SEPTIC TANK EFFLUENT TREATMENT USING AN ANAEROBIC FILTER

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1. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1.1 Summary

Experimental studies on anaerobic filter treatment of septic tank effluent have been carried out in some countries such as U.S.A., India, and Thailand. No such study has been carried out in Canada.

This report has reviewed the literature on the subject, assessed the suitability of such a treatment for Canadian conditions and presented a suitable conceptual system for use along with some cost information. Areas for further research have also been identified and reported.

1.2 Conclusions

The following general conclusions can be drawn based on the study.

(1) A review of the published studies showed that septic tank effluent treatment using an anaerobic filter is practical and generally cost-effective for achieving a much better effluent quality.

(2) Anaerobic filter treatment of septic tank effluent appears to be suitable under Canadian conditions as a treatment step especially to reduce BOD and SS level in the effluent discharged for disposal through the tile field system.

(3) There are no specific regulations governing the use of anaerobic filters for onsite treatment in any province or territory of Canada and it is believed that such a system would be permitted on an experimental basis in most of the provinces in Canada.

(4) Under Canadian climatic conditions, it is expected that BOD removals through the anaerobic filter would be much lower especially during colder months to permit direct discharge of the

effluents to surface water courses in many provinces where effluent BOD and SS levels of 20 mg/L and 20 or 30 mg/L respectively are usually stipulated for discharge to surface waters.

(5) In the case of anaerobic filter effluent disposal through soil, it may not be prudent to lower the usual size requirements of subsurface disposal systems; the additional treatment would enhance the longevity of the subsurface system.

(6) A typical design for a household would involve generally a septic tank combined with an anaerobic upflow filter of same capacity as the septic tank allowing room for a small cleaning chamber to remove sludge periodically from the anaerobic filter.

(7) It is preferable to use a medium which is relatively inexpensive and which is sturdy in comparison to other media; rock is generally preferred and other media such as clay support media can be tried.

(8) Laboratory studies under low temperature and long-term field studies in Canada are required to assess potential of its use in Canada more realistically.

1.3 Recommendations

(1) It is recommended that the provinces may be encouraged to consider this additional treatment especially when effluent is to be discharged in marginally suitable soils or in areas where groundwater elevations are high.

(2) It is also recommended that, because of its possible potential, studies should be undertaken as indicated in Section 6 to examine realistically its suitability for use in Canada.

2. INTRODUCTION

Much of the earlier work on anaerobic treatment was related to anaerobic digestion of municipal wastewater sludge including uncontrolled digestion in a septic tank. It was followed by anaerobic treatment of high strength industrial wastewaters. Recently several successful attempts have been made on an experimental basis (both laboratory and pilot scale) to treat dilute wastewaters such as municipal wastewaters (raw and settled) and septic tank effluent by anaerobic processes, especially by the fixed film process such as an anaerobic filters.

Experimental studies on anaerobic filter treatment of septic tank effluent have been carried out in India (National Environmental Engineering Research Institute), in U.S.A. (Washington State University) and in Thailand (Asian Institute of Technology). The World Bank has expressed an interest in such a system especially for use in developing countries. A recent seminar on anaerobic filters held in Florida emphasized the need for additional research and demonstration effort in this field. No study pertaining to anaerobic filter treatment of septic tank effluent has been carried out in Canada.

It was considered necessary to assess the suitability of this form of treatment for use in Canada. In this context, a proposal entitled "Septic Tank Effluent Treatment Using an Anaerobic Filter" was submitted to Canada Mortgage and Housing Corporation (CMHC) in March 1983. This proposal was accepted by CMHC in June 1983 and this report outlines the work carried out as per the agreement with CMHC and presents the results of the study.

3. OBJECTIVES AND SCOPE

3.1 Objectives

The basic objectives of this study were:

(1) to prepare a literature review of anaerobic treatment of dilute wastewaters, with special reference to anaerobic filtration of septic tank effluent;

(2) to assess the suitability of anaerobic filter treatment of septic tank effluent for Canadian conditions based on the information available (as part of this assessment, the reactions of provincial health/environmental agencies will be obtained on this form of treatment);

(3) if anaerobic filtration of septic tank effluent is feasible, to develop a conceptual system/configuration along with approximate cost for typical onsite applications (residential/institutional); and

(4) to identify areas of research pertaining to this form of treatment relevant to Canadian conditions.

3.2 Scope of the Study

The scope of the investigation is identified below as a number of tasks.

Task 1. Literature search and preparation of literature review.

Task 2. Obtain the reaction of provincial health/environmental agencies on this form of treatment.

Task 3. Assess the suitability of anaerobic filter treatment of septic tank effluent based on information obtained in Task 2 and on an analysis of literature data.

<u>Task 4</u>. Develop conceptual system and prepare approximate cost estimates.

<u>Task 5</u>. Based on gaps in knowledge, identify areas for further research with special reference to Canadian conditions.

<u>Task 6</u>. Prepare a report.

