The Application of membrane filtration to silage effluent

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Dunlea, A. P. and Dodd, V. A. 1989. **The application of membrane filtration to silage effluent.** Can. Agric. Eng. **31**: 39–43. Silage effluent, formed by grass fermentation, contains variable amounts of soluble organic matter which is readily oxidized, having a high biochemical oxygen demand of about 90 000 mg/L, and is the cause of summertime water pollution. Effluent production is dependent on grass moisture (MC), producing 10 L/t at 75% MC and 200 L/t at 85% MC. Fifty percent of total volume can be produced within 7 d after silo filling. Currently, disposal is by land spreading. Wilting is not widely practiced due to the climate. Feeding 21.6 L of effluent (95.4% MC) to cattle and pigs is equivalent to 1 kg of barley (20% MC). A study of effluent concentration and treatment by membrane filtration was carried out. Six different reverse osmosis membranes were tested in series at a transmembrane pressure of 0.3 kPa; effluent temperature was kept at less than 32°C. Three membranes were then selected for individual testing. Percentage reduction in chemical oxygen demand varied from 75 to 85%. Permeate flux declined from 18 L/m^2/h at 2% DM concentration to 2 L/m^2/h at 12% DM. Percentage retention in DM, nitrogen, phosphorus, potassium, calcium magnesium, carbohydrate and lactic acid were also measured. Application at farm level is unlikely due to low permeate flux. Application is considered possible as part of an integrated waste management facility.

INTRODUCTION

Silage effluent is produced during the fermentation of grass to produce silage as a winter forage for livestock. It is estimated that a crop ensiled at moisture content of 80% loses 5% of its dry matter in the effluent (Patterson 1983). Silage effluent is disposed of by one of the following methods:

(1) Collection and spreading on land as fertilizer.
(2) Collection and storage for animal feeding.

Silage making, and the production of effluent, lasts from late April to late September. The volume of effluent produced depends mainly on the moisture content of the grass ensiled. Typical effluent production values of 229 L/t of grass ensiled at 85.0% MC and 50 L/t at 75.0% MC have been referenced by Patterson (1983).

In order for no effluent to be produced it is necessary for the grass moisture content to be less than 75%. During the 1985 and 1986 seasons, grass was ensiled at 85–83% MC while in 1983 and 1984, moisture contents were much lower due to the exceptionally dry summers. Silage effluent continues to flow for about 6 wk from the start of ensiling, the flow, however, is 70% completed after 3 wk.

The fertilizer value of effluent is variable. Typical values quoted are (O'Kiely and Flynn 1985):

2.6 kg N, 0.5 kg P, and 3.7 kg K per 1000 litres.

The current recommended spreading rates on pasture are 90 m^3/ha for triple application over a 2-wk period and 30 m^3/ha for a single application (O'Kiely and Flynn 1985). Such application rates are not recommended during periods of dry weather for fear of scorching the grass due to low effluent pH.

Silage effluent is the strongest water polluting farm effluent with a biochemical oxygen demand of 90 000 mg/L compared with 25 000, 15 000 and 300 mg/L for pig manure, cow slurry and domestic sewage, respectively (O'Callaghan et al. 1973).

Feeding silage effluent to cattle and pigs as a means of disposal has much to recommend it when compared to land spreading. The intake of silage effluent by cattle is variable with an average value of 14 L per head per day (O'Kiely and Flynn 1985). A rate of dietary inclusion of the effluent for pigs of 150 g/kg DM intake from meal which amounts to 5 L per day at 6.5% effluent DM has been employed successfully (Patterson and Steen 1982). On a nutritional basis 21.6 L of silage effluent (4.6% DM) is equivalent to 1 kg barley (O'Kiely and Flynn 1985).

Typical composition of silage effluent dry matter is shown in Table I.

The silage can be collected, stored and fed to housed animals throughout the winter. Silage effluent stores quite well if formalin (3 L/m^3) is used as a preservative. However, the high cost of providing a storage tank is a deterrent and land spreading continues to be the recommended and most widely used method of disposal.

The objective of this experiment was to concentrate and to treat silage effluent; to utilize the feeding value of the concentrate fraction and to facilitate the disposal of the permeate fraction.

