Comprehensive pig manure treatment using the BIOSOR^{TM} biofiltration process.

Traitement global du lisier de porc par le procédé de biofiltration biosor^{TM}.

Gerardo Buelna,
Rino Dubé, Marie-Claude Michel,
Nicolas Turgeon, Yves Bernard.
Centre de Recherche Industrielle du Québec (CRIQ). 333 Franquet,
Sainte-Foy, Québec, Canada G1P 4C7
E-mail : gbuelna@criq.qc.ca

Paul Lessard
Université Laval,
Department of Civil Engineering,
Québec, Canada G1K 7P4.

Abstract

Increasingly stringent standards and heightened public awareness regarding environmental issues has led to an increase in research on various treatment methods used in different countries. Among manure treatment options, organic bed biofiltration represents a very promising technique for treatment and recovery of liquid and gaseous effluent on pig farms.

Considering this technology's potential, industrial-scale research and development has been carried out to prove that the BIOSOR^{TM} process is effective in treating pig manure and foul air in farm buildings. This work was recently done on-site at a livestock farm using a 400 m^3 industrial biofiltration system. The system consists of a combined decanter-digester, a protective prefilter and a double-action biofilter.

The system performed well despite variations in temperature and organic load at the manure pretank outlet. Despite wide variations in BOD_5 (10 000 - 20 000 mg/L), in SS (10 000 - 20 000 mg/L), in TKN (2 000 - 3 800 mg/L) and in Ptot (500 - 900 mg/L), the BIOSOR^{TM} system was able to maintain an overall pollutant removal performance averaging > 95% for the BOD_5, > 97% for the SS, > 75% for the TKN and > 87% for the Ptot. By reducing the raw manure's organic load by more than 95%, BIOSOR^{TM} eliminates close to 95% of the odours produced when the manure is transported, stored and spread.

Résumé

La sévérisation des normes et la sensibilisation sans cesse croissante du public aux problèmes environnementaux ont entraîné une recherche accrue de diverses méthodes de traitement dans différents pays. Parmi les alternatives de traitement du lisier de porc, la biofiltration sur support organique constitue une technique très prometteuse pour le traitement et la valorisation des effluents liquides et gazeux des fermes porcines.

Compte-tenu du potentiel de la technologie, des travaux de recherche et développement à grande échelle, visant à démontrer l'efficacité du procédé BIOSOR^{MC} lors du traitement du lisier de porc et de l'air vicié du bâtiment de production, ont été réalisés récemment sur le site d'élevage à l'aide d'un système de biofiltration industriel de 400 m^3 de volume. Le système est constitué d'un décanteur-digesteur, d'un préfiltre de protection et d'un biofiltre à double action.

Le système a bien fonctionné malgré les variations de température et de charge organique à la sortie de la préfosse à lisier. En effet, en dépit des fortes variations de DBO$_5$ (10 000 - 20 000 mg/L), des MES (10 000 - 20 000 mg/L), de NTK (2 000 - 3 800 mg/L) et de P$_{tot}$ (500 - 900 mg/L), le système BIOSOR^{MC} a permis de maintenir globalement une performance épuratoire moyenne de > 95% pour la DBO$_5$, > 97% pour les MeS, > 75% pour NTK et > 87% pour le P$_{tot}$. En réduisant de plus de 95% la charge organique du lisier brut, le procédé BIOSOR^{MC} permet d'éliminer près de 95% des odeurs provenant de l'entreposage,du transport et de l'épandage du lisier.

1. Introduction

Over the past twenty years, there has been a considerable increase in pig production in Québec. The number of pigs now produced has almost tripled. In 1985, there were 1200 farms with more than 100 sows in their livestock and 793 operations feeding over 1000 pigs a year (1). The growth of this industry has caused a surplus of manure to be disposed of in comparison to the areas available for it to be spread. As a result, there is a greater problem of water, air and soil pollution, not to mention undesirable odours, particularly in and around production buildings, storage areas and when the pig manure is spread (Figure 1). By measuring the intensity and duration of odour emissions, it was established that the sources of odour in Québec were at 20% for buildings, 10% for storage, 5% for recovery and 65% for spreading (2).

