Reusing liquid manure as a possible source of drinking water for pigs

M. Navaratnasamy, J.J.R. Feddes and J.J. Leonard

Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5

Navaratnasamy, M., Feddes, J.J.R. and Leonard, J.J. 2004. **Reusing liquid manure as a possible source of drinking water for pigs**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **46**: 6.27-6.32. A number of experiments were conducted using treatment methods such as chemical settling, aeration, ozonation, slow-sand filtration, and reverse osmosis to treat liquid swine manure as a possible source of drinking water for pigs. Addition of alum, lime, and gypsum to the liquid swine manure did not result in a significant reduction in total suspended solids (TSS) compared to natural settling of solids (24h). Aeration, ozonation, and natural settling reduced total dissolved solids (TDS) levels. Aeration at two levels, 2.2 and 3 L/min, reduced TDS levels at a faster rate than ozone treatment (1.8 mg/L) and natural settling in 6-L liquid manure volumes. Aeration at a rate of 3 L/min reduced 83 % of TDS in 7 days to meet the recommended TDS level (3000 mg/L) for swine drinking water. Aerated supernatant water was filtered using a slow sand filter and analyzed for chemical and biological drinking water parameters. Blending 20% fresh water with liquid treated by a slow sand filter after 7 days of aeration at 3 L/min provides a liquid that can be used as a possible source of drinking water for pigs. **Key words:** aeration, liquid swine manure, drinking water, total dissolved solids, total suspended solids.

Différents systèmes de traitement faisant appel à la précipitation chimique, l'aération, l'ozonation, la filtration lente au sable et l'osmose inversée ont été utilisés avec le lisier de porc afin d'en faire une source d'eau potable pour les porcs. L'addition d'alum, de chaux et de gypse au lisier de porc n'a pas permis une réduction significative des solides totaux en suspension (STS) comparativement à la sédimentation naturelle des solides (24h). L'aération, l'ozonation et la sédimentation naturelle ont réduit les niveaux de solides totaux dissous (STD). L'aération d'échantillons de lisier d'un volume de 6 L à deux niveaux, 2,2 et 3 L/min, a réduit les niveaux de STD plus rapidement que le traitement par ozone (1,8 mg/L) et la sédimentation naturelle. L'aération à un taux de 3 L/min a réduit de 83% les STD en 7 jours, ce qui a permis de rencontrer les niveaux de STD recommandés (3 000 mg/L) pour l'eau d'abreuvement des porcs. Le surnageant aéré a été filtré en utilisant un filtre lent au sable et a été analysé sur la base de paramètres chimiques et biologiques de l'eau potable. L'addition de 20% d'eau potable fraîche au surnageant traité par le filtre lent au sable après avoir été aéré pendant 7 jours à un taux de 3 L/min a permis d'obtenir un liquide qui peut potentiellement être utilisé pour l'abreuvement des porcs. **Mots clés**: lisier de porc, eau potable, solides totaux dissous, solides totaux en suspension.

INTRODUCTION

Pork production is a flourishing industry in Canada while water is becoming a scarce commodity. The large water requirements for pork production can concern pork producers especially during periods of drought. Reusing the treated liquid fraction of manure as a source of drinking water may provide a method of water conservation. Normally, livestock manure contains more than 90% water (Bayne 1998). The remaining (up to 10%) solids consist of total suspended (TSS) and total dissolved solids (TDS). TSS and TDS should be removed to an acceptable level to reuse liquid manure as a source of drinking water for pigs.

Liquid-solid separation methods are used to reduce the suspended solid concentration in the liquid fraction. Chemical additives such as aluminum sulfate (alum), lime, and gypsum can be added to enhance liquid-solid separation. Alum is an effective coagulant to enhance the settling rate in liquid manure (Zhang and Lei 1998). Lime is also used as a coagulant for settling. Lime is usually used to precipitate calcium, magnesium, and some heavy metals from water and wastewater (Cecen and Guersoy 2000). Gypsum is also added to water ponds for clarification (Johnson 2000). Gypsum is cheap and in abundant supply in Canada. Gypsum is used as a soil amendment in agriculture where sulfur is deficient. However, the natural settling method, which depends mostly on the size and density of the suspended matter, is a less expensive method. This method is widely used in livestock manure handling facilities to separate the liquid fraction.

