COMPARISON OF TEXTILE MEMBRANES FOR MOISTURE TRANSPORT

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Abstract: *Membranes are commonly used in garment and especially for technical garments to allow the flow of moisture and keep the micro climate dry. There are different kinds of membranes working on unique principles. In this research we compared 3 most commonly used membranes used for different types for garments, which are hydrophilic, hydrophobic and the microporous membrane. All 3 membranes types work on different principles and help to remove moisture from the microclimate. Different tests like water vapour permeability, air permeability and drape test were performed to obtain comparable results. The research work gives a good comparison of membranes for clothing considering the flow of moisture. The results show that nano porous membranes are much more permeable and have high drape ability as compared to other membranes.*

Keywords: *membranes, textile structures, moisture transport.*

1 INTRODUCTION

Membranes are semi-permeable substrates which allow certain compounds to transport from one phase to another. Therefore, membranes act as obstacles for some species while separating others [1-2]. Polymeric membranes like polyurethane, polyacrylate, polyester and polytetrafluoroethylene are primary substrates employed as inner layer or middle layer for multilayer clothing having several applications [3]. The membrane must display certain set of characteristics contingent on application and requisite characteristics of multilayer assembly i.e. in case of protective clothing and modern sports clothes which require outstanding barrier properties along with comfort and hygienic parameters, the membranes having high water-tightness must be utilized to deliver efficient and effective shield air non permeability and soaking through and at same time must allow high amount of water vapor to pass through them [4]. In multilayer clothing, various kinds of water and wind-tight membranes are utilized which are impermeable to liquid water vapor but permeable to water vapor.

There are 2 basic types of membranes [4, 5] i.e.:

1- Hydrophilic solid membranes,
2- Hydrophobic microporous membranes with compacted configuration.

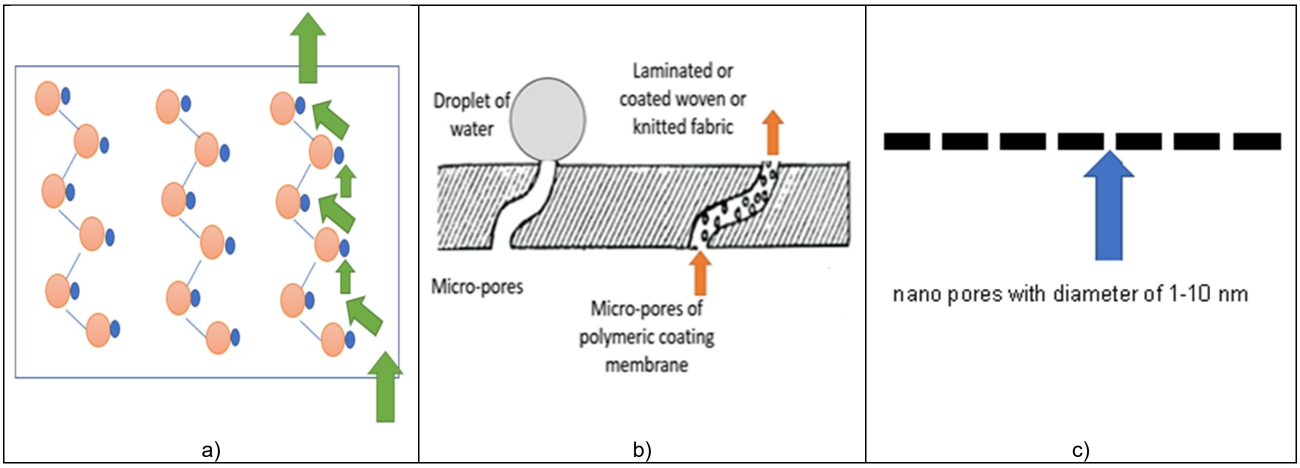

Figure 1 Mechanism of hydrophilic membrane [13] (a), hydrophobic membrane [3] (b) and nano porous membrane structure (c)

1. In hydrophilic solid membranes, a breath through procedure for absorption and migration is instigated by heat and high humidity. There is chain of chemicals groups which entice water vapor molecules. Water vapor molecules utilize these chains as stepping stones to migrate from one side towards another.

