DEVELOPMENT OF MEMBRANE OXYGEN ENRICHMENT SYSTEM FOR WASTEWATER AERATION SYSTEM

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ABSTRACT

The availability of hollow fiber membranes and membrane modules has brought forth the development of simple processes for the production of oxygen and nitrogen from ambient air. In conventional wastewater aeration systems, compressed air is directly injected into the wastewater for aeration processes. However, air contains only 21 percent of oxygen and most of this oxygen is often not ideally transfer into liquid phase, thus making it difficult to obtain even the minimal dissolved oxygen level required to sustain organism growth and maintain the desired production level.

The simplicity and low capital investment of membrane oxygen enrichment system have lead to the development of membrane system for oxygen enrichment. The aim of this particular project is to apply the locally produced asymmetric polysulfone hollow fiber membranes into a locally developed air separation system, which able to enrich the percentage of oxygen into wastewater aeration system for oxidation processes. This would reduce time required for oxidation and simultaneously reduces energy consumption in the compressor thus leading to an ultimate cost saving.

Keywords: Polysulfone; Hollow fiber membranes; Oxygen enrichment system; Wastewater aeration system; Dissolved oxygen

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Introduction

The production of oxygen via surrounding air separation is a major important in many industries and has been practiced nearly a century. The three technologies that are commercially significant for air separation are cryogenic distillation, non-cryogenic methods of pressure swing adsorption (PSA) and membrane separation. The oxygen enrichment from air by selective permeation through polymer membranes is probably the oldest and most widely investigated membrane process for gas separation. Matson et al. [1] have correctly stated, " There seems to be an almost emotional appeal for membrane oxygen enrichment, perhaps because air is free and the market for oxygen is huge". The use of oxygen-enriched air from selective permeation membranes has grown to well till having extended its industrial reach to newer fields of chemical, fermentation, medical purposes and combustion.

Membrane air separation is based principally on the use of composite asymmetric hollow fiber membrane that permeate oxygen faster than nitrogen. Membrane systems derive their economic and technical attractiveness from their simplicity and low capital investment relative to

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both adsorptive and cryogenic separation, whereas membrane systems primarily require only a compressor and a membrane assembly. By comparison, adoption of membrane technology for oxygen production has not been extensive, primarily due to the lower purity levels, which can be achieved with currently available commercial polymeric membrane. A number of companies worldwide currently offer membrane enrichment systems (or modules) with oxygen-enriched air capacities ranging from under 10 to over 500 SCFH and oxygen purities ranging from 28 – 60 % [2]. Higher oxygen concentrations are possible with a membrane recycle process in which the permeate stream is recompressed and passed over a second membrane unit. Although technical feasible, such an approach is relatively expensive.

This paper summaries some of the background of oxygen enrichment and wastewater aeration system, and also describes recent new developed oxygen enrichment system by using locally produced asymmetric polysulfone hollow fiber membrane, which feasible to provide oxygen-enriched air into a wastewater aeration tank. Particular emphasis is placed on the design and fabrication of the membrane system.

Initial Exploratory of Wastewater Aeration System

A number of different methods have been employed for wastewater treatment. Many of these methods involve biochemical oxidation by aerobic bacteria to convert various pollutants to other form of matter. A common example is the activated sludge process, which utilizes an aeration tank where biochemical oxidation takes places. Air is often used as the sole oxygen source in fermentation. Oxygen is normally makes available to the bacteria in the form of dissolved oxygen (DO) by dissolution of oxygen into the liquor from the aerating gas bottom part of the aeration tank. In the conventional wastewater treatment systems, compressed air is directly injected into wastewater for aeration processes. However, air contains only 21 percent oxygen, this sometimes making the oxygen transfer rate efficiencies not particular good in conventional aeration systems, in consequent, resulting in limitation of quantity of oxygen dissolved in the liquid phase from the feed air [4, 5]. The compressor capacity may be also inadequate to supply more air, or the powers to operate the feed air compressor will increase.

