# Membranes add edge to old technology

By Bill Ross and Heinz Strohwald

Industrial effluents of a soluble and biodegradable nature generally create serious treatment or disposal problems, due to their high organic load. The anaerobic digestion process is widely accepted as a more appropriate technology than aerobic methods for the cost-effective treatment of such effluents.

Various anaerobic reactor designs are advocated for maintaining high biomass levels, longer sludge retention times (SRT) and shorter hydraulic retention times (HRT), which are considered major requirements and key economic factors for successful anaerobic treatment of effluents. The principle of solids-liquid separation and biomass retention in conventional digester configurations generally relies on sludge pelletization and settling properties (UASB process) or immobilization of biofilms on stationary packing media (filter process) or carrier assisted non-stationary surfaces (fluidized bed process).

Recent surveys conducted in Europe identified biomass wash-out as one of the most prevalent problems of industrial anaerobic digestion plants. Few of the conventional digester designs consistently prevent loss of biomass from the digester. The presence of suspended material in the treated digester effluent will prejudice its reuse potential or increase the discharge tariff unnecessarily.

## Solutions to problems

The use of membranes for biomass retention is a recent innovation to overcome these problems. Independent research on membrane-assisted anaerobic processes commenced in South Africa in 1987 with the main objective of optimizing the pivotal role of biomass inventory control. Significant departures from overseas practice in the form of differences in UF membrane design and the use of 9mm tubular polyethersulphone membranes in combination with low pressure (500 kPa) unsupported modules led to the development of the ADUF (anaerobic digestion-ultrafiltration) process for the treatment of organically polluted industrial effluents (Ross et al., 1990).

**Adding membranes to anaerobic digestion systems is proving to be an effective way to prevent biomass washouts. The new process has proved successful, despite some difficult effluents.**

The ADUF process comprises two main unit operations: an anaerobic digester coupled with an external pressure-driven ultrafiltration unit (diagram below). Positive phase separation is effected by a membrane which acts as a microscopic filter. The UF permeate constitutes the final effluent while the rejected sludge concentrate containing the bacteria is rapidly recycled back to the digester with minimal loss in metabolic activity or reduction in temperature. This beneficially promotes good mixing in the digester, enhancing its performance. Influent macromolecules and particulate organics are also rejected at the membrane surface and are selectively retained in the digester by the UF unit until metabolized by the bacteria to the molecular mass cut off (MMCO) of the membrane.

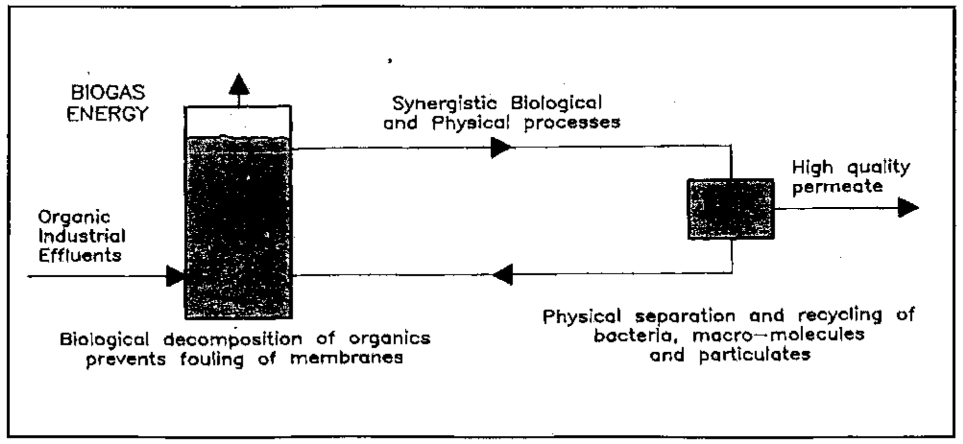
Anaerobic digestion and ultrafiltration are admirably complementary, interdependent and synergistic processes. Anaerobic digestion decomposes organics which would otherwise foul the membrane filters, while these membranes serve to separate and retain all biomass which would otherwise be lost in the effluents from conventional digester systems.

## Associated membranes and modules

The tubular ultrafiltration membranes and modules used in the ADUF process are manufactured in Paarl, South Africa by Membratek (Pty) Ltd. The polyethersulphone membrane has a pore size typically less than 0.10µm and the MMCOs can vary from 6,000 to 80,000 Dalton. The length of each tube is 3 m and each module has two parallel flow paths of 20 series tubes each. The unsupported tubular MEMTUF® modules are economically competitive with conventional tubular systems as they do not require the customary high pressure support structure.

Investigations to date have been conducted in pilot-scale (0.05–3.0 m$^3$) and full-scale (80–2,600 m$^3$) plants treating mainly effluents from the food and beverage industries. A major advantage and feature of the ADUF process is that membrane flux could be maintained for periods of several months or longer without recourse to chemical or physical cleaning. The principal operating conditions and results of the ADUF studies on brewery, wine distillery, malting, egg-processing and maize-processing effluents are presented in Table 1 and summarized below:

- COD removal (77–97%)
- digester space load rate (3–15 kg COD.m$^{-3}$.d$^{-1}$)
- hydraulic retention time (0.8–5.2 days)
- particulate-free permeate is final effluent
- permeate membrane flux rate (10-80 litres.m$^{-2}$.h$^{-1}$)
- rheology of MLSS and flow velocity largely govern flux rate
- bacterial cleaning minimizes chemical cleaning of membranes.