Membrane filtration includes both hyperfiltration (reverse osmosis) and ultrafiltration. The process involves applying a pressure to the feed side of a semipermeable membrane in order to overcome the osmotic driving force and cause solvent (principally water) to move in the opposite direction which causes the feed solution to become more concentrated. Membrane concentration has the advantage of avoiding thermal effects, unlike evaporative processes, there is no phase change involved and no alteration in the chemical composition of the liquid under concentration. Successful membrane concentration of cheese whey and skim milk has been referenced by McKenna and Martin (1974), while the integration of biological conversion techniques with pressure-driven membranes for the treatment of organic wastes has been discussed by Okey (1972).

Hyperfiltration or reverse osmosis uses semipermeable membranes with low molecular weight cut-off points and high-pressure application. As the solvent is removed from the membrane surface area, the liquid in contact with the membrane surface becomes more concentrated. Solvent diffusion to the membrane surface from the feed liquid does not equal the rate of solvent removed in the form of permeate flux, therefore the osmotic pressure increases with the increased concentration at

Table I. Composition of silage effluent dry matter (Patterson and Steen 1982)

Component	Content (g/kg)
Crude protein (N% × 6.25)	225.0
Lactic acid	285.0
Carbohydrate	201.0
Ash	223.0
Calcium	21.9
Phosphorus	10.2
Potassium	63.7
Magnesium	5.6

its polarized layer on the membrane surface. Eventually the polarized layer will cause permeate flow to cease altogether as the membrane surface will be fouled. The process of membranes filtration is well detailed and continues to find new applications.

EXPERIMENTAL PROCEDURE

The experimental unit used for the experiment was a plate and frame DDS lab 20 model (De Danske Sukkerfabrikker); this model has a maximum surface area of 0.36 m^2; a smaller area may, however, be selected if required. Figure 1 shows a flow diagram of the DDS lab 20 unit and Fig. 2 shows the flow diagram of the experimental rig. The unit was powered by a three-phase electric motor and the operating pressure, 3000 kPa, was supplied by two Bif diaphragm pumps (General Signal Corporation, Providence, RI, U.S.A.). It is important to maintain as high a degree of turbulence as possible over the membrane to reduce concentration polarization. The unit was equipped with 10 plates thus enabling up to 10 membranes to be employed in series. DDS hyperfiltration membranes were used throughout the tests. Membrane selection was based on published molecular weight cut-off (MWCO) values and membrane types. Table III shows the MWCO values and sodium chloride (NaCl) permeability percent for each of the membrane types used. Four cellulose acetate membranes, one aromatic polymer and one polysulfone were tested. Initially the six different membranes were tested in series. This was achieved by testing five different membranes (each duplicated) at the same time and collecting individual permeate samples. Two runs of these series tests were carried out initially. The three best membranes in terms of dry matter retention and COD reduction (%) were then selected for individual membrane testing.

The silage effluent used was produced by the fermentation of a *Lolium perenne* (perennial ryegrass) sward. The silage effluent tested was collected and stored at 4°C until required. The storage period of the effluent was variable as the samples were tested after each test. 0.3 percent (vol/vol) formic acid was used as a preservative for all the effluent that was stored before use; however, the fresh effluent that was tested received no preservative. The effluent was filtered using a Whatman no. 181 filter with a sintered glass and vacuum to remove coarse particles such as pieces of grass, prior to transfer to the DDS lab 20 unit.

Operating conditions were kept constant for all tests. These conditions provided for operating at a bulk feed temperature of less than 30°C using a water cooling system, a transmembrane pressure of 3000 kPa and a feed rate of 6–7 L/min.

Permeate flux and feed flow rate was determined using a stopwatch and graduated cylinder. Samples of both concentrate and permeate were taken hourly and stored at 4°C until analyzed.