Oxygen demand is highest during the exponential growth phase. In this phase, extensive primary metabolite production creates a very high oxygen demand, stimulating cell growth. Viscosity increase rapidly during this phase and into the secondary metabolites are produced. High viscosity is this phase inhibits oxygen transfer [7]. The resultant oxygen-starved condition can be avoided by using oxygen-enriched air to increase the mass transfer rate of oxygen into liquid phase. Many conventional methods have been proof that enable to supply higher purity oxygen to hasten the biological and oxidation processes [4, 6]. But its high cost and complexity are the main factors that need to be considered. In order to have a reliable, low cost and simple process for oxygen enrichment for wastewater treatment plants, membrane oxygen enrichment systems are the alternative technology that being developed and encouraged in many industries.

Membrane Oxygen Enrichment System Development

The foregoing works and results utilizing oxygen from various conventional enrichment systems clearly showed that the additional of oxygen to the wastewater aeration tanks could produce significant advantages. The oxygen concentration required for optimum performance is totally depend on the membrane being used, and also the operating conditions in the system. For low purity application, such as fermentation and combustion, single stage configuration is the best based on investment cost effectiveness. This is because no additional costs are needed for further stages of separation. However, membrane process design for air separation generally consists only of a single-stage membrane [3].

In general, hollow fiber technology provides the module of choice for membrane gas separation [8-10]. The advantage of hollow fibers is that they are self-supporting and resistant to collapse in high-pressure (up to several hundred psi pressure) and environmentally difficult condition. The simpler module design and sealing that can be imagined for hollow fibers and the fact that separate support structures are not necessary to be provided result in low cost, simpler fabricating processes, and, ultimately, an economic benefic when compared to various sheet and spiral design.

The key factors governing the economics of permeable membrane oxygen enrichment processes are intrinsic membrane properties of selectivity and effective permeability. Selectivity indicates the degree to which one gas preferentially permeates the membrane relatively to another gas [10]. This ratio of gas (i) to gas (j) permeability is the primary measure of separation achievable by the membrane. Membrane effective permeability is a function of the gas solubility in the membrane separating layer and its diffusivity through this layer [10-12]. In the absence of defects, the selectivity is a function of the material properties at the operating conditions. The permeation rate is a function of the material properties as well as the thickness of the barrier, where the lower the thickness, the higher the permeation rate. The rate of permeation is also proportional to the pressure differential across the membrane. Generally, the solubility of a component increase and the diffusivity decrease with increasing molecular weight [13-14]. The higher the selectivity, the more efficient the process and the lower the driving force (pressure ratio) required to achieve a given separation and consequently result in the lower operating cost of the membrane system. The higher the flux, the smaller the required membrane area and therefore, the lower the capital cost of the membrane system [15].

Effect of Operating Conditions in Oxygen Enrichment

The gas permeation through the membrane is affected by the operating pressure and flow rate, module flow pattern, and stage cut of the system. Operating in high pressure will increase the differential pressure, where allows higher driving force for gas diffusing through the membrane. But for air separation, at higher pressure, the permeation driving force increase and causes passage of larger amount of gas through the membrane, resulting O_2 purity in permeate stream reduces. As for the effect of flow rate, at higher flow rate, the gas residence time is lower, which increase the permeation resistance and as a result the O_2, which have higher permeation rate than N_2, permeates at higher rate than N_2 into the membrane. Specifying the reject flow rate and feed pressure will able to control the value of the feed flow rate. The above performance indicates that selection of the system operating condition is depending on what product is going to be obtained. If the product is the permeate stream, the system is necessitates to operate at low pressure and higher flow rate [16].

The performance of the gas separation module is significantly affected by the flow patterns that exist on the feed and permeate sides as well as the extent of concentration polarization in the substrate. In air separation application, the O_2 concentration is continuously depleted as the supply airflow through the membrane module. Since the rate of O_2 permeation is a function of partial pressure difference across the membrane, the membrane must be operated, in most cases, as close to a true countercurrent mode as possible to maximize the membrane module selectivity [2, 9, 10].