Total dissolved solids (TDS) are the sum of all dissolved organic and inorganic material in water. In case of reusing liquid swine manure as a source of drinking water, the total dissolved solids must be removed after liquid-solid separation. According to the Pork Production Reference Guide (PPRG 2000), TDS should be less than 1500 mg/L for drinking water for pigs. However, this limit can be exceeded depending on the minerals in the TDS. According to Canadian water quality guidelines, 3000 mg/L of TDS level is suitable for all classes of livestock drinking water provided that the salinity level is less than 1000 mg/L (CWQG 1995). In treating liquid swine manure as a drinking water source, the realistic target TDS level can be 3000 mg/L, since liquid manure has a high level of TDS which consist mostly of organic matter. Treatment methods such as aeration, ozonation, and reverse osmosis can be used to remove TDS. In aerobic treatment, aerobic bacteria use the dissolved and suspended organic matter as a source of energy to produce cell mass. Cell mass produced by aerobic treatment can be easily removed by settling and filtration. Aerating pig slurry with 3% suspended solids for 168 hours resulted in 71 and 40% reduction in chemical oxygen demand (COD) and total suspended solids, respectively (Doyle et al. 1987). Ozone, being a powerful oxidant, can react with organic matter and also reduce BOD and COD levels. Ozone is used in wastewater treatment plants mostly for disinfection purposes. Reverse osmosis (RO) is a membrane filtration technique that is very effective in removing TDS. Most reverse osmosis membranes are capable of removing at least 90% of the dissolved solids (Cheremisinoff 1995).

Table 1. TSS values of supernatant liquid after various settling treatments.

Treatment	Chemical	Concentratio (mg/L)	Mean TSS (mg/L)	SD
1	Aluminum sulfate	250	160 a	139
2	Aluminum sulfate	500	160 a	137
3	Aluminum sulfate	250	193 a	148
	Gypsum	500		
4	Aluminum sulfate	250	172 a	185
	Gypsum	1000		
5	Lime	3000	173 a	180
6	Lime	4500	153 a	151
7	Lime	3000	162 a	177
	Gypsum	500		
8	Lime	3000	261 a	165
	Gypsum	1000		
9	Control		162 a	178

a Means with the same letter are not significantly different ($P<0.05$).
R^2 - 0.75
CV - 50

From the literature review, treatment methods such as chemical addition and natural settling for TSS removal and aeration, ozonation, and reverse osmosis for TDS removal appear to be promising to meet the objective of recycling liquid manure as a source of drinking water for pigs. The primary objectives of this research were to study the effect of chemical additives such as alum, lime, and gypsum in removing TSS from liquid manure against natural settling and to investigate treatment methods such as aeration, ozonation, and reverse osmosis to remove TDS and reuse the liquid manure as a source of drinking water for pigs.