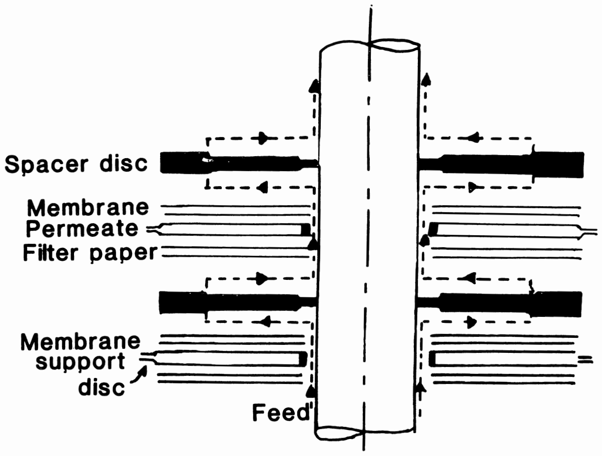

Figure 1. Flow diagram of plate and frame type plant.

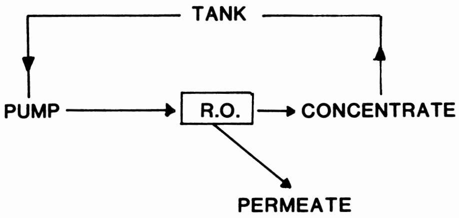

Figure 2. Flow diagram of experimental rig.

Concentrate and permeate samples were analyzed for the following:

- Dry matter % (oven dried at 100°C for 24 h).
- Chemical oxygen demand mg/L (COD as described by the American Water Works Association 1975).
- Nitrogen % (standard Kjeldahl method, crude protein = %N × 6.25).
- Calcium, magnesium and potassium ppm (atomic absorption and flame emission).
- Phosphorous ppm (colormetric method (Murphy and Riley 1962)).
- Lactic acid % (thin layer chromatography (Wilson 1970).
- Carbohydrate % (colorimetric method using phenol (Wilson 1978)).

Membrane performance for all tests was calculated in terms of percent reduction in COD and percent retention of the other components analyzed.

RESULTS AND DISCUSSION

Table II shows data on the composition of the effluent used. Silage effluent tested at a later stage contained no lactic acid due presumably to inadequate addition of preservative, formic acid or formalin (0.3% by volume); all the other components, however, were present. These results show reasonable agreement with previously published data.

Chemical oxygen demand increased as effluent dry matter increased according to the regression equation:

$$\text{COD mg/L} = 11\,759\ (\text{DM\%}) + 4013$$

$$\text{Correlation coefficient } R = 0.95 \quad (P > 0.999)$$

Table II. Composition of silage effluent tested

Component	Mean (g/kg)	SD ±
Dry matter	51.0	2.44
Nitrogen	43.4	2.42
Phosphorus	14.1	4.24
Potassium	51.8	19.95
Calcium	38.5	7.64
Magnesium	8.9	5.48
Carbohydrate	58.9	34.70
Lactic acid†	352.0	41.23

†Later effluent contained no lactic acid.

Table III shows performance data for the six membranes tested in series. Percent reduction in COD ranged from 58.7% for membrane 865PP to 85.4% for membrane 990PP. Dry matter retention ranged from 60.2% for membrane HMX65PP to 94.3% for membrane 995PP. Comparing membrane types having the same MWCO values of 500, performance in terms of COD reduction was 58.7, 54.4 and 62.2% for the cellulose acetate, polysulfone and aromatic polymer types, respectively. Cellulose acetate membranes 990PP, 992PP and 995PP gave the highest overall performance of the six membranes tested in series. These membranes were then tested individually and gave the following results.

Figures 3–5 show individual performance data for membranes 990PP, 992PP and 995PP. Permeate flux (Fig. 3) decreased rapidly as the feed DM% increased due to the increase in osmotic pressure and to the concentration polarization at the membrane surface. Permeate DM% and permeate COD values (Figs. 4 and 5) increased as the feed DM% increased.

Figures 6–8 show the gradual increase of COD reduction percent with decreasing flux. This may be explained by the buildup of a layer of feed concentrate at the membrane surface reducing the effective pore size of the membrane. Membranes 990PP and 995PP indicate a maximum flux (at the operating conditions stated) of about 7 L/m²/h while a maximum for 992PP was about 5 L/m²/h at which values COD reduction of 82–87% was achieved.