2a. Microporous hydrophobic membranes in which breathing procedure is done by permitting sweat in the form of water vapor molecules to transmit by interconnecting micro-pores instigated by heat and high humidity. Transportation of liquid water is inhibited by micro-pores (100 times smaller than droplets of water) and by surface tension effect due to hydrophobic nature of membranes i.e. repels droplets of water.

2b. Nano porous membranes have pore size of 1-10 nm and mostly made from polyethylene terephthalate (PET). The membranes are commonly used for filtration and moisture transport. They are famous for low weight and better performance; these membranes are commonly used as sandwich layer in many sport wares

2 COMMONLY USED MEMBRANES FOR CLOTHING

Following membranes are commonly used in the field of comfort and clothing:

1. Hydrophobic microporous membranes of several polymers generated by perforations of compact membranes i.e. by employing micro-beams of radiation of high energy pulsation lasers or bombardment of electrons [3].
2. Microporous hydrophobic membranes like poly-urethane (PU) membranes created by phase separation procedure (inversion) as a consequence of selective evaporation of solvent and non-solvent. Primarily there are two procedures. First one is the wet coagulation in which extraction of solvent is an inductive factor. The second way is to have phase separation procedure caused by evaporation of solvent like thermal coagulation. Membranes like Porelle membranes, are one of such kind [3].
3. Microporous hydrophobic polytetrafluoroethylene (PTFE) membranes synthesized by drawing procedure under critical conditions from compact membranes, resulting in creation of several micro cracks. Normally this procedure is utilized to manufacture membranes from PTFE and sold in market under trade name of Goretex XCR, Goretex Paclite and some others [6, 7].
4. Hydrophilic membranes mostly consist of polyester (PES) and polyurethane. Sympatex Composites Co synthesizes hydrophilic membranes from polyester under trade name of Sympatex. On the other hand, Toyo Cloth generates hydrophilic membrane from polyurethane called BION [8, 9].
5. Nano porous membranes made by electro-spinning or other techniques in which multiples webs are layered above each other to achieve nano porous structure. These membranes are available in market as Goretex, Crosstech, Tetratex, Porelle, Proline, Vapro, Sympatex, Action and Neoguard [10-12].

3 THERMAL CLOTHING COMFORT

One of the prime requirements of clothing is of course to provide protection from extremes of climatic conditions and it acts as a barrier between human body and the external environment [9].The most important feature of thermal clothing is to create a stable microclimate next to the skin in order to support body's thermoregulatory system, even if the external environment and physical activity change completely [17]. The thermal comfort of clothing system is related with thermal balance of body and thermoregulatory reactions to dynamic interactions with clothing and environment. Clothing acts as a regulator of heat and moisture transport between human body and the surrounding environment [12]. Transmission of heat and moisture plays very significant role in preserving thermo-physiological comfort. The fabric should permit moisture (in the form of sensible and insensible perspiration) to be transferred from the body to the environment for cooling the body and decline the possibility of thermal decrease in thermal insulation of fabric due to build-up of moisture within the microclimate environment [4]. If clothing in contact with human beings is not dry, there will be escalation of heat flow from body, consequently resulted in undesirable heat loss from the body. This ultimately creates cool feel. In reality transmission of heat and moisture through clothing system is carried out in steady as well as dynamic/transient conditions [5].

3.1 Moisture transport [13]

Liquid and moisture transfer mechanisms in the fibrous textiles include:

- vapour diffusion in the void space
- absorption, transmission and desorption of the water vapour by the fibres,
- adsorption and migration of the water vapour along the fibre surface,
- transmission of water vapour by forced convection.

Water vapour moves through textiles as a result of water vapor concentration differences. Fibres absorb water vapor due to their internal chemical compositions and structures. The flow of liquid moisture through the textiles is caused by fibre-liquid molecular attraction at the surface of fibre materials, which is determined mainly by surface tension and effective capillary pore distribution and pathways.

Evaporation and/or condensation take place, depending on the temperature and moisture distributions.
Moisture vapour transmission parameters are calculated by following different standard methods:

- evaporative dish method or control dish method (BS 7209),
- upright cup method or gore cup method (ASTM E 96-66),
- inverted cup method and desiccant inverted cup method (ASTM F 2298),
- the dynamic moisture permeable cell (ASTM F 2298),
- the sweating guarded hot plate, skin model (ISO 11092).