MATERIAL and METHODS

TSS removal

Alum, gypsum, and lime were used to study their effectiveness in promoting settling compared with natural settling used as a control. The alum and lime used were laboratory grade. The gypsum used was waste crushed wallboard gypsum. Two different concentrations were chosen for alum, lime, and gypsum based on visual observations made during preliminary jar test experiments. During the preliminary experiments, different chemical concentrations were added to 500-mL glass jars of swine manure, mixed well, and allowed to settle before visual observations were made. Two concentrations of alum (250 mg/L and 500 mg/L) and lime (3000 mg/L and 4500 mg/L) were used. Two concentrations of gypsum (500 and 1000 mg/L) were added to two alum and lime concentrations. All chemical concentrations and combinations are shown in Table 1. Nine cylindrical jars with capacity of 2 L were used. Each jar represented a treatment. Each jar was filled to the 2000-mL level with liquid swine manure. Liquid swine manure was collected from the Edmonton Research Station Swine Research Centre and stored in a cold room at 4°C. Chemicals with concentrations shown in Table 1were added to all jars except the controls and manually stirred . After stirring, each jar was left undisturbed for a period of 24 h. After 24 h, the supernatant water was slowly siphoned off into a 500-mL container and sent to a laboratory (Agricultural Food and Nutritional Science Department, University of Alberta) for analysis of total suspended solids. Total suspended solids were analyzed according to Standard Methods for Examination of Water and Wastewater (Eaton et al. 1995). This experiment was repeated seven times. Another set of jar tests was conducted in three 500-mL beakers using different alum concentrations (1000, 2000, and 3000 mg/L) to determine the amount of alum needed for separating the liquid fraction from the solid fraction. Liquid manure was stirred well manually after adding the chemicals and allowed to settle for a period of 24-h before visually observed.

TDS removal by aeration, ozonation, and natural settling

Four 10-L containers were used to measure TDS removal for 2 levels of aeration, 1 level of ozonation, and natural settling. Two sets of ceramic air diffusers were connected to two air pumps and each of them were placed at the bottom of the aeration treatment containers. Each set of diffusers were made up of two individual diffusers with a diameter of 10 mm and length of 25 mm. Another set of air diffusers was connected to an ozone generator (Ozotech, Model 02-4PC10, Yreka, CA) and placed in the ozone treatment container. An air pump supplied with the ozone generator, pumped air through the ozone generator at 2.6 L/min. Ozone concentrations from the ozone generator with airflow rate of 2.6 L/min was 1.8 mg/L under local atmospheric conditions. Ozone concentration in the gaseous phase was found by using the KI method (Eaton et al. 1995). No off gas measurement was made as initial off gas analysis showed that negligible concentration of ozone was present in the off gas. Liquid swine manure collected from the Edmonton Research Station Swine Research Centre was stored in a container at about 4°C. Chemical parameters of the liquid manure are shown in Table 2. Six liters of supernatant liquid fraction of manure

Table 2. Chemical parameters of raw liquid manure and aerated liquid manure (aeration level 1 at 2.2 L/min).

Parameter	Liquid manure	Aerated liquid manure	Standards	Detection limits
pH	7.6	8.7	6.5 - 8.5 a	0.1
TDS (mg/L)	6500	3475	3000 b	1%
Calcium (mg/L)	129	25.9	1000 b	0.5
Sodium (mg/L)	317	362	500 a	1
Sulfate (mg/L)	1150	791	750 a	0.5
Nitrite-Nitrate N (mg/L)	1.5	1.8	100 b	0.1
Total Suspended Solids (mg/L)	N/A	82	N/A	3

a PPRG (2000)
b CWQG (1995)

was poured into all containers.Air was dispersed through the liquid fraction in the aeration treatment containers at 2.2 and 3 L/min, respectively, to determine if aeration reduces TDS levels in liquid manure. Air flow rates were chosen so that the air flow rates provided adequate mixing of the liquid manure as mixing was important to maintain a consistent dissolved oxygen level throughout the liquid fraction of manure. The ozone treatment container was kept inside a larger plastic container which was connected to a room exhaust fan. Manure was poured into the natural settling container and left without any mechanical aeration. All the experiments were carried out at room temperature (10 – 15°C). Total dissolved solids measurements were obtained every 24 h for 18 days, using a TDS meter (Model 50150, Hach, Loveland, CO) which has an accuracy of 1% of readings. Aeration at two levels, ozonation, and natural settling treatments were repeated once and the measurements were recorded.

