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# Opportunities to use of self pressurized membrane bioreactors in food industry

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***Abstract***

The effect of self pressurization due to the accumulation of gas produced by specific microorganisms can be used as the driving force for hydraulic and separation processes. This paper aims to explore more possibilities for using these types of bioreactors to improve some processes and also to minimize energy consumption.

***Keywords***: self pressurized membrane bioreactor, yeast, modular membrane bioreactor

## 1. Introduction

The membrane separations involve the action of a force on the liquid what must be separated, also called driving force, for permeate to penetrate the microporous membrane. This thing imply the use of energy not negligible for driving the pressure pumps.

Using the carbon dioxide derived from yeast fermentation to obtain pressure needed for membrane separation processes can reduce the energy consumption by eliminating the pressure pumps and as result it will increase the the overall efficiency.

Due to the existence of the two processes fermentation and membrane separation there are two options of plant operation:

- direct separation, when is necessary to separate components from nutritive medium (ex. ethanol produced by yeast fermentation) or
- indirect separation when the solution who must be separated is another then nutritive medium and is in another compartment in direct contact with membrane. In this case there is a direct communication with bioreactor only through carbon dioxide channel.

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## 2.Material and Method

The design of installation is modular so there is possibility to create an ensemble of many modules in series for desired production. Each module is made from successive boards coupled into a whole and the interior profile of each board create an specific internal cavity in module for each process.

Carbon dioxide and ethanol production process depends on yeast viability and also by nutritive medium composition. Entire process must be conducted so permanently all parameters must be constants. Yeast and nutritive medium alimentation and evacuation must be performed simultaneously to have a constant carbon dioxide and ethanol production. Being a closed environment carbon dioxide accumulate at the top of the bioreactor and as result we obtain the pressure needed for membrane separation in next module.

The best method applied using membrane technique for alcohol removing from nutritive medium is pervaporation. By definition, pervaporation is a method for the separation of mixtures of liquids by partial vaporization through a non-porous or porous membrane.

It is considered an energy efficient combination of membrane permeation and evaporation.

Pervaporation involves the separation of two or more components across a membrane by differing rates of diffusion through a thin polymer and an evaporative phase change comparable to a simple flash step. A concentrate and vapor pressure gradient is used to allow one component to preferentially permeate across the membrane. Applying a vacuum to the permeate conduct to condensation of the permeated vapors. Pervaporation is typically suited to separating a minor component of a liquid mixture, thus high selectivity through the membrane is essential.

Pervaporation can used for breaking azeotropes, dehydration of solvents and other volatile organics, organic/organic separations such as ethanol or methanol removal, and wastewater purification. An azeotrope mixture is a combination of two or more liquids in such a ratio that its composition cannot be changed by simple distillation [1]. This occurs because, when an azeotrope is boiled, the resulting vapor has the same ratio of constituents as the original mixture.

The membranes used in pervaporation processes are classified according to the nature of the separation being performed. *Hydrophilic membranes* are used to remove water from organic solutions. These types of membranes are typical made of polymers with glass transition temperatures above room temperatures. Polyvinyl alcohol is an example of a hydrophilic membrane material. *Organophilic membranes* are used to recover organics solutions. These membranes are typically made up of elastomer materials (polymers with glass transition temperatures below room temperature). The flexible nature of these polymers make them ideal for allowing organic to pass through. Examples include nitrile, butadiene rubber, and styrene butadiene rubber.

The membrane performance can be affected by several factors: membrane structure, feed solution composition, system pressure and device configuration.

Higher fluxes can be obtained with an increased thermal motion of the polymer chains and the diffusing species. Properties of the polymers that affect diffusion include the degree of cross-linking, and porosity. Molecular-level interactions between membranes and diffusing species is expressed via a permeability constant used in the Arrhenius relationship:

$$P = P_o e^{-Ep/RT} \qquad (1)$$

where,

$E_p$ - activation energy
$P_o$ - permeability constant
R - general constant of gases
T - temperature

The main pervaporation characteristics are: molecular flux, permselectivity and permeability coefficient

Molecular flux is the amount of a component permeated per unit area per unit time for a given membrane.

$$J_i = Q_i / (At) \qquad (2)$$

where,

$J_i$ = Flux of component "i" (moles/h $cm^2$)
$Q_i$ = Moles of component "i" permeated in time "t"
A = Effective membrane surface area ($cm^2$)

The performance of a given membrane can be expressed in terms of a parameter called permselectivity, α:

$$\alpha = (X_i^p/X_j^p)/(X_i^f/X_j^f) \qquad (3)$$

$$\alpha = (V_i^p\rho_i^p/V_j^p\rho_j^p) / (V_i^f\rho_i^f/V_j^f\rho_j^f) \qquad (4)$$

where,

X – weight fraction
V – volume fraction
ρ – density

Assuming the density of the components in the feed is the same, then:

$$\alpha = (V_i^p/V_j^p)/ (V_i^f/V_j^f) \qquad (5)$$

Superscripts "p" and "f" denote "permeate" and "feed" respectively while "i" and "j" represent individual components.