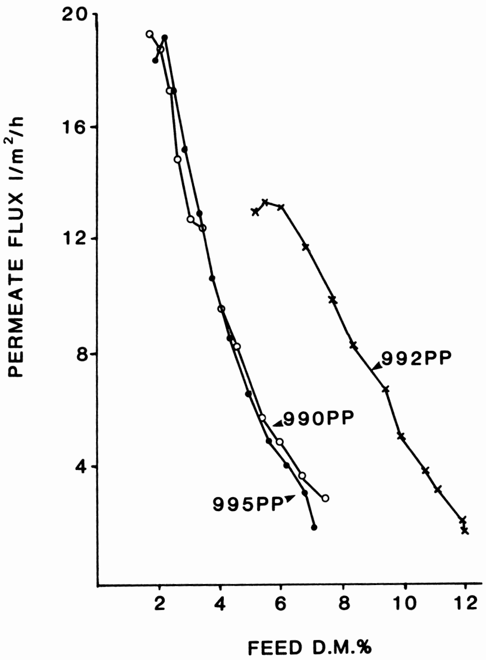

Figure 3. Effect of feed DM percent on permeate flux.

Throughout the range of flux, the three membranes gave in excess of 99% retention of P and 98% retention of Mg and Ca. Membranes 990PP and 995PP gave in excess of 98% retention of CHO, while membrane 992PP obtained in excess of 95% retention. Between 90 and 97% retention in dry matter and nitrogen was achieved by all three membranes. Potassium retention varied in the range 82–95% and decreased rapidly at the lower flux values.

Table III. Average membrane performance (SD) versus feed solution dry matter content (2.5–9.8% DM)

	Membrane type					
	992PP C.A.	995PP C.A.	990PP C.A.	865PP C.A.	HS65PP Polysulfone	HMX65PP Aromatic Polymer
MWCO†	<500	<500	<500	500	500	500
NaCl permeability%	< 10	< 6	< 15	66–74	60–75	60–75
DM retention (%)	91.6	94.3	92.4	65.7	72.2	60.2
	(2.2)	(3.0)	(3.8)	(4.8)	(2.1)	(5.7)
N retention (%)	90.7	94.5	92.2	66.2	69.9	61.1
	(1.6)	(2.0)	(2.6)	(3.9)	(5.7)	(8.8)
P retention (%)	97.3	99.4	99.2	76.5	80.0	71.9
	(1.1)	(0.7)	(0.9)	(13.7)	(12.3)	(7.6)
K retention (%)	63.6	74.4	67.4	6.32	15.8	20.4
	(13.5)	(14.7)	(15.7)	(8.8)	(22.6)	(20.2)
Ca retention (%)	96.0	95.8	97.1	73.2	76.8	66.9
	(1.5)	(2.9)	(1.6)	(4.4)	(9.7)	(14.2)
Mg retention (%)	96.8	98.6	96.7	80.5	76.4	70.4
	(2.0)	(0.9)	(2.9)	(4.6)	(14.2)	(17.8)
Lactic acid retention (%)	92.1	95.6	93.8	N.A.	81.6	59.7
	(5.1)	(3.2)	(3.4)		(4.2)	(12.4)
CHO retention (%)	97.1	97.9	97.5	95.0	93.6	90.7
	(2.2)	(1.5)	(2.7)	(2.6)	(3.2)	(2.7)
COD reduction (%)	82.1	84.5	85.4	58.7	65.4	62.6
	(3.8)	(5.9)	(3.0)	(16.6)	(9.0)	(7.6)

†Molecular weight cut-off.

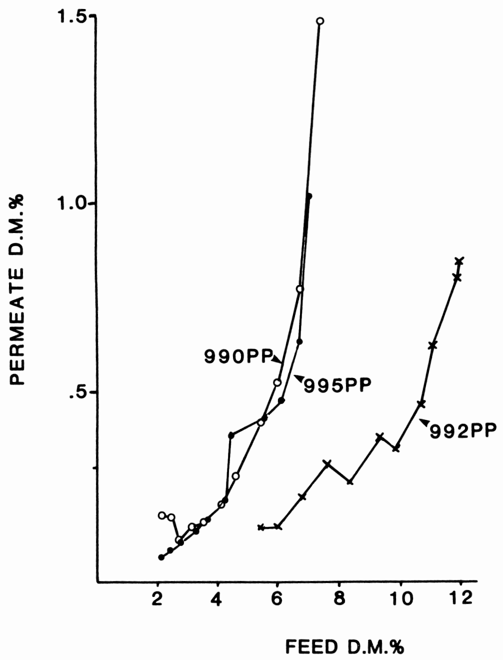

Figure 4. Effect of feed DM percent on permeate DM percent.