Chemical and biological analysis for aerated liquid

After 18 days of aeration, the aerated supernatant liquid was filtered using a slow sand filter to remove suspended matter. The slow sand filter had a depth of 0.3 m and diameter of 0.05 m. Average size of the sand media used in the slow sand filter was 0.27 mm. The filtration speed in a slow sand filter is usually about 0.1 – 0.2 m/h (Logsdon 1991). As limited amount of filtered samples was obtained from aeration level-1 (2.2 L/min) and aeration level-2 (3 L/min) treatments, the filtered liquid (1 L) from aeration level-1 was sent to a private laboratory (Envirotest, Edmonton, AB) for analysis of chemical parameters shown in Table 2. Slow-sand filtered liquid from aeration level-2 was used for biological analysis. The analysis for biological quality of slow-sand filtered liquid was repeated once. The analysis for chemical and biological quality of the treated liquid was carried out according to Standard Methods for Examination of Water and Wastewater (Eaton et al. 1995). In biological analysis, amount of fecal coliform, total coliform, and *e-coli* were found by using the most probable number (MPN) method.

Filtration using reverse osmosis

Another study used a domestic reverse osmosis (RO) package unit (Filmtec, Edina, MN) to remove TDS from the liquid fraction of manure. Thin film composite membrane (TFC) was used in this RO unit. The RO package unit can provide about 0.5 L/min treated drinking water at 415 kPa. This RO unit was connected to a pump (Shurflo, Garden Groove, CA). This pressure pump is a diaphragm pump with a rated delivery of 6.4 L/min at 415 kPa. The pressure was adjusted by using a screw arrangement in the pump assembly. RO units can remove more than 90% of the TDS in the influent. Therefore, liquid fraction of manure and tap water were passed through the reverse osmosis unit at two pressure ranges (207-278 and 345-414 kPa) and ten observations of TDS were made on permeate and concentrate volume at 5-min intervals to make a comparison between liquid fraction of manure and tap water at high and low pressure levels. This experiment had three replicates. Samples of liquid fraction of manure and permeate collected at high pressure were analyzed at a private laboratory (Envirotest, Edmonton, AB) to compare the chemical parameters of permeate and drinking water standards for pigs. The analysis of the chemical parameters was carried out according to Standard

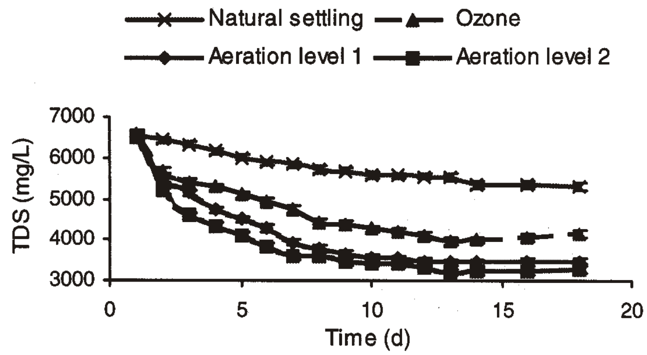

Fig. 1. TDS levels over time for natural settling, ozonation, and aeration.

Methods for Examination of Water and Wastewater (Eaton et al. 1995). Initial mean TDS values for the tap water and liquid fraction of swine manure were 200 and 4120 mg/L, respectively.

Statistical analysis

One-way classification in ANOVA was used to analyze the TSS values obtained in the experiments to remove TSS. Split plot design was used to analyze TDS values in the experiments to remove TDS using aeration, ozonation, and natural settling.

RESULTS and DISCUSSION

TSS removal

Table1 shows mean TSS values for the siphoned off supernatant liquid after the treatment and settling for 24 h. Statistical analysis showed no significant difference among the treatments and control ($P>0.05$). The siphoned off supernatant water, after chemical addition and settling, was as dark in colour as the control indicating that the organic matter was not completely removed. In this experiment, alum addition produced visible flocs. Masters (1991) stated that colloidal particles stay in suspension due to the net surface negative charge. When alum is added to a liquid, positively charged aluminum ion (Al^{3+}) is produced to neutralize the liquid and allow the colloidal particles to form flocs (Masters 1991). As liquid manure contains a high amount of colloidal particles, the concentration of alum added (250 and 500 mg/L) was not sufficient to form settable flocs. High dosage of alum appears to be expensive as simple jar tests showed that alum addition (3000 mg/L) is estimated to cost $1.51 per growing pig. Therefore, natural settling appears to be as effective as chemical additives to remove total suspended solids from liquid manure. As natural settling is a process to separate suspended solids (Kiely 1998), further treatments were needed to remove dissolved organic solids.