The stage cut at a given product purity increases with the increase in feed pressure, because of increase of permeation driving force. Stage cut also increases when decrease of feed flow rate, which increases the gas residence time and lead to reduce the resistance for gas transport within the membrane. Increase of stage cut will decrease the O_2 enrichment [16]. The optimum stage cut must be determined from economic consideration. The stage cut can be varied by varying either the membrane area or the feed rates at constant permeate rate, or both [16].

Advantages of Oxygen Enrichment System in Wastewater Aeration Systems

Sometimes, oxygen from air is difficult to dissolve into the liquid due to inadequate mass transfer capability of a specific system. By using permeable membranes, high purity oxygen will able be produced, and possible to increase the driving force available for mass transfer from the gas to mixed liquor; consequently, dissolution rates increase above those normally possible for conventional air systems. High O_2 transfer efficiency means require less air, which allows for smaller compressor and lead to reducing of energy consumption and eventual cost saving.

Application of membrane into wastewater aeration systems gives the attraction of low cost, simplicity, replaceable and space saving compare to conventional oxygen enrichment systems. Whereas, membrane system is just applied to aeration systems without much changing of original equipments on the system. In addition, membrane oxygen enrichment is easy to operate and it can supplies oxygen continuously into the wastewater aeration tank.

Membrane enrichment system in wastewater aeration system also gives the advantage of long-term operating cost saving, where the power requirement for low purity production in membrane system is typically lower than that required by conventional enrichment systems.

Design and Fabrication of Membrane Oxygen Enrichment System

Among the various technologies for commercial air separation, membranes have perhaps the greatest potential for future improvement for low purities applications. A new developed oxygen enrichment system by using locally produced asymmetric polysulfone hollow fiber membrane has been developed for low purity oxygen production. The following sections of this paper will general describe the design and fabrication of the oxygen enrichment system.

Fabrication of Hollow Fiber Membrane Module

The hollow fiber membrane module for this project is designed for shell site feed. Hollow fiber membrane is prepared by wet-spinning process. The membrane that being used for this system is polysulfone membrane, where the individual fiber has an average inner diameter of 0.3mm and an outer diameter of 0.5mm. Before testing the hollow fibers membrane, hollow fibers are necessary to be coated with silicone in order to treat the defect areas on the membrane, and also to improve the selectivity of the membrane [18].

In the potting process, a 1 feet long and ½ inch stainless steel pipe is used as a housing for hollow fibers membrane. Hollow fibers are glued with epoxy or polyurethane at the both ends, where one of the ends is free end and the other end is a dead end, where fibers are potted within an aluminum cap.

Hollow fibers after gluing are necessary to be left for at least one day for hardening. When the glue of both sides is hardened, the complete potted hollow fiber will then put into the ½ inch pipe and locked it by female connector. And then the protruding end of the fibers is cut to expose the lumens. The complete hollow fiber module is shown in FIGURE 1.

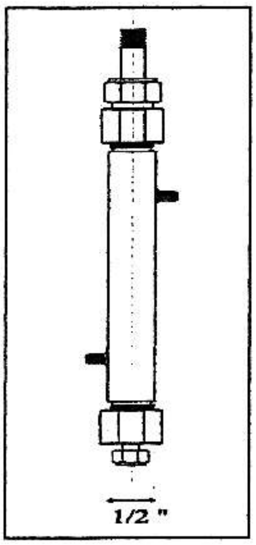

FIGURE 1. Hollow Fiber Membrane Module

Description of The Newly Designed Membrane Oxygen Enrichment System in Wastewater Aeration System

The main components of the present oxygen enrichment system include the compressor, pretreatment sections, and membrane modules. A typical arrangement of these components is shown in FIGURE 2. The design of this system is easy to operate and suitable for lab scale testing. The whole system is using stainless steel fitting and tubing for joining.