Figure 1
Standard manure management

Literature on the subject of gas emissions from pig manure indicates that these gases are composed mainly of methane, carbon dioxide, ammonia and hydrogen sulphide (3, 4 and 5). While ammonia is the main component, it is nevertheless not the one with the strongest odour. Literature shows that average concentrations of NH_3 rarely exceed 66 ppm, while its odour threshold is evaluated at 47 ppm. There has nevertheless been a great deal of monitoring of this compound before and after treatment since it has been identified on the one hand as being responsible for acid rain (6, 7) and, on the other, as a good indicator of odour control during pig manure treatment (8). Trimethylamine and hydrogen sulphide are compounds found in the ambient air of pig farms and have the lowest odour threshold values (respectively 0.00021 and 0.00047 ppm).

A study carried out by ROCHE LTÉE (9) shows that pig manure is a liquid effluent with high concentrations of organic matter (6.7%), N_{total} (0.61%) and P_2O_5 (0.33%). The volume of manure produced per day per animal is estimated as being on average 7% of its live mass, depending on several factors, such as the animal's weight and livestock practices (feeding, frequency of cleaning, etc.).
Increasingly stringent standards and heightened public awareness regarding environmental issues has led to an increase in research on various treatment methods used in different countries. Among manure treatment options, organic bed biofiltration represents a very promising technique for treatment and recovery of liquid and gaseous effluent on pig farms.

The principle of biofiltration is to have liquid and gaseous effluents pass through a filter containing an organic bed. As a pollutant removal agent, the organic bed can act in two ways, as a natural resin able to fix several types of pollutants and/or as a medium for different microorganisms capable of degrading the retained substances. These pollutants are degraded into CO_2 and H_2O as a result of microbial activity (10). The constituents of the organic support, particularly the lignine and the organic acids, contain many polar functional groups: alcohols, phenols, aldehydes, ketones, acids and ethers. This polar character provides a good adsorption capacity for the organic molecules and transition metals (11). Adsorption properties can also be linked to the presence of a porous structure, conducive to physical adsorption (12).

Different studies have been carried out on the use of organic beds, mainly peat, to control water pollution (13, 14). The first research work on the use of organic bed biofilters for purifying air contaminated by foul air can be traced back to Bohn (15), Zeizig (16) and Rand et al. (17). In these studies, organic bed biofilters were proved effective in reducing the polluting load of liquid and gaseous effluents at less cost than conventional technologies.

Research carried out at the Centre de Recherche Industrielle du Québec (CRIQ) has also proven that organic bed biofiltration can be used in treating highly concentrated effluent. Pilot biofilters were able to effectively treat the leachate of dairy cattle manure compost (around 9000 mg O_2/L in BOD_5, 1200 mg/L in TKN). Anaerobic phases followed by an aerobic treatment were able to remove 90% of the BOD_5, 80% of the SS and 70% of the TKN (18). Research work by Buelna et al. (19), Dubé et al. (20) and Blais (21) show that it is possible to reduce the polluting load of pig manure by more than 90% using organic bed biofiltration. The organic bed used as a filter medium increased TKN concentrations threefold and P_{tot} concentrations eightfold (20).

Biofilters succeeded in deodorizing over 95% of the offensive odour in foul air (22). Figure 2 illustrates how the BIOSOR™-MANURE operates, simultaneously treating liquid and gaseous effluents.