TDS removal using aeration, ozonation, and natural settling

Figure 1 shows that both aeration at level-1 and 2 reduced the TDS levels faster than ozonation. Deleris et al (2000) reported that ozonation increased the dissolved organic carbon from suspended or settled sludge. Because of the effect of ozone on the suspended and settled organic matter, the TDS reduction was lower than aeration. Figure 1 also shows that aeration reduced the TDS levels faster than natural settling ($P<0.05$).

Table 3. Statistical results for TDS removal experiment.

Treatment	Total Dissolved Solids LS mean
Aeration level-1	4151 a
Aeration level-2	3894 a
Ozonation	4710 b
Natural settling	5796 c

a-c LS means with different letters are significantly different ($P<0.05$).
R^2 - 0.98
CV - 3.25

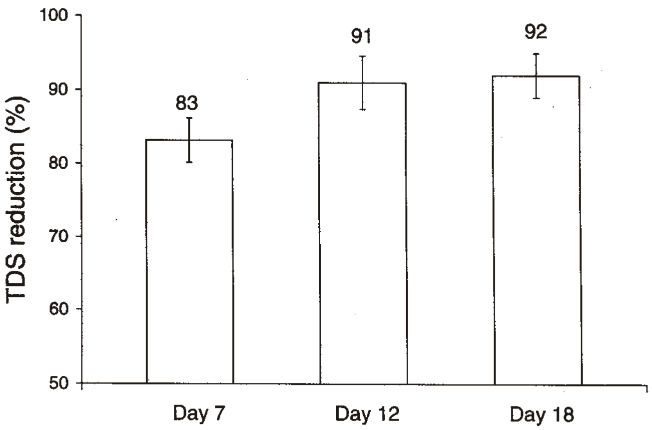

Fig. 2. TDS levels on days 7, 12, and 18 for aeration level-2 (3L/min).

Table 3 shows LS mean values of TDS for four treatments. Natural settling reduced the TDS levels at the slowest rate. Natural aeration lagoons alone are not commonly recommended because of their size and performance which indicates that the natural aeration lagoons do not provide a dischargeable effluent (Overcash et al. 1983). Figure 1 also shows that as time progressed TDS reduction by both levels of aeration became less. Heavy foam formation was also noticed during the initial period of aeration which might have been due to filamentous bacteria as reported by Winkler (1981). As time progressed, the availability of the substrate for microorganisms became limited. Therefore, TDS reduction became slower and foam formation became less. After 13 days, TDS levels were almost stable for both levels of aeration. Aeration at level-2 reduced TDS at a faster rate than aeration at level-1 during the first 7 days (Fig. 1). Oxygen transfer from gas to the liquid phase is a function of overall oxygen transfer coefficient (Bayramoglu et al. 2000). The overall oxygen transfer coefficient increases with the air flow rate (Boyle 1986). Therefore, TDS levels reduced faster at a higher aeration rate.

Table 4. TDS levels after 7 days of aeration at aeration level-2 at 3 L/min.

Parameter	Liquid manure	Aerated liquid (7 days)	Standard	After blending with 20% fresh water
TDS (mg/L)	6500 ± 75	3590 ± 75	3000 a	2914

a CWQG (1995)

Chemical and biological analysis

The drinking water parameters shown in Table 2 were compiled from available standards (CWQG 1995; Coote and Gregorich 2000; PPRG 2000). After 18 d of aeration, pH had increased (Table 2) and the pH level was just above the suitable level recommended for drinking for pigs. Ndegwa et al. (2001) reported that stripping of volatile fatty acids during aeration can increase the pH in liquid swine manure.