Above: Schematic diagram of ADUF (anaerobic digestion–ultrafiltration) process.

## Industrialization of ADUF process

The first commercial application on an industrial scale (digester capacity 2,600 m$^3$, membrane area 800 m$^2$) was commissioned at the Meyerton mill of African Products (Pty) Ltd, South Africa in 1990 for the treatment of a maize-processing effluent (Ross et al., 1992). The results after four years have illustrated the merits of the process for the production of a colloid-free effluent at a mean COD removal efficiency of 97%. The permeate flux has averaged 25 litres.m$^{-2}$.h$^{-1}$ at 35°C, inlet pressure 500 kPa, linear flow velocity through the tubes of 1.5 m.s$^{-1}$ and digester suspended solids concentration of 25 kg.m$^{-3}$. A mean space load rate of 3 kg COD.m$^{-3}$.d$^{-1}$ guaranteed reliability to withstand high COD shock loadings due to variations in the feed load. This plant was occasionally subject to peak load rates of 12 kg COD.m$^{-3}$.d$^{-1}$ due to COD values as high as 60 kg.m$^{-3}$.

The membrane flux at the full-scale Meyerton plant has exhibited a fluctuating trend over the four year period in the range 10 to 70 litres.m$^{-2}$.h$^{-1}$ (see graph right). The lower flux rates recorded were generally due to inferior operating conditions such as low linear flow velocity across the membrane surface, high MLSS concentration or feed shock loading. No long term predictions can as yet be made regarding membrane flux stability and membrane system life. These factors will naturally have a direct bearing on process running costs.

## Cost aspects

Strohwald (1994) carried out a capital and operating cost estimate for a 1500 m$^3$.d$^{-1}$ ADUF system with energy recovery from the generated biogas.

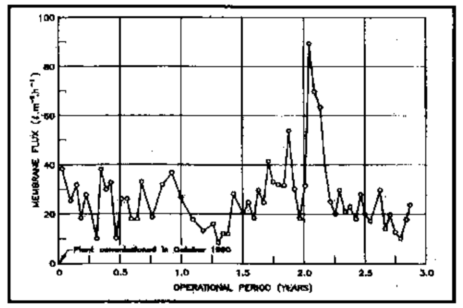
| | Brewery | Wine distillery | Malting | Egg process | Maize process |
|---|---|---|---|---|---|
| Volume of digester (m$^3$) | 0.05 | 2.4 | 3.0 | 80 | 2610 |
| Operational period (months) | 3 | 18 | 5 | 8 | 36 |
| Feed COD (kg.m$^{-3}$) | 6.7 | 37.0 | 3.5 | 8.0 | 4-15 |
| Permeate COD (kg.m$^{-3}$) | 0.18 | 2.6 | 0.8 | 0.35 | 0.3 |
| COD removal (%) | 97 | 93 | 77 | 95 | 97 |
| Space load rate (kg COD.m$^{-3}$.d$^{-1}$) | 17.0 | 12.0 | 5.0 | 6.0 | 3.0 |
| Sludge load rate* (kg COD.kg VSS$^{-1}$.d$^{-1}$) | 0.70 | 0.58 | 0.50 | 0.33 | 0.24 |
| Hydraulic retention time (d) | 0.8 | 3.3 | 0.8 | 1.3 | 5.2 |
| Temperature (°C) | 35 | 35 | 35 | 30 | 35 |
| Digester MLSS (kg.m$^{-3}$) | 30-50 | 50 | 10 | 10-30 | 23 |
| Membrane area (m$^2$) | 0.44 | 1.75 | 9.6 | 200 | 800 |
| Membrane flux (l.m$^{-2}$.h$^{-1}$) | 10-40 | 40-80 | 20-40 | 15-30 | 10-70 |
| Inlet pressure (kPa) | 340 | 400 | 500 | 500 | 600 |
| Flow velocity (m.s$^{-1}$) | 1.5 | 2.0 | 1.8 | 1.8 | 1.6 |
| Tube diameter (mm) | 9.0 | 12.7 | 9.0 | 12.7 | 9.0 |

*VSS - volatile suspended solids

Table 1: Mean operation criteria of ADUF plants treating various industrial effluents

