Pervaporation; Precision Irrigation of Strawberries Using Moderate EC Water Sources

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Introduction

There are many areas of the globe where crop growth is limited by access to suitable water- it's there, but is of too high a salinity for use on most crops. The extreme, of course, is land next to the ocean. In this presentation we would like to share information about a technology known as "pervaporation" that can be used to precisely deliver water to crops using lower quality water. You may be hard pressed to find a definition of pervaporation; it's not in any standard dictionary, and most textbooks mention it only in passing while discussing membranes separation processes including it's better known cousin reverse osmosis. For instance, a quick search of a web browser came up with 180,000 hits on reverse osmosis, but only 9,000 on pervaporation, a 20:1 ratio. Industry is a little more aware; the ratio of mention in US patent abstracts is only 6:1.

Definition of Pervaporation

Pervaporation is the separation of mixtures by differing rates of diffusion and solubility in a non-porous membrane, followed by an evaporative phase change. The permeant appears to evaporate through the membrane. The separation occurs because different materials permeate through such membranes, also termed as dense or monolithic, at different rates. This observation dates back to at least 1831, but it was not until the 1960's that scientists started developing commercial applications. Some of these include;

- treatment of wastewater contaminated with organics
- recovery of valuable organics from process side streams
- dehydration of ethanol and isopropanol
- purification and harvesting of organics from fermentation broths

Typically these technologies employ a membrane in sheet or tubular form; the product that permeates through the membrane is removed by vacuum or condensation.

Pervaporation Basics

The flow rate of a permeant across a dense is described by the following equation;

$J = DS\,(C_1 - C_2)/\,l$

Terms are defined as follows;

J = Flow rate
D = Diffusion coefficient
S = Solubility constant
l = thickness
C_1 = Concentration of permeant in feed
C_2 = Concentration of permeant in product

The fundamental consequences for pervaporation in the context of a membrane used in irrigation are;

- **Flow increases as $(C_1 - C_2)$ increases**

This means that the flow varies depending on the difference in relative humidity between the fluid in the membrane system and the exterior soil water content. Exact determination requires understanding of things like the rate at which the water vapor condenses, how it moves in the soil, etc. Dry soil and low moisture content will pull water vapor across the membrane; if the soil is at capacity, it will not. It has the potential to provide water to the crop as it needs it

- **Flow increases as membrane thickness decreases**

This provides a means to fine tune the delivery capability of the membrane to meet the needs of a particular crop

- **Flow increases with increasing temperature**

The diffusion coefficient correlates with temperature through the Arrhenius equation. Just like chemical reactions go faster at higher temperature, as the temperature increases, the membrane is capable of providing a greater flux of water

- **Permselectivity (α) is independent of membrane thickness**

$\alpha = Cproduct / Cfeed$

$Separation\ (\%) = (1 - \alpha)\ 100$

Features a Pervaporation Irrigation System Can Provide

The immediate benefit from a pervaporation based irrigation system is salt rejection. Because the membrane is non-porous, little or no salt will pass through it. In the same vein, the membrane will be a barrier to pathogens and non-soluble materials.

A pervaporation irrigation system will deliver water only when the surrounding soil is not at capacity; this creates a situation in which delivery occurs only on demand, when the crop requires it. This opens up opportunities for significant water conservation through precise irrigation.

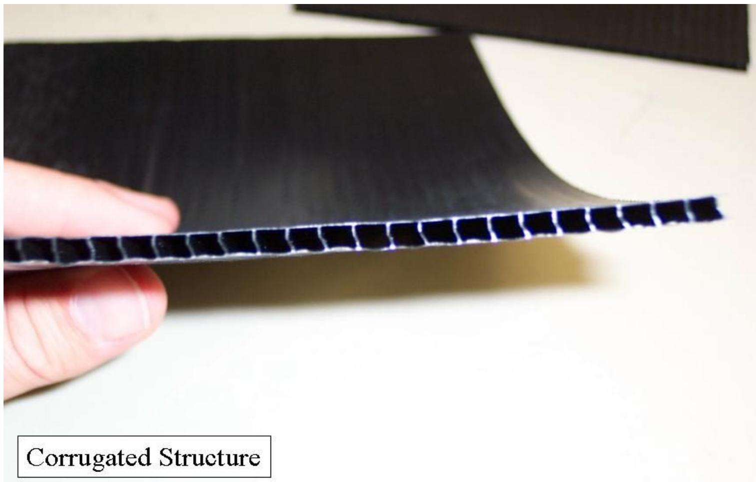
On the operations side, on demand delivery should reduce the control systems needed to initiate irrigation events; the system can always be "on". In addition, no backpressure is required to force the flow, so energy requirements for pumping can be reduced. It is possible that even filtration requirements can be reduced, as water deliver is not dependent on small holes which can be clogged.

Design of a Pervaporation Based Irrigation System

The key physical attributes of the membrane would the capability to transmit enough water to meet the needs of crop and to provide excellent barrier to any dissolved salts. Once this basic science in place, it must also mechanical integrity and strength to be efficiently installed without damage and to have mechanical integrity for its expected lifetime. All this and it must deliver value to the grower; the payback for installation must meet his or her financial return criteria based on improved return or reduced costs.

Description of a Pervaporation Based Irrigation System

A system under current evaluation is based on specific grades of a polymer known to the plastics industry as a ***polyetherester***. Its key attributes are strength and extremely high water permeability. These polymers can be converted into strong and durable membrane based structures using conventional thermoplastic extrusion technology. The specific structure under evaluation is termed “corrugated sheet”;



Corrugated Structure

Installation is carried out using conventional SDI machinery with a modified drop tube;

Field Installation

Description of a Pervaporation Based Irrigation System

Rows of membranes are connected to a header system using conventional piping;

From a distance, you can't tell what irrigation system is in use;

Properties of a Pervaporation Based Irrigation System

Dimensions	
Width	85 mm (6.75 inches)
Height	4 mm (0.16 inch)
Channel width	4 mm (0.16 inch)
Top/ bottom membrane gauge	0.2 mm (0.007 inch)
Roll length	up to 180 m (600 feet)
Color	Black
Water delivery	24 –32 USG/ 100 linear ft/ 24 hrs
Separation of Dissolved Salts	≥ 95%

Typical Trial Conditions

Seven trials of 4-8 strawberry beds were carried out over October 2002 to mid 2003 between Oxnard and Watsonville in coastal California. One additional trial was conducted in Mexico. Typical conditions were as follows;

Soil Type	predominantly sandy loam
Bed Specifics	
Center line	64 inch
Top	40 inch
Plants	4/ bed
Row length	200-250 feet
Mulch film	dark opaque
# Pervaporation lines/ bed	2
Configuration of Pervaporation lines	surface or buried (5" depth)
Water EC	1-2.5
Control	Drip tape

Results

Field results were analyzed in the following terms. The small number of trials and the amount of natural precipitation led to wide variation in results between trials.

Total marketable berry weight		
	Buried	up to 88% of control
	Surface	up to 100% of control
Plant Vigor		No significant difference
Plant diameter		No significant difference
Soil salinity over trial		Control generally higher
Total water usage		
	Buried	typically 45%
	Surface	typically 60%
Soil Moisture		Control always higher

Conclusions

Pervaporation is a new technology that has the potential for irrigation of high value row crops, with the benefits of;

- Salt exclusion from moderate EC water sources
- Reduction in overall water needs
- Water delivery on demand