4. REVIEW OF LITERATURE

4.1 General

Many data bases were consulted through the services of the University of Regina and relevant publications related to the subject were identified. Copies of most of the needed publications were obtained.

The disposal of septic tank effluent in soil becomes difficult under certain conditions such as compact soils, high water table and limited area. Under these conditions, generally sand filters, mounds or similar alternatives are resorted to for septic tank effluent treatment. An alternative that can also be considered is the use of an anaerobic filter, with the filter effluent disposed of through the soil medium or discharged to a water course, if permissible.

The anaerobic filter consists of a reactor filled with a solid medium which in turn supports microbial growth. This medium consists of materials such as rock, crushed stone, gravel, filamentous "curtains", and various artificial packing materials. Such reactors are typically operated in an upflow mode thereby ensuring the medium remains submerged to maintain anaerobic conditions. The filter can also be operated in the downflow or in the horizontal modes.

The filter influent is usually introduced at the bottom of the filter through a system of underdrains, hence flowing upward through the medium (1). Laboratory studies normally involve vertical columns of various configurations, while pilot plants and full-scale designs have been as simple as a pit filled with rock. A typical full-scale unit is shown in Figure 1 (2). A United States patent has been applied for on an adaptation of this process by Al Green and Associates of Tacoma, Washington, shown in Figures 2 and 3. Gravel media is filled around the excavation space to a

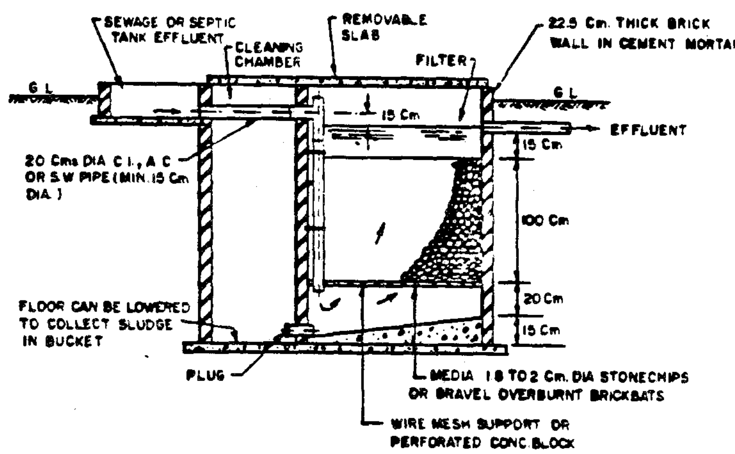

FIGURE 1 Upflow (Anaerobic) Filter (2)