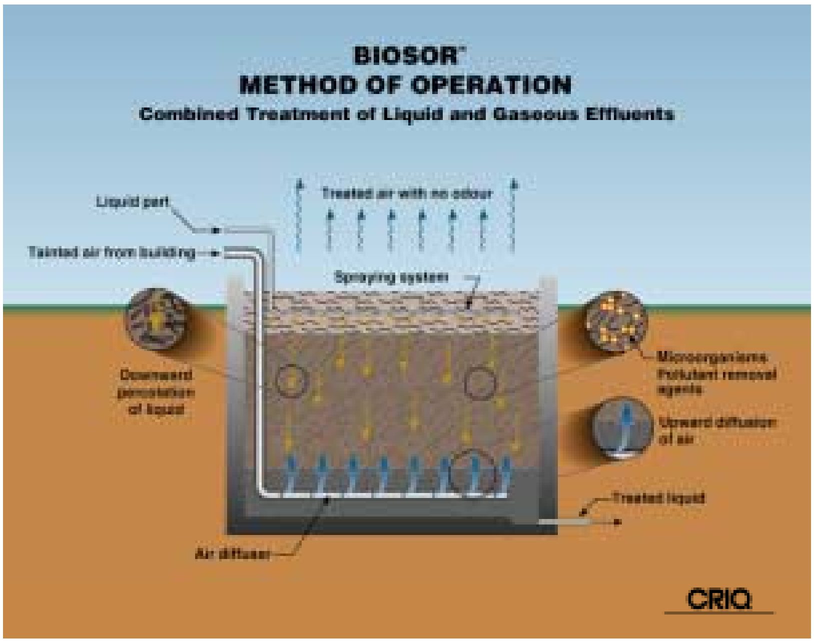


Figure 2
The BIOSOR™-MANURE technology

Considering this technology's potential, industrial-scale research and development has been carried out to prove that the BIOSOR™ process is effective in treating pig manure and foul air in farm buildings. This work was recently done on-site at a livestock farm using a 400 m³ industrial biofiltration system. The system consists of a combined decanter-digester, a protective prefilter and a double-action biofilter.

The system performed well despite variations in temperature and organic load at the manure pretank outlet. Despite strong variations in BOD_5 (10,000 - 20,000 mg/L), in SS (10,000 - 20,000 mg/L), in TKN (2000 - 3800 mg/L) and in P_{tot} (500 - 900 mg/L), the BIOSOR™ system was able to maintain an overall pollutant removal performance averaging > 95% for the BOD_5, > 97% for the SS, > 75% for the TKN and > 87% for the P_{tot}. By reducing the raw manure's organic load by more than 95%, BIOSOR™ eliminates close to 95% of the odours produced when the manure is transported, stored and spread.

NH_3 and H_2S contents in the farm production buildings vary respectively from 1.0 to 7.1 ppm and from 0.03 to 0.21 ppm, depending on the season. The biofilter installed at the pig farm and operating at a rate of 7000 m^3/h can treat 94 to 100% of the ammonia present in the gaseous effluent. The treatment is 100% effective in treating hydrogen sulphide. Olfactory measurements indicate that the biofiltration treatment of gaseous emissions clearly reduces odour intensity.
An effective, simple and safe system able to control odours is a major asset in reducing the problem of surplus manure and transportation costs. By increasing

the acceptability rate of the manure, more of the surplus can be managed inside the maximum economic distance for transportation and spreading (23).

2. Materials and Methods

An industrial biofilter system was designed, built and started up in January 1997, to treat the liquid and gaseous effluents of a pig farm with 150 sows, nursery to finish (around 2000 pigs produced/year). The system was designed to treat up to 12 m^3/d of manure and 15,000 m^3/h of foul air.

Figure 3 illustrates how the pig manure is first treated by separating liquid and solid fractions in a 1200 m^3 combined decanter-digester (a refitted storage tank). The settled sludge, representing 15 to 20% of the total volume of manure produced, is stabilized and deodorized by anaerobic digestion. The residual liquid fraction (80 to 85%) is directed to an 8-m^3 protective prefilter, made up of coarsely textured natural materials. Next, this fraction is pumped to the surface of a 400-m^3 biofilter composed of a multi-layer organic bed (wood chips, peat and bark). To meet current regulations, the treated manure is stored in an existing tank before being used as washwater or for irrigation purposes. The foul air of the production building is simultaneously directed toward the biofilter base where it undergoes a backflow treatment.