The adsorption and migration phenomenon mechanism functions depend not only on the hydrophilicity of the fibre surface but also on the extent of the fibre surface available for adsorption. All the factors we mentioned about heat and mass transfer that affects the comfort are affected by some fabric and clothing parameters. At the time of designing the textile for thermal comfort or for improvement of thermal comfort it's important to know about these parameters and their possible effects. Textile structure and chemical nature of fibres effects the thermal comfort properties of textiles such as: fibre type, fibre diameter, fibre shape, texture method of fibre yarn types and production, porosity, pore size distribution, complexity of pores (open cell or closed cells), fabric structure and thickness, clothing design, fitting and thickness of clothing, position of layers (hydrophilic/hydrophobic), sorption of fibres and fabric and finishing applied to the fabric, etc. The moisture transport proceeds generally also by other mechanisms (capillary, sorption), but at the barrier textiles we can suppose that the diffusion way will be the more dominant. It is possible to describe moisture transport by a relation for mass transport:

$$q_{dif_i} = -D_i . \nabla . \rho_i \quad (1)$$

where: D_i is coefficient of diffusion transport of mass for the i^{th} component [$m^2.s^{-1}$], $\nabla\rho_i$ is gradient of partial mass density for the i^{th} component [$kg.m^{-3}$].

For a unit flow of moisture as a compound of gaseous environs with a partial pressure of p_i (p_i' – partial pressure inside of porous clothing material, p_i'' – partial pressure outside the porous clothing material) it is possible to use a relation:

$$q_{dif_i} = D_i \frac{M_i}{RmT} \frac{p_i' - p_i''}{s} \quad (2)$$

where: R_m is universal gas constant [$kJ.kmol.K^{-1}$], M_i is molar mass [mol], T is temperature [K] and s is layer thickness [m].

From this relation it is possible to determine a coefficient of diffusion transport of a mass, which determines the diffusion transport of the water vapour in a fabric.

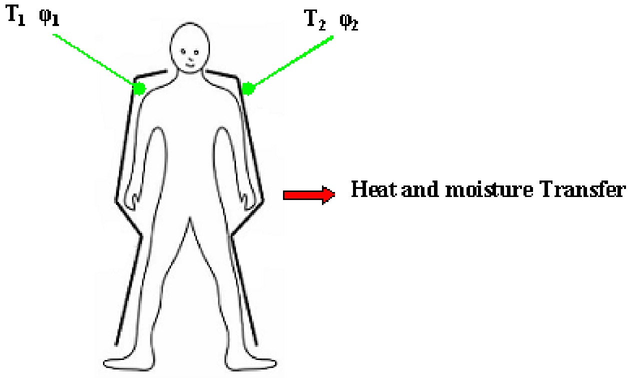

Figure 2 Heat and moisture transfer.
T_1 - temperature under cloth, φ_1- relative humidity under cloth (100%=extreme sport), T_2 - temperature of environment, φ_2 - relative humidity of environment

3.2 Water vapor permeability

It is also known as "breathability" and is defined as capability of textile substrate to transmit water vapour from surface of skin through the fabric to the exterior climate. Diffusion of water vapor should take place instinctively due to the vapour pressure difference through textile substrate. The water vapour disperses from the region of high vapour pressure (surface of human body) to the region of lower vapour pressure (exterior drier climate). The diffusion of water vapour takes place through fabric interstices and air spaces between the skin and the textile substrate [10].

3.3 Water vapor resistance

Water vapour permeability has inverse relation with water vapour resistance which is illustrated as amount of resistance against the transmission of water vapour through textile substrate. As liquid water has an excellent conductivity of heat, the thermal resistance of a garment is directly affected by quantity of moisture present in the fabric. Consequently, the more occurrence of water in textile substrate, either due to normal absorption from the air or absorption of water due to perspiration, the greater will be the rate of conduction of heat [10].

3.4 Permeability index

Woodcock established permeability index which displays evaporative performance of clothing. The permeability index (i_m) can be explained by the following equation:

$$i_m = \frac{R_t}{R_{et}.LR} \quad (3)$$

where: R_t is the total thermal resistance of the clothing plus surface air layer ($m^2.°C/W$), and R_{et} is the total evaporative resistance of the clothing plus the air layer (m2.kPa/W).