The TDS reduction rate decreased after 7 days of aeration at level-2 due to the limitation of readily available substrate. Eighteen days of aeration appears to be expensive in terms of power consumption. Figure 2 shows that 7 days of aeration at level-2 achieved most of the TDS reduction needed (about 83%) to meet recommended TDS levels to recycle the treated liquid manure as drinking water for pigs. Therefore, it was suggested that blending of fresh water after 7 days of aeration at level-2 to reduce the TDS levels would be more economical. TDS level after 7 days was 3590 ppm, which was higher than the drinking water standard for pigs (Table 4). This level could be reduced by blending 20% fresh water (Municipal water TDS 209 ppm), which is low in TDS (Table 4). Addition of fresh water is also likely to reduce sulfate and pH levels sufficiently. However, PPRG (2000) claimed that higher sulfate levels, as high as 2000 ppm, did not result in reduced pig growth. It was also noted that the aerated liquid should be passed through a slow sand filter to remove suspended solids and pathogens before blending with fresh water. The aerated water possessed organic colour indicating that some organic compounds, which were not easily biodegradable, were left in the treated liquid. The presence of residual organic content would be lower in treated water as a significant amount of TDS was made up of inorganic matter. The US Food and Drug Administration reported that manure has been incorporated into animal diet locally for their nutrient values (FDA 1995). Therefore, the treated liquid with little organic matter could be used as a source of drinking water for pigs.

Table 5 shows that slow sand filtration removed fecal coliform, total coliform, and *Escherichia coli* sufficiently to meet swine drinking water guidelines (PPRG 2000) which is 5000/100-mL. Linda (1983) also reported that slow sand filtration removed at least 90% *E-coli* effectively. The comparisons of before and after filtration were not statistically compared as the concentration of microorganisms in the raw manure was very high compared to the concentration of the treated liquid.

Pathogens can leak through a sand filter. Thus further research is needed to look at ozone as a disinfectant. Liberti et al. (1999) reported that a concentration of 15-32 mg/L of ozone in gaseous phase provided sufficient reduction in fecal coliform (1000 CFU/100mL) to reuse the ozonated water for agricultural purposes. Table 2 shows that the TSS values after slow sand filtration are very low. Slow sand filtration was very effective in removing suspended matter as the TSS value obtained after aeration and slow sand filtration was lower than the TSS values obtained after reverse osmosis filtration (Table 6). In the reverse osmosis system, some impurities can leak through mechanical seals (Cheremisinoff 1995).

Table 5. Pathogen count in liquid manure before and after slow sand filtration.

Pathogen	Raw manure	After slow sand filter	SD
Total coliform (MPN/100 mL)	>15,000	12	16.3
Fecal coliform (MPN/100 mL)	>15,000	12	16.3
Escheria. coli (MPN/100 mL)	>15,000	23	

Table 6. Chemical parameters before and after RO filtration.

Parameter	Liquid manure	After RO treatment	Drinking Water Standards
pH	7.25	7.5	6.5 - 8.5 a
TDS (mg/L)	4095	800	3000 b
Calcium (mg/L)	113	6	1000 b
Sodium (mg/L)	160	32	500 a
Sulfate (mg/L)	788	6	750 a
Nitrite-Nitrate N (mg/L)	<0.1	<0.1	100 b
Total Suspended Solids (mg/L)	5100	123	N/A

a PPRG (2000)
b CWQG (1995)

Slow sand filters are usually prone to clogging. To avoid clogging it was recommended that the cell mass in the aerated liquid be allowed to settle well before the supernatant liquid was filtered through slow sand filter.