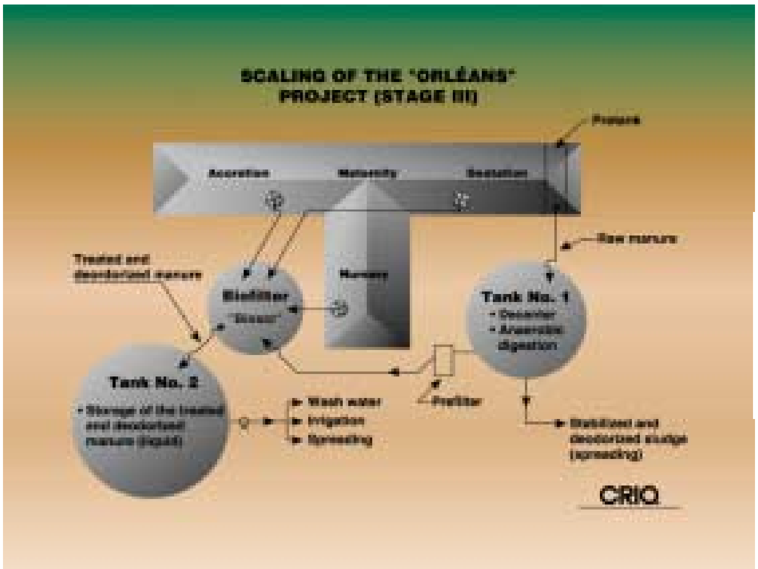


Figure 3

Scale-up of the BIOSOR™-MANURE process

Several physical, chemical, microbiological, sensory and hydrodynamic parameters were monitored over several months to assess the biofilter's performance and working order. The biochemical oxygen demand (BOD_5), suspended solids (SS), total Kjedahl nitrogen (TKN) and phosphorous (P_{tot}) were measured to establish the effectiveness of the biofiltration system in treating pig manure. Ammonia (NH_3), hydrogen sulphide (H_2S) and a sensory evaluation (olfactometric) were selected as parameters to establish the biofilter's pollutant removal rate for the foul air of the production building. The solid fraction (sludge) was characterized for the following parameters: water content, bulk density, organic matter, nitrogen, phosphorous and potassium.

All the analysis techniques that were used to characterize the liquid fraction of the pig manure conform with standard recommended practices (24). Sludge analyses were conducted at CRIQ's laboratory, which is accredited by the ministère de l'environnement et de la faune du Québec (MEF). The sampling method to characterize the foul air of the production building used a device to selectively sample families of compounds (25). This technique consists of trapping volatile compounds so they can be measured by specific reagents. The trapped ammonia in the form of ammonium ions in the chlorhydric solution is measured by colorimetry using a Nessler reagent according to the AFNOR NFT 90 15 standard. As for the sulphur compounds, they are measured with an iodemetric test.

To conduct the sensory analysis of the treated or untreated gaseous effluent, a technique of sampling by adsorption on a piece of fabric is used. The fabric having adsorbed the odours undergoes an organoleptic evaluation. A panel of 10 to 12 people uses their sense of smell to conduct the olfactometric analysis.

The results of the sensory tests are processed according to a statistical method: the triangle test. This method, described by Larmond (26), is used to determine whether appreciable differences exist between two types of samples (tainted air/treated air and treated air/control air). Results are expressed in degrees of significance. If a difference is established, the overall effectiveness of the deodorization process is then calculated in terms of odour intensity (OI) and odour nuisance rating (ONR).

3. Results and Discussion

Characteristics of pig manure

The average physical, chemical and biochemical characteristics of the effluent at the pretank outlet can be seen in Table 1. These results show an effluent with high concentrations of phosphated (P_{tot}) and nitrogenated (TKN) organic matter (BOD_5) and suspended solids (SS). The values obtained were from 60 to 100 times higher than those reported for domestic sewage, which is normal for effluent from a pig farm.

The first stage of treatment is to pass the manure through the decanter-digester with the aim of neutralizing the variations in load, reducing the concentration of suspended solids and stabilizing the decanted sludge by anaerobic digestion. Table 1 shows that the decanter-digester maintained a relatively constant concentration of the different parameters as well as reducing SS concentrations by 94% and total phosphorus by 71%. As will be seen further on, this represents an advantage both in terms of manure management (reduction of transportation costs, conservation of the agronomic value) and in terms of the biofilter's operation.