3.5 Air permeability of textiles

Generally, the air permeability of a fabric can influence its comfort behaviors in several ways. In the first case, a material that is permeable to air is, in general, likely to be permeable to water in either the vapour or the liquid phase. Thus, the moisture-vapour permeability and the liquid moisture transmission are normally related to air permeability. In the second case, the thermal resistance of a fabric is strongly dependent on the enclosed still air, and this factor is in turn influenced by the fabric structure.

Air permeability is an important factor in determining the comfort level of a fabric as it plays a significant role in transporting moisture vapours from the skin to the outside atmosphere. The air in the microclimate between individual items of clothing also has a physiological function. When the body is at rest, this air in the microclimate contributes up to approximately 50% of the effective thermal insulation properties of the clothing. When the body is in motion, approximately 30% of the heat and moisture can be removed by air convection in the microclimate and air exchange via the clothing. The assumption is that vapours travel mainly through fabric spaces by diffusion in air from one side of the fabric to the other

4 EXPERIMENTAL PART

A total of 4 samples were chosen for the testing of water vapour permeability. All membranes were on a laminate of polyester knitted fabric with 1 mm thickness and areal weight of 135 g/m^2.

Table 1 Samples details

Number	Type	Composition	Thickness [mm]
1	Microporous	ePTFE	1.22
2	Hydrophilic	PET	1.19
3	Hydrophilic	PET	1.22
4	Nano membrane	PU/PES	1.58

Multiple devices were used to measure the water vapour permeability; following standards were used for following testing devices

1- Sweating Guarded Hot plate ISO11092

2- Desiccant Cup method ISO15496(B3)

3- Inverted cup method ISO 15496 (A2)

4- Permatest

5 RESULTS AND DISCUSSION

All membranes were tested for thickness and then four standard methods were used for the water vapour permeability. It is important to use different methods as it gives us a good comparison of performance. It can be seen from the Table 2, the nano porous membrane has the highest water vapour and air permeability followed by microporous membrane and then hydrophilic membrane respectively.

Table 2 Membranes results

No.	Type	Composition	Thickness [mm]	SGHP [m2.pa/w]	B3 [g/m^2.Pa.24h]	A2	Permatest [m^2.Pa/W]
1	Microporous	ePTFE	1.22 (±0.3)	4.30	5.67	5.1	2.3
2	Hydrophilic	PET	1.24 (±0.4)	8.05	1.67	1.2	9.05
4	Nano membrane	PET	1.25 (±0.54)	3.85	6.85	5.4	2.2

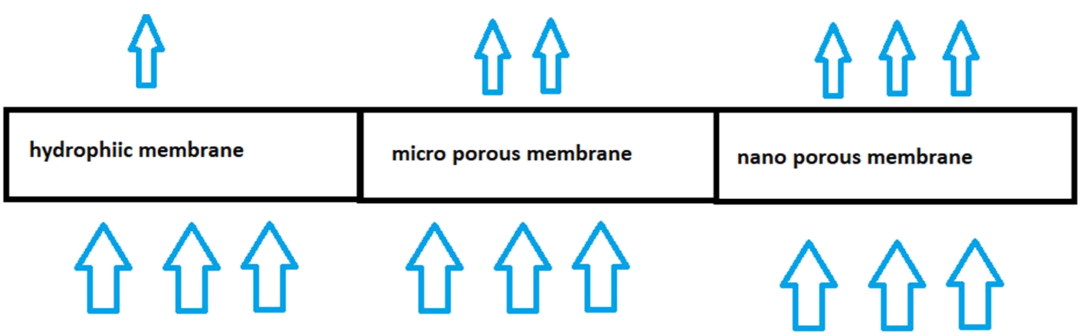

Figure 3 Graphical illustration of water vapour flow through different membranes

5.1 Air permeability of textiles

Air permeability tester (FX-3300) and SDLMO21S by using standard ISO9237 were used for air permeability testing. Generally, the air permeability of a fabric can influence its comfort behaviors in several ways. In the first case, a material that is permeable to air is, in general, likely to be permeable to water in either the vapour or the liquid phase. Thus, the moisture-vapour permeability and the liquid moisture transmission are normally related to air permeability. In the second case, the thermal resistance of a fabric is strongly dependent on the enclosed still air, and this factor is in turn influenced by the fabric structure.