Filtration using reverse osmosis

The treated water appeared as clear as tap water (Fig. 3) and did not posses any offensive odour. Chemical parameters of the untreated liquid manure in Table 6 show that the TDS and sulfate levels are higher than the drinking water standards. The RO filtered water meets the drinking water standards for chemical parameters as shown in Table 6. However, treating liquid swine manure by using reverse osmosis produced as low as 4% of the influent at high pressure as shown in Fig. 4. Further, Zhao et al (2000) and Belfort (1984) reported that RO membranes are prone to fouling by organic matter. Therefore, RO is not recommended for a treatment scheme to remove TDS from liquid manure.

From the above discussion natural settling was chosen as the economical and relatively simple method that can be used in separating the liquid fraction from the solid fraction of swine manure in this study. After natural settling, aeration was chosen to degrade and reduce the total dissolved solids (TDS) in the liquid fraction of swine manure. Aeration techniques appeared to be feasible relative to reverse osmosis and ozonation. After aeration, the liquid was passed through a slow sand filter to remove pathogens and suspended matter. Both the chemical and biological parameters obtained for this project showed that the treated liquid after blending with 20 % fresh water would be suitable to be used for pig consumption. However, disinfection of the treated liquid using ozone after slow sand filtration was recommended to ensure that harmful pathogens were eliminated.

CONCLUSIONS

The following conclusions were drawn from this study:

1. Since alum, lime, and gypsum addition did not produce satisfactory results with regard to settling, natural settling (24 h) was considered a suitable method to separate the liquid fraction from swine manure.
2. An aeration level of 3 L/min was very effective during the first 7 d in reducing the TDS level in the liquid manure (3590 mg/L, 83% reduction). After 7 d, reduction of TDS slowed due to lower availability of biodegradable substrate. Blending of 20% fresh water with the filtered liquid after 7 d of aeration at 3 L/min, provides a liquid with TDS less than 3000 mg/L, which meets the Canadian Water Quality Guidelines (CWQG 1995).

Fig. 3. Picture of liquid manure before and after RO filtration.

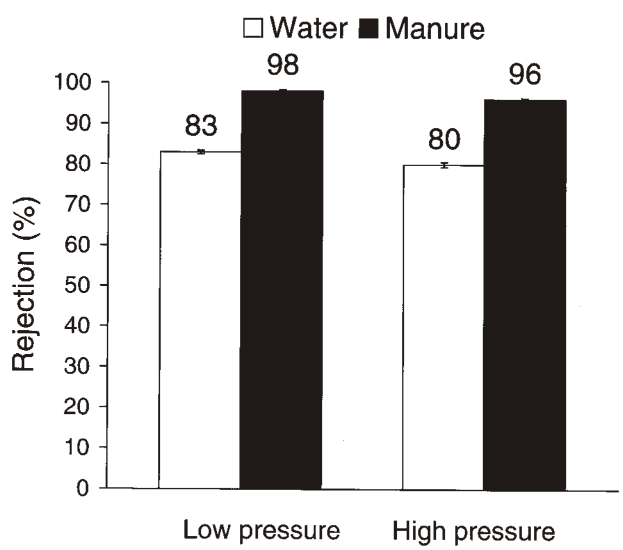

Fig. 4. Percentage rejection at low and high operating pressures.

3. Slow sand filtration removed pathogens and TSS from the aerated liquid fraction and met the drinking water guidelines for pathogens. However, further disinfection using ozone needs to be investigated to ensure that there is no pathogen outbreak.
4. The water treated by an RO system appeared as clear as tap water and met the chemical parameters for drinking water for pigs. However, the volume of treated water produced by RO treatment was as low as 4% at 345-414 kPa. Therefore, RO is not recommended as a treatment method.

ACKNOWLEDGEMENT

The authors acknowledge the financial support of the Alberta Pork Producers and the use of the facilities at the Swine Research Center at the University of Alberta, Edmonton, Alberta.

REFERENCES

Bayne, G. 1998. Determination of nutrient values of manure in Saskatchewan. 1997 Data collection. Regina, SK: Saskatchewan Agriculture Food.