Parameters (mg/l)	Raw manure mg/l (variation) average	Manure after decantation mg/l (variation) average	Average effectiveness of decantation (%)
BOD5	(10,000-20,000) 13,000	(7,200-9,600) 8,500	35
SS	(10,000-20,000) 16,000	(730-1,600) 940	94
Ptot	(500-900) 650	(180-200) 190	71
TKN	(2,000-3,800) 2 300	(1,600-1,800) 1,700	26

Table 1
Physical, chemical and biochemical characteristics of the raw manure and after decantation

Simultaneous Treatment of Manure and Foul Air by Biofiltration

Treatment of the liquid fraction of the pig manure after decantation

The pollutant removal performance of biofiltration was established using a manure flow of 7 m^3/d and a ventilation rate of 7 000 m^3/h. Figure 4 shows the results obtained for pH, SS, BOD_5, TKN and P_{tot}. It is important to note the consistency and quality of the performances of the biofiltration system throughout the entire experimental period. The adsorption, absorption and cationic exchange properties of the organic bed allow the system to support wide variations in load without a noticeable impact on its pollutant removal rates.

The pig manure's pH remained almost neutral throughout the experimental period. The organic bed used proved to be an effective buffer for discharging effluent with a pH of 8.

The elimination of organic carbon is not very sensitive to wide variations in the pig manure's BOD_5 (7,200 - 9,600 mg/L). Figure 4 shows that the biofilter's average pollutant removal rate was around 95%. The drop in effectiveness seen on day 40 and day 70 can be attributed to a lower air flow rate from the production building.

The SS concentration at the biofilter inlet varied greatly during our experiments. These variations were linked to the hydraulic behaviour of the decanter-digester. Despite heavy peak loads (~ 1 600 mg/L), elimination rates maintained SS in the effluent at concentrations of under 200 mg/L (> 80% effectiveness). Two maintenance sessions a year (cleaning and stirring the bed) are necessary to backflush and declog the organic bed.

High TKN concentrations were detected in the pig manure. Despite peaks of 1,800 mg N-TKN/L, effluent concentration in the biofilter remained under 500 mg in N-TKN/L, an average effectiveness rate of 75%. The drop in effectiveness on day 40 and day 70 was also linked to a lower air flow rate from the production building.

Although most earlier research reports only a low phosphorous up-take, Figure 4 shows that during our experiments, the average reduction in P_{tot} was on average 80%. Performances were such that they maintained P_{tot} concentrations of less than 50 mg P_{tot}/L in the effluent.