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Table 3 Air permeability of membrane samples

Samples	Air permeability [L/m²/s]
Hydrophilic membrane	0.2
Microporous membrane	550
Nano porous membrane	720

5.2 Stiffness / bending moment

Bending properties describes stiffness of fabric. Stiffness is the ability of material to resist deformation when force is applied on it. The instrument Tuhomer TH-4 measures force required to bend specimen by 60 degree. This instrument evaluates the bending moment of textile substrates by CSN 80 0858 standard. The size of specimen was 5×2.5 cm.

This can be explained by following equation:

$$M_o = F \times K \tag{4}$$

where: M_o is the bending moment [mN.cm], F is the force applied in mN and K is constant whose value is 0.52 (from standard).

Results show that the nano porous membrane is the most flexible. The greater the bending force F required to bend the textile substrate at particular angle, greater will be the bending moment which ultimately results into greater stiffness of textile substrate.

5.3 Electron microscope

The electron microscope images of all membranes give us a clear idea of the structure of the membranes, Figure 5 shows the SEM image of the hydrophilic membrane, there are no visible pores and the moisture molecules are attracted to layers and moves to other layers in steps. The close pore structure gives no air permeability to these membranes.

The hydrophobic microporous membrane are shown in Figure 6, the micro sized pores are visible which are the paths for the moisture transport. These are layers are commonly used in clothing as they are permeable to moisture as well as to the air.