The molecular flux for pervaporation across a membrane can be related to the permeability coefficient by:

$$J_i = -P_i \Delta^{p/l} \qquad (6)$$

Here $\Delta P = P_1 - P_2$ and

$P_1 = P_i^o X_{r,i;}\gamma_i$ & $P_2 = P\, Y_{p,i}$ , therefore

$$\Delta P = (P_i^o X_i - P\, Y_{p,i}) \qquad (7)$$

Equation 6 becomes:

$$J_i = - p_i (P_i^o X_{r,i} - P\, Y_{p,i})/L \qquad (8)$$

$$P_i = -J_i L/(P_i^o X_{r,i,\gamma i} - P\, Y_{p,i}) \qquad (9)$$

where:

$P_i$ – permeability coefficient of component i;
$\gamma_i$ – activity coefficient of component i;
$\Delta P$ – pressure difference across the membrane;
$P_i^o$ – saturation pressure of pure component i at feed temperature;
$X_{r,i}$ – mole fraction of component i in liquid feed;
$X_{p,i}$ – mole fraction of component i in permeate;
$J_i$ – flux of component i
L – membrane thickness;
k – permeability constant

## 3.Results and discussion

According to model presented above, the azeotrope solutions can be separated applying vacuum at permeate zone witch can permit to low boiling temperature constituent from mixture to condense.

The fermentation process, by carbon dioxide production, create in system the pressure needed for direct separation. Also, this pressure can be used to create vacuum for condens the permeate using a vacuum system.

The general schema of self presurized membrane bioreactor with pressure drived vacuum system is presented in figure 1.

The vacuum system is controlled by an ensemble of solenoid valves whose opening is given by the level of vacuum needed for separation in membrane module. The pressure drived vacuum system is illustrate in figure 2.

In food industry this system can have a great impact because its main characteristic: this type of bioreactor can produce the pressure needed as driving force for useful compounds separation from liquids and also separations of azeotrope solutions like ethanol-water by creation of vacuum.

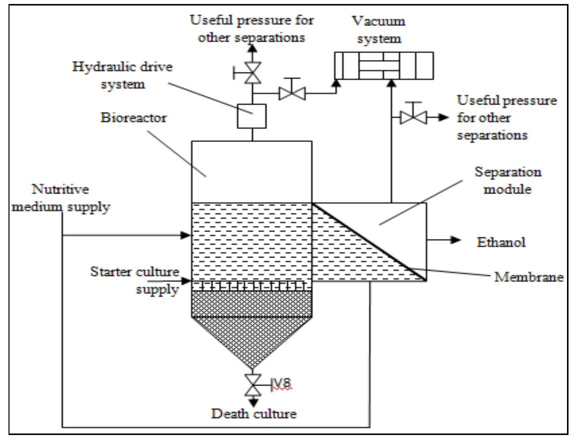


***Figure 1.*** Self pressurized membrane bioreactor with vacuum system

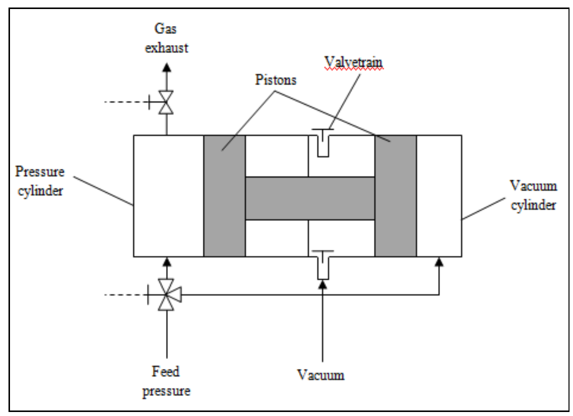


***Figure 1.*** Vacuum system used for pervaporation process

Using only pervaporation, this system can be implemented in some areas of food industry as follow:

- Pollution control applications [2];
- The treatment of wastewater contaminated with organics [2];
- Harvesting of organic substances from fermented broth [3];
- Separation of 99.5% pure ethanol-water solutions [4];
- Recovery of valuable organic compounds from process side streams [5]

If it is not used the vacuum system, the pressure generated by the membrane bioreactor can be used in any places where separation through membrane is needed.

## 4.Conclusions

The system presented above can have great perspective to be implemented in food industry. Its versatility in use, the low energy consumption and the modularity make this system useful in many fields were is needed pressure and/or separation.

Latest developments in yeast growth, genetic implications in finding of new yeast strains to increase production of carbon dioxide conducted to this moment when we can use microorganisms metabolic energy generated during fermentation in other fields of food industry and not only.

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