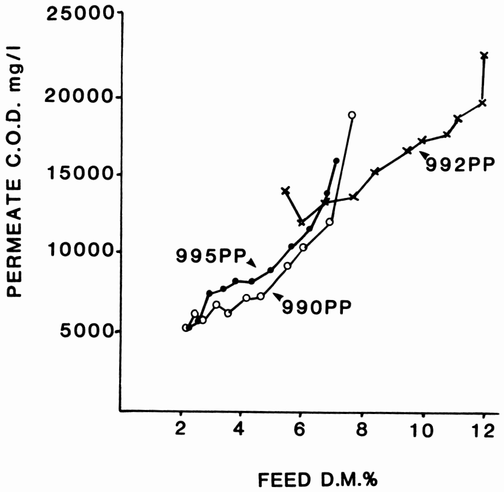

Figure 5. Effect of feed DM percent on permeate COD.

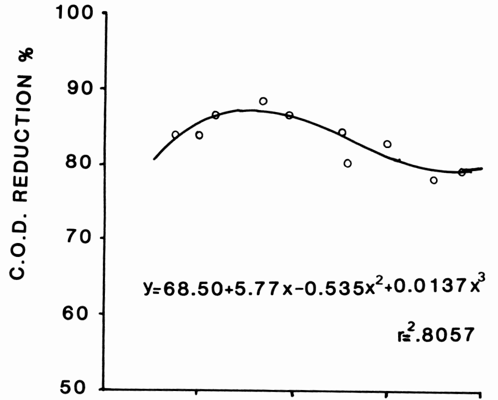

Figure 6. Effect of permeate flux on COD reduction for membrane 990PP.

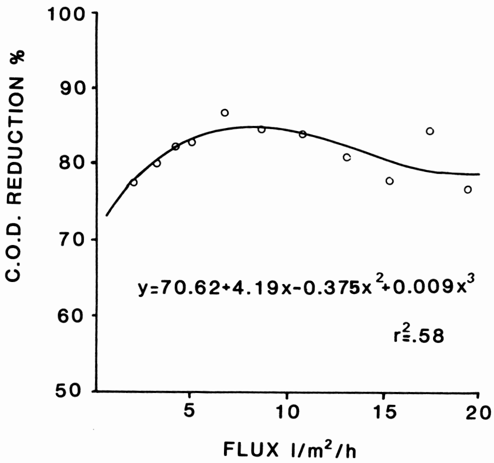

Figure 7. Effect of permeate flux on COD reduction for membrane 995PP.

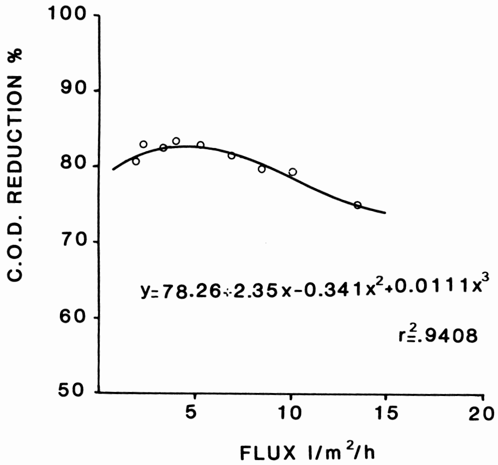

Figure 8. Effect of permeate flux on COD reduction for membrane 992PP.

CONCLUSIONS

Membrane concentration as a method of disposal of silage effluent is unlikely to be applied at the farm level as the permeate fraction, because of its high COD value, would still require disposal land spreading rather than by discharge to a water course. The increase in concentrate dry matter percent and the consequent reduction of its volume is unlikely to justify its use as a concentration technique at farm level. Its application as part of the first stage treatment phase of a central waste treatment plant for agricultural effluents, including manures, is considered, however, to be more reasonable.

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