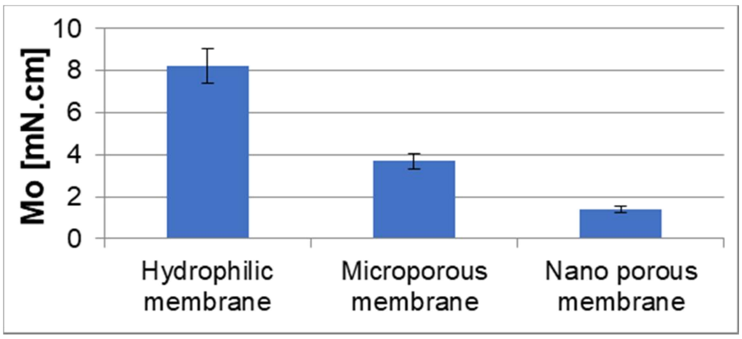

Figure 4 Bending moment of membranes

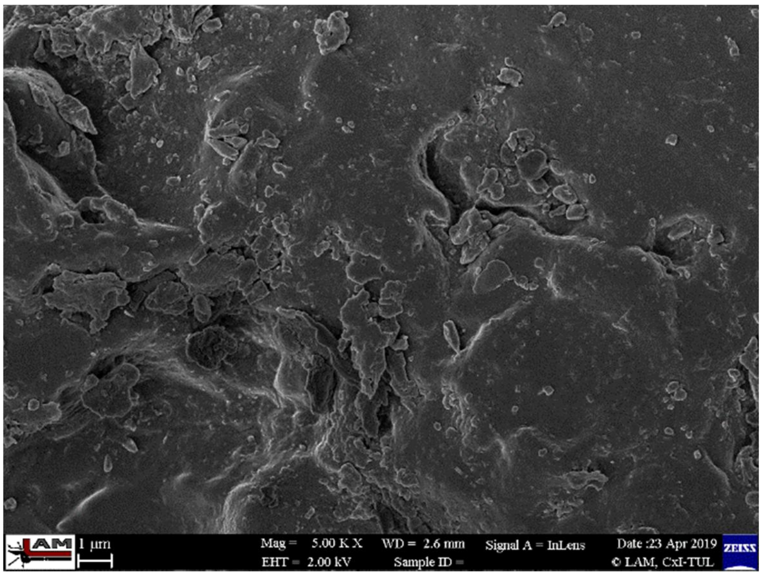

Figure 5 Hydrophilic membrane

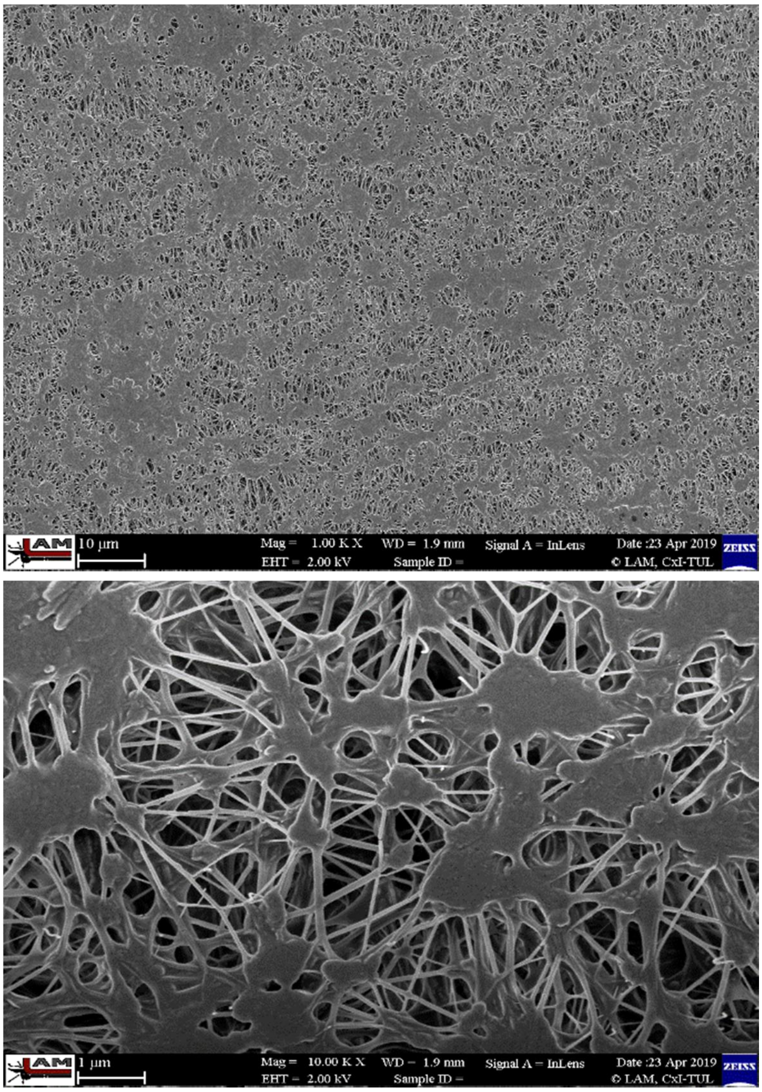

Figure 6 Hydrophobic microporous membrane

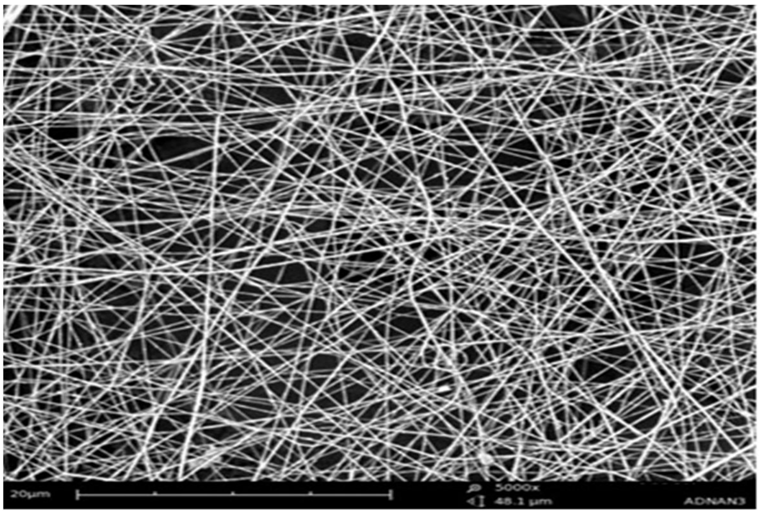

Figure 7 Nano porous membrane

The nano porous membrane shows in Figure 7, in which multiples webs are layered above each other to achieve nano porous structure, these kinds of membranes are first choice for filtration but are also used in clothing. The layers provide good air and moisture permeability.

6 CONCLUSION

From the research work we are able to conclude that nano membranes has the highest air permeability, better flexibility and higher water vapor permeability followed by microporous and hydrophilic membranes respectively. In clothing the flexibility of the garment is very important and using a non-flexible membrane just not recommended.

We did mention that ePTFE is a synthetic material, as such it does affect the environment, making it the least eco-friendly of the two. It is also very slow to degrade in nature, unlike polyether and ester.

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