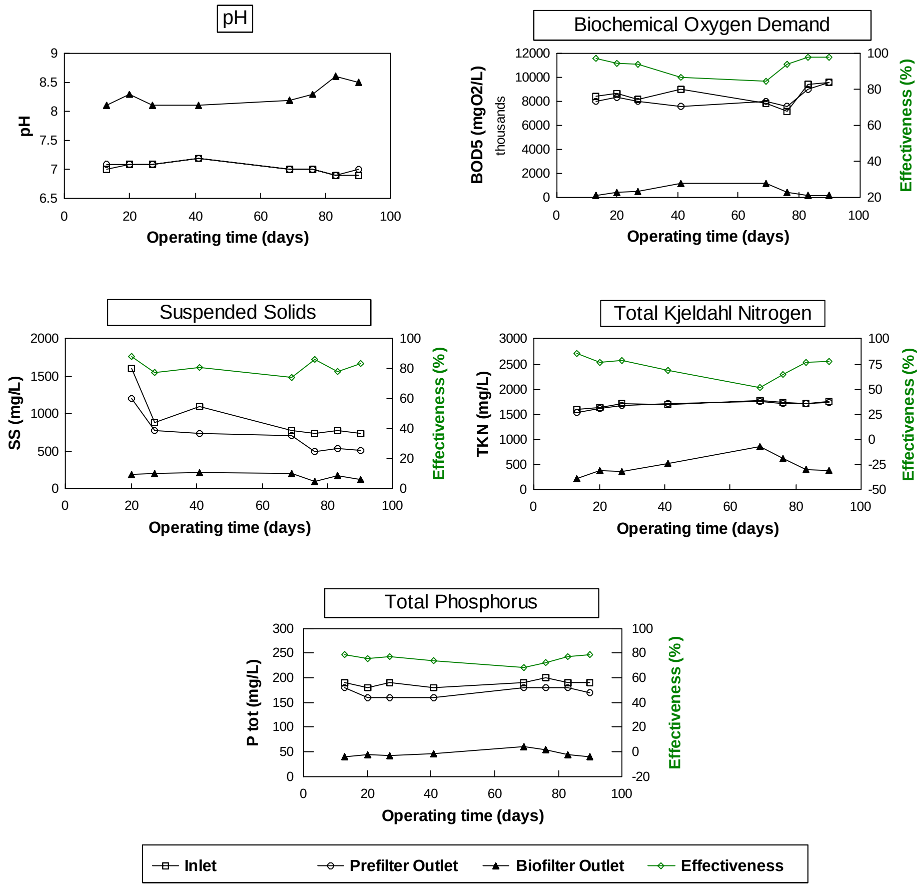


Figure 4

Pollutant removal performance of the BIOSOR™-MANURE treatment system

Treatment of foul air from the production building

The graphs in Figure 5 show the overall results obtained for ammonia and hydrogen sulphide concentrations in the pig farm air before (inlet) and after (outlet) biofiltration.

