate member of Institution of Kenya Engineers. He is a senior lecturer at the department of Environmental and Biosystems Engineering, University of Nairobi.

Emmanuel Kinyor Mutai holds a Diploma in Soil and Water Engineering from Egerton College, a B.Sc. in Agricultural Engineering from Egerton University. He also holds Master degree in Agricultural Engineering, Processing and structures Option from University of Nairobi. He is PhD student at the University of Nairobi. He is a graduate member of both Engineering Registration Board and Institution of Engineers of Kenya. He is a Lecturer at the Department of Agricultural and Biosystems Engineering, University of Eldoret.

Gibson Mutuli Peter holds a Bs.c. in Industrial Engineering from Makerere University and M.Sc. in Environmental and Biosystems Engineering from University of Nairobi and currently undergoing PhD at the same University. He is a graduate member of both Engineering Registration Board and Institution of Engineers of Kenya. He is also a consultant in industrial Engineering.