Bayramoglu, M., Cakici,A. and Tekin, T. 2000. Modelling of oxygen transfer rate in diffused air aeration tanks. *Transaction of Institute of Chemical Engineers* 78 (B): 209-213.

Belfort, G. 1984. *Synthetic Membrane Process Fundamentals and Water Applications*. London, UK: Academic Press.

Boyle, W.C. 1986. *Aeration System Design, Testing and Operation and Control.* Pollution Technology Review No. 127. Park Ridge, NJ: Noyes Publication.

Cecen, F. and G. Guersoy. 2000. Characterization of landfill leachate and studies on heavy metal removal. *Journal of Environmental Monitoring* 2(5): 436-442.

Cheremisinoff, P.N. 1995. *Handbook of Water and Wastewater Treatment Technology*. New York, NY: M. Dekkar.

Coote, D.R. and L.J. Gregorich. 2000. *The Health of Our Water*. Ottawa, ON: Agricultural and Agri-Food Canada.

CWQG. 1995. *Canadian Water Quality Guidelines*. Ottawa, ON: Canadian Council of Resource and Environment Ministers, Environment Canada.

Deleris, S., P. Etienne, A.J. Marc, R. Michel and D. Hubert. 2000. Effect of ozonation on activated sludge solubilization and mineralization. *Ozone Science and Engineering* 22(5):473-486.

Doyle, Y. and J. De La Noue. 1987. Aerobic treatment of swine manure. *Biological Wastes* 22 (3):187-208.

Eaton, A.D., C.S. Clesceri and A.E. Greenberg. 1995. *Standard Methods for Examinationof Water and Wastewater.* Washington, DC: American Public Health Association.

FDA. 1995. Food and drug administration compliance policy guide. Sec 685.100, Recycled Animal Waste-CPG 7126.34. http://www.fda.gov/ora/compliance_ref/cpg/cpgvet/cpg685-100.html (2003/12/10).

Johnson, K. 2000. Gypsum. http://wwe.net/~jrjohns/ gypsum .htm (2004/01/10).

Kiely,G. 1998.*Environmental Engineering*. New York, NY: McGraw Hill International.

Linda. K,M. 1983. Effect of sand filter on removal of reovirus and *escheria.coli* by slow sand filtration. In *Proceedings of American Water Works Association Annual Conference*, 367-376.

Liberti, L, M. Notarnicola and A. Lopez. 1999. Advanced treatment for municipal wastewater reuse in agriculture. 111-ozone disinfection. *Ozone Science and Engineering* 22(2):151-166.

Logsdon, G.S. (ed.). 1991. *Slow Sand Filtration.* A Report proposed by the Task Committee on Slow Sand Filtration of the Environmental Engineering Division, American Society of Civil Engineers. New York, NY: ASCE.

Masters, G.M. 1991. *Introduction to Environmental Engineering and Science*. Englewood Cliffs, NJ: Prentice Hall.

Ndegwa, P.M., J. Zhu and A. Luo. 2001. Effect of batch aeration-treatment on the solubility of phosphorus in pig manure. *Journal of Agricultural Engineering Research* 80(4): 365-371.

Overcash, M.R., J.R. Miner and F.J. Humenik. 1983. *Livestock Waste Management*. Boca Raton, FL: CRC Press.

PPRG. 2000. *Pork Production Reference Guide*. Saskatoon,SK: Prairie Swine Centre Inc.

Winkler, M.A. 1981. *Biological Treatment of Wastewater Treatment Plants*. Ellis Horwood, NY: Halsted Press.

Zhang, R.H. and F. Lei. 1998. Chemical treatment of animal manure for solid liquid separation. *Transaction of the ASAE* 41: 1103-1108.

Zhao, Y.-Y., K.F. Wu, Z. Wang, L. Zhao and S. Lee. 2000. Fouling and cleaning of membranes - A literature review. *Journal of Environmental Science* 2 (2): 241-250.