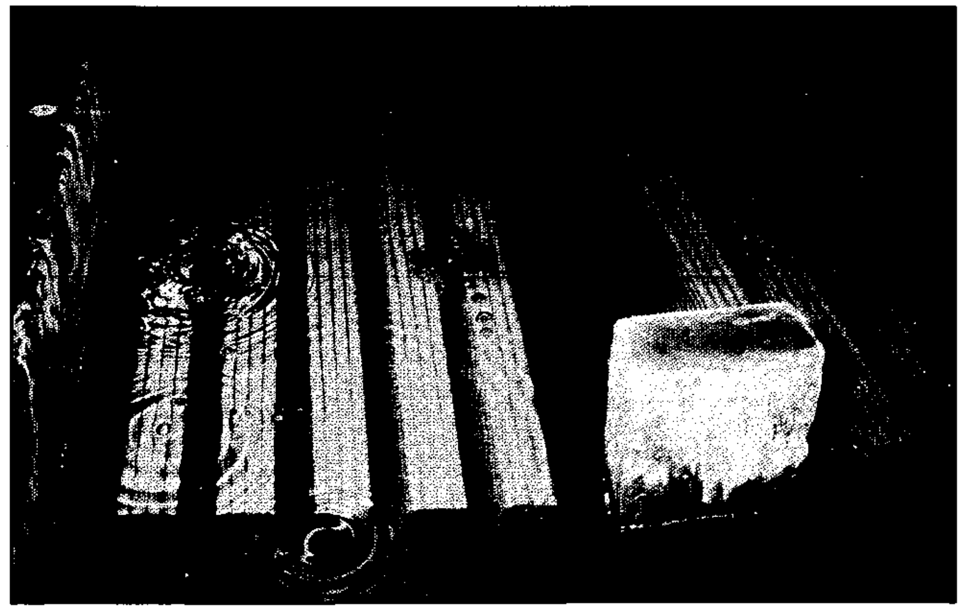
The design incorporated the following: total digester volume 1800 m$^3$; total MEMTUF® membrane area 1400 m$^2$. The specific cost calculations are summarized in Table 2, assuming a five year depreciation and interest at 20%, based on a total capital cost for the system of 2.1 million Rand ($385,000).

The redemption of capital is the largest cost contributing factor which is to be expected. With respect to the operating cost breakdown, a conservative two year membrane life was assumed for membrane replacement. The combined specific capital and operating cost of some 2.15 Rand ($0.40) per m$^3$ effluent treated for a complete ADUF plant compares




Above: Mean operational membrane flux at the Meyerton plant, treating maize processing effluent.

Below: MEMTUF® modules comprise unsupported tubular polyethersulphone membranes. Sludge liquor flows within the tubes while the permeate escapes through the tube walls as final effluent.



# Membranes

| | | | |
|---|---|---|---|
| **Capital costs:** | **Investment** | | **$0.282 m³** |
| **Operating costs:** | **Electricity** | **$0.023 m³** | |
| | **Membranes** | **$0.042 m³** | |
| | **Maintenance** | **$0.026 m³** | |
| | **Manpower** | **$0.021 m³** | |
| | **Subtotal** | | **$0.112 m³** |
| **Total Costs:** | **(Capital and Operating)** | | **$0.394 m³** |
| ($0.01 = 0.054 Rand) | | | |

**Table 2. Specific cost summary of a full-scale ADUF plant (Strohwald 1994).**

favourably with the cost for direct disposal of untreated effluent to municipal treatment works. The added benefit of water conservation by possible permeate reuse increases the economic attractiveness of on-site ADUF treatment

Compact external MEMTUF® modules can also be easily retrofitted to conventional digester systems which experience problems with biomass washout. The current (1994) capital cost of retrofitting a basic MEMTUF® system (comprising membrane modules, container, pump and manifolding) to an existing digester system is some 833 Rand ($153) per square metre of membrane area. This does not provide for building, power supply, switchgear and biogas recovery which will strongly depend on site specific conditions and can best be estimated by the client. The cost of membrane replacement alone is 180 Rand ($33) per square metre of membrane area.

The ADUF process is a new technology and there are a variety of aspects regarding optimization that have yet to be addressed for future improved efficiency.

The advent of the membrane-assisted anaerobic process significantly enhances and exploits the potential of microorganisms so that it is now possible to design appropriate reactors by taking into account microbiological process criteria and not having to rely only on empirical and mechanical data. This new generation treatment process holds important advantages for the anaerobic treatment of a wide range of organically polluted industrial effluents.

## References


Ross, W.R., Barnard, J.P., Le Roux, J., De Villiers, H.A. (1990) Application of ultrafiltration membranes for solids-liquid separation in anaerobic digester systems: The ADUF process. Water SA, 16 (2), 85-91.

Ross, W.R., Barnard, J.P., Strohwald, N.K.H., Grobler, C.J., Sanetra, J. (1992) Practical application of the ADUF process to the full-scale treatment of a maize-processing effluent. Wat. Sci. Technol., 25 (10) 27-39.

Strohwald, N.K.H. (1994) Personal communication. Membratek (Pty) Ltd, PO Box 7240, Noorder Paarl, 7623 South Africa.


*Article based on a paper presented at the 7th IAWQ Anaerobic Digestion symposium, 23-27 January 1994, Cape Town, South Africa.*

*Bill Ross is with Ross Consultancy, Bellville, South Africa; Heinz Strohwald is with Membratek, Paarl, South Africa.*