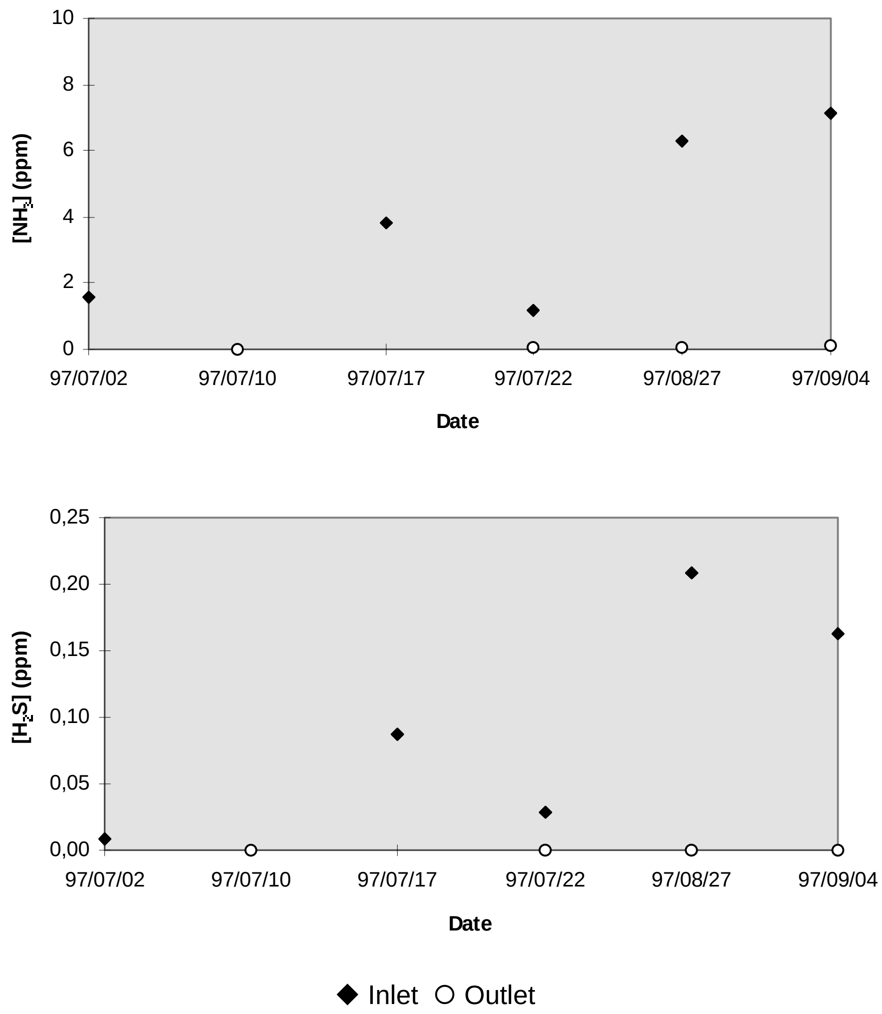


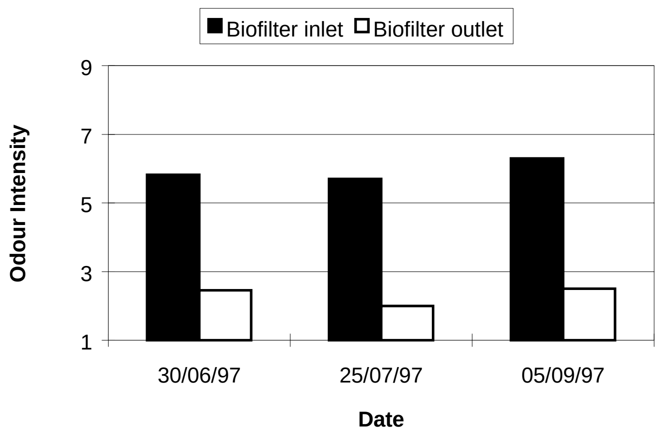
Figure 5
NH_3 and H_2S concentrations at the biofilter's inlet and outlet over time

The increase in concentrations at the biofilter's inlet observed at the end of the summer was caused by a decrease in ventilation of the ambient air of the pig farm. This operation is done to meet criteria regarding air flow rate in winter. This air flow is transferred entirely to the ventilators that supply the biofilter.

Ammonia is the main compound with concentrations varying between 1.0 and 7.1 ppm. H_2S concentrations measured in the pig farm air (from 0.03 to 0.21 ppm), even if they seem low, nevertheless exceed the odour threshold for this compound (25).

The system's pollutant removal effectiveness varies from 94 to 100% for ammonia. As for the H_2S, it was not possible to detect in the air at the biofilter's outlet. The system therefore performs very well, despite the increase in the concentrations of pollutants.

Sensory evaluation results show a marked difference between the foul air and treated air. This difference was due in large part to the intensity of the odour smelt and the degree of discomfort experienced by the panel. Figure 6 illustrates that the ambient air of the pig farm is characterized by moderate to strong intensity and is qualified as very unpleasant. The air leaving the biofilter causes a slight olfactory sensation qualified as very tolerable. The biofilter's effectiveness in terms of odour reduction was not influenced by the variations in load observed.



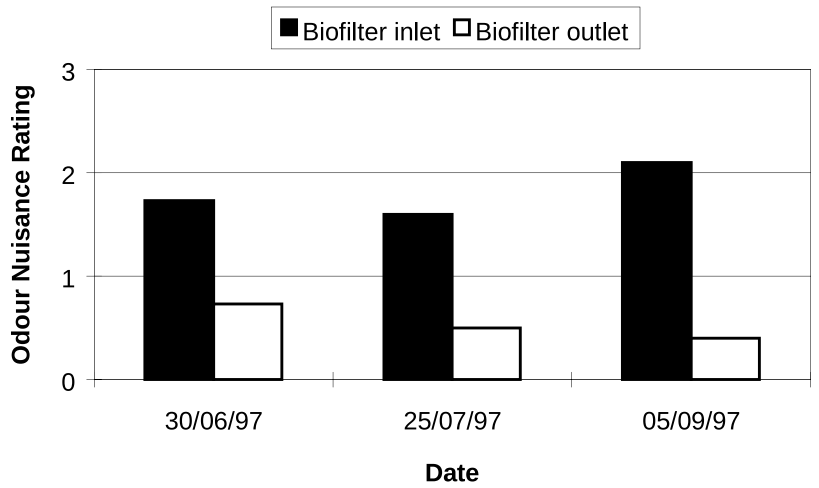


Figure 6
Odour intensity and concentration of gases at the bioflter's inlet and outlet

In addition, the air leaving the biofilter is described as having damp earth smell (the characteristic odour of peat). The biofilter's role is therefore twofold: it degrades the pollutants from the pig farm (NH_3 and H_2S) and provides a pleasant smell to the gaseous flux.