A compressor is used to compress air into the system. Air is typically compressed to pressures in the range of 30 to 70 psi. Pressures are controlled by an air regulator at the inlet of the overall system. The compressed air will go through several pre-treatment sections, such as air filter, CO_2 trap, and moisture trap, where to withdraw undesired substances such as large particles, compressor oil, CO_2 and moisture from the air feed stream. The undesired substances need to be removed from the system in order to avoid product purity being contaminated. In additional, these undesired products could affect the system operating conditions. Large particles could cause clogging problem and also damage the fibers when high pressure is applied. Oil can coat the membrane and foul irreversibly, increasing the resistance to gas transport [9]. CO_2 needs to be stripped out to prevent a buildup of CO_2 in the aeration tank, which will affect the oxygen transfer rate and lower the efficiency of the purification process [19]. Membranes may be susceptible to degradation from liquid water, especially in combination with other feed stream contaminants, which can produce acids. Therefore, air moisture needs to be filtered out with moisture trap before going into membrane module.

Pretreated air is delivered and feed at shell side of a single stage membrane module in a certain pressure and flow rate. In the membrane module, air separation process will occur and air is separated to two streams, viz., oxygen enriched-air and nitrogen enriched-air.

Oxygen enriched-air is produced at the bore side of hollow fibers membrane and delivered along in permeate stream 1. Outlet pressure and flow rate is measured by pressure gauge and flow meter. The reading from the flow meter will indicate the productivity of oxygen enriched-air, and the flow at permeate stream can be controlled to obtain a suitable stage cut for separation. Percent mole of oxygen enriched-air is analyzed by a *Divex* oxygen type analyzer before send into aeration tank. By-product nitrogen is collected in a sampling cylinder for further purity testing.

On the other sides, nitrogen enriched-air is relief via retentate stream 1. Flow rate of reject stream is controlled by a needle control valve, where the controlling of flow will determine the stage cut of membrane separation. Oxygen contents in retentate stream 1 is also necessary to be measured, where it will show the nitrogen permeability and membrane selectivity in different pressures, flow rates, and stage cuts.

Aeration tank is designed as a continuous flow system because air is continuously injected into the aeration tank in order to avoid pressure builds up at the permeate stream. Oxygen enriched-air produced is directly injected into the wastewater with an air diffuser at the bottom of the aeration tank. Diffuser will cause bubbles formation in the water, instantaneously; bubbles provide O_2 transfer surface area for O_2 transferring. Small bubbles are desired for higher transfer efficiencies. Therefore, flow rate of permeate stream needs to be control to a suitable level.

Low-speed stirrer is used to stir the wastewater intentionally to provide uniform oxygen dispersion and mixing in the water. Faster rate might fasten the oxygen transfer rate but increase power demand. When oxygen transferring occurs, oxygen will dissolve into liquor form as dissolved oxygen. Dissolved oxygen will be measured *in-situ* by a membrane probe, which attached to *Hanna* Dissolved Oxygen Meter

Temperature could cause influent on the oxygen transfer coefficient and oxygen saturation values in the system. Temperature in the aeration tank is measured by using a thermometer during the system operation. A pH meter is used to measure the pH values during the process variation.

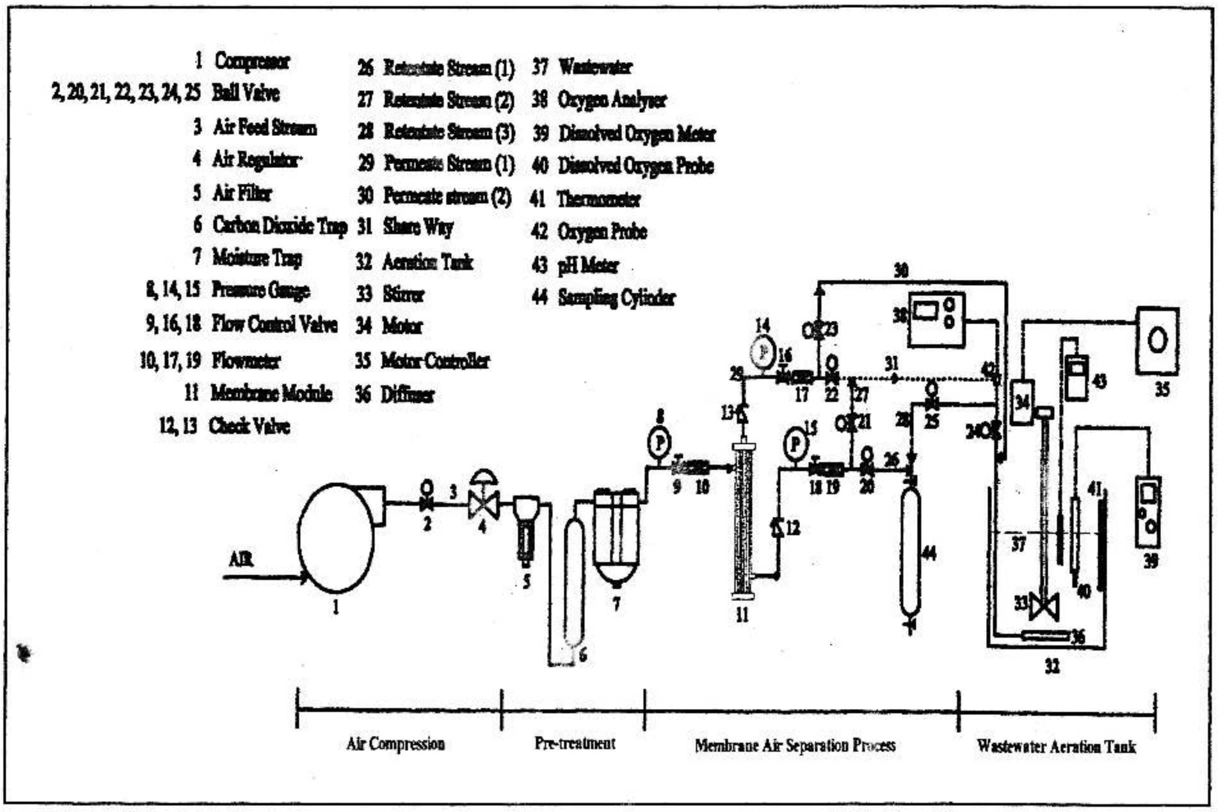

FIGURE 2. Combination of Membrane Oxygen Enrichment System and Wastewater Aeration Tank

Conclusions

The rapid evolution of membranes in commercial air separation during the last decade has been paced by significant technological innovations in material science, membrane formation processes and systems design.

The oxygenation of water and wastewater by gas permeable membranes is not new. Many module configurations and types of membranes have been evaluated for this purpose. However, this technology still has great potential for future improvement. Obviously, it will be most strongly influenced by improvement in material properties.

Application of Oxygen enrichment membrane system into wastewater aeration systems is counted as a new-sprung technology in Malaysia, although it is a common practice in USA, Europe and Japan. Development of membrane oxygen enrichment system for wastewater treatment system by locally produced membrane is a good idea that able to improve the weakness of wastewater treatment in our country. By using this system in wastewater aeration system, the oxygen transfer rate in the water body will increase apparently, where this will cause reduce of time required for oxidation, and simultaneously reduces compression cost thus leading to cost saving.

Local developed membranes and application systems obviously will show cost effectiveness if compare to foreign products. Furthermore, the efficiency of the local products and systems also comparative with the world standard. In order to develop and further advance the membrane oxygen enrichment technology, it is necessary to further study for the future requirements, where not only limited in environmental field, but also in other fields such as chemical, combustion and medical uses.

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