Recovery of decanted sludge

The fertilizing value of pig manure is conserved in the form of a semi-liquid sludge, deodorized and stabilized by anaerobic digestion. This sludge represents only 15% to 20% of the total volume of the manure to be spread, which considerably reduces the costs of transportation associated with spreading. Among other things, Table 2 shows that the characteristics of this sludge are highly appreciated for agricultural use. It contains 77% organic matter, 3.8% total nitrogen, 2.1% total phosphorus and 0.9% total potassium. No salmonella and a significant reduction in faecal coliform were also observed in the digested sludge.

Parameters	Value
Water content (%)	89
Organic matter	77
C/N	10.2
pH	6.8
Bulk density (kg/m3)	1030
Total nitrogen	4.3 (3.8%)
Total phosphorous	2.4 (2.1%)
Total potassium	1.0 (0.9%)

Table 2
Characterization of the decanted sludge of the pig manure

Note: The organic matter content is expressed in % on a dry basis.
Total nitrogen, total phosphorus and total potassium contents are expressed in kg/m.t. on a wet basis and the results in parenthesis are in % on a dry basis.

4. Conclusion

This project's results show that the organic bed biofiltration process (BIOSOR™) is a very promising biological alternative to treat and recover the liquid and gaseous effluents from pig farms. Indeed, the BIOSOR™ technology is a process that treats pig manure globally. It reduces the polluting load of pig manure by more than 90% and eliminates close to 95% of the odours coming from buildings, storage, transportation and spreading. The BIOSOR™ system is installed directly at pork producers without modifying their production practices. It enables existing storage installations to be recuperated.

Pig manure is a waste product with high concnentrations of phosphated and nitrogenated organic matter and suspended solids. Moreover, it is characterized by wide variations in load and foul odours. The values obtained are 60 to 100 times greater than those for domestic sewage.

Studies of the pollutant removal rates show that the BIOSOR™ system performed well despite variations in temperature and organic load of the liquid fraction of the pig manure. Despite wide variations of BOD_5 (10,000 - 20,000 mg/L), SS (10,000 - 20,000 mg/L), TKN (2000 - 3800 mg/L) and P_{tot} (500- 900 mg/L), the BIOSOR™ system maintained overall average pollutant removal rates of > 95% for the BOD_5, > 97% for the SS, > 75% for the TKN and > 87% for the P_{tot}. The treated manure can be used as washwater for the manure recuperation systems from the buildings, as irrigation water or it can be discharged into a disposal field.

Measuring programs showed that ammonia (NH_3) and hydrogen sulphide (H_2S) contents in the pig farm production buildings vary respectively from 1.0 to 7.1 ppm and from 0.03 to 0.21 ppm depending on the season. The biofilter installed in the pig farm and operating at a flow of 7000 m^3/h can treat from 94 to 100% of the ammonia present in the gaseous effluent. This treatment is 100% effective for hydrogen sulphide.

The results of olfactometric evaluations indicate that there is a noticeable difference between the foul air and the treated air. The untreated air is perceived as being unpleasant while the treated air is judged as tolerable. The treatment by biofiltration of gaseous emissions gives a very marked reduction in odour intensity.

The decanted and stabilized sludge, which represents 15 to 20% of the total volume of manure to spread, preserves its fertilzing value. Analyses of the sludge show very promising characteristics for agricultural recovery of the product (77% of organic matter, 3.8% of TKN, 2.1% of Ptot and 1% of Ktot on a dry basis). Moreover, no salmonella and a significant reduction in faecal coliform were observed. The characteristics of the stabilized sludge and the reduction of transportation costs associated with spreading will no doubt contribute to increasing the manure acceptability rate within economic distances.

In light of these results, there is no doubt that the BIOSOR™ process is a sound, simple and effective technique that provides a global solution to the environmental problems associated with manure management. This technology now makes it possible to reconcile people's environmental concerns with the pork industry's potential for growth.

5. Acknowledgements

This work was made possible due to the financial contribution of the Conseil de recherches en pêche et en agroalimentaire du Québec (CORPAQ - MAPAQ), of the coopérative fédérée du Québec, of the Fédération des producteurs de porcs du Québec (FPPQ), of Génétique NPD (Québec) inc., of the ministère de l’agriculture des pêcheries et de l’alimentation du Québec and of the porcherie Orléans inc. The authors would also like to thank Bel Environnement inc. for its technical support during this project.

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