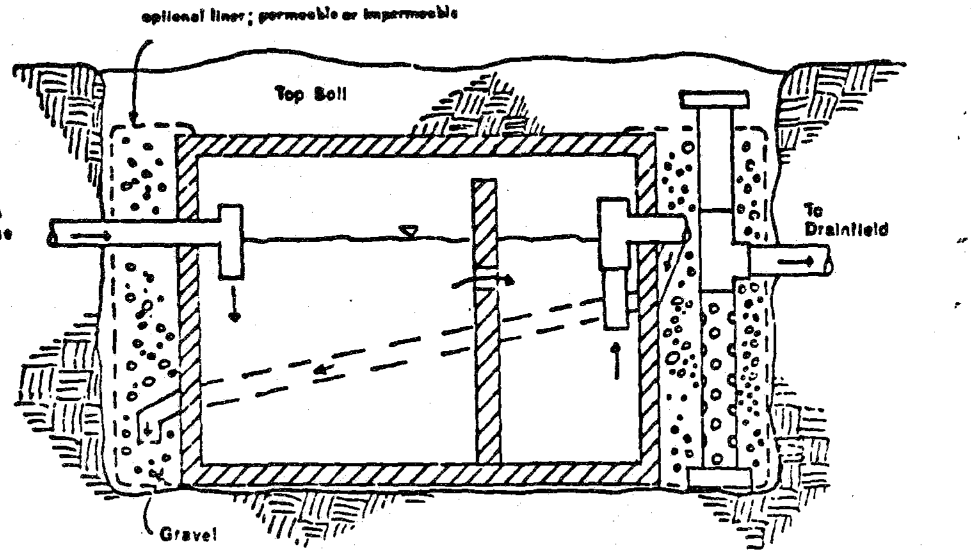

FIGURE 2 Wrap-Around Filert Longitudinal Section

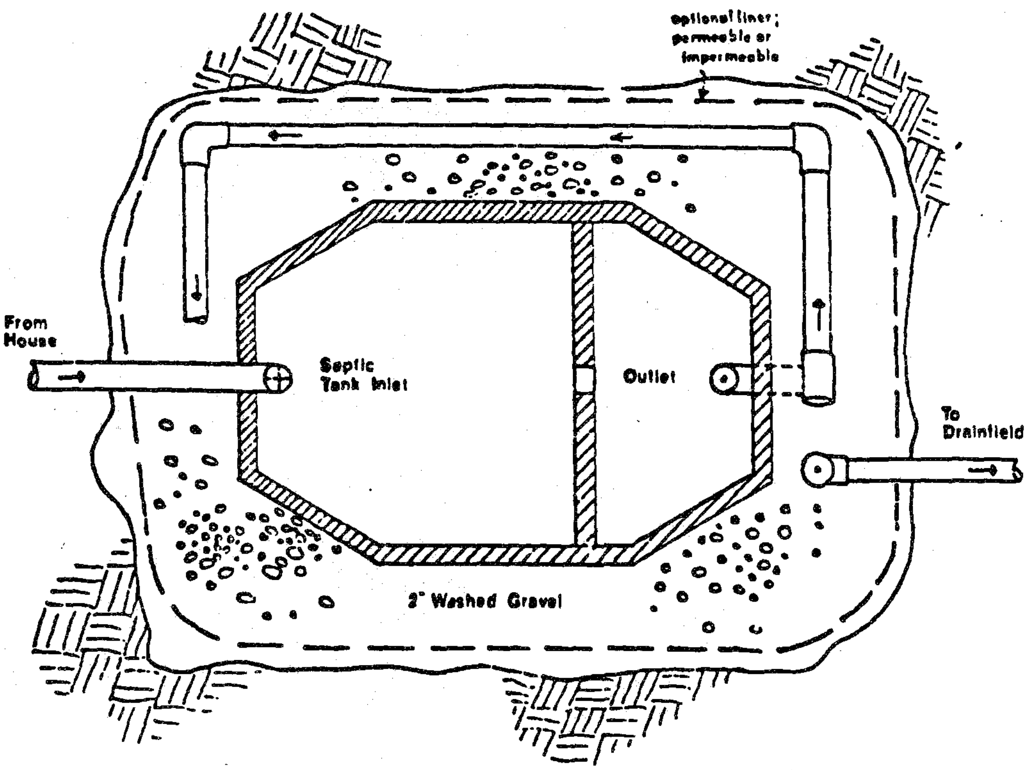

FIGURE 3 Wrap-Around Filter (Plan View)

depth equal to that of the septic tank and effluent then piped around the tank to the influent side of the excavation. Effluent filters through the media towards a perforated riser which is the influent pipe to the tile field (3). Two of these units have been operating satisfactorily for almost six years (4).

Removal mechanisms are primarily adsorption, filtration, and oxidation (4). Polprasert and Hoang (5) found similar mechanisms for the removal of bacteria and bacteriophages, and also included natural die-off under anaerobic conditions as an additional mechanism.

The use of anaerobic filters for industrial wastewater treatment is well documented. Mueller and Mancini (6) listed information on anaerobic filters treating various industrial wastes such as potato processing waste, wheat starch waste, petrochemical wastes and pharmaceutical wastes. A state-of-the-art review on the treatment of high-strength organic wastes by submerged media anaerobic reactors has been recently presented by Wu et al (7). Recently attempts have also been made to evaluate the performance of the anaerobic filter as a treatment device for sanitary wastewater and septic tank effluent.

4.2 Anaerobic Treatment of Dilute Wastewaters and Sanitary Wastewater

A summary of anaerobic filter investigations on dilute wastewaters including sanitary wastewater is presented in Table 1.

DeWalle et al. (8) reported on studies at the University of Washington which evaluated the applicability of the anaerobic filter to treat sanitary wastewater. Caudill (1968) treated settled domestic wastewater and noted a 60 percent COD removal at a loading rate of 0.1 kg COD/m^3.day. Thaulow (1974) noted a 75 percent COD removal and 90 percent SS removal at a maximum loading rate of 0.18 kg COD/m^3.day for a similar wastewater.

TABLE 1. Anaerobic Treatment of Sanitary Wastewater and Dilute Wastewaters

Nature of Wastewater	Characteristics of Wastewater	Process	Type of Study	Loading Rate	HRT (h)	% Removal	Temp °C	Reference
Settled wastewater (Washington State)	COD - 226 mg/L BOD - 90 mg/L	anaerobic filter	laboratory study	0.1 kg COD/m^3.day	25	60(COD)		(8)
Settled wastewater (Washington State)	BOD - 124 mg/L	anaerobic filter	laboratory study	0.18 kg COD/m^3day	19	75(COD) 90 (SS)		(8)
Diluted raw wastewater (Pretoria, South Africa)	COD - 500 mg/L	contact digester	laboratory and pilot scale	0.48 kg COD/m^3.day	24	90		(9)
Dilute synthetic wastewater	COD - 900 mg/L	anaerobic filter	laboratory	0.8 kg COD/m^3.day	12.8	96	24-33	(10)
				1.2 kg COD/m^3.day	9.1	95	24-33	
				1.6 kg COD/m^3.day	6.4	91	24-33	
				2.2 kg COD/m^3.day	4.8	90	24-33	
Sanitary wastewater (India)	BOD - 210 mg/L SS - 272 mg/L	upflow filter	fullscale	0.01 kg BOD/m^3.day	6to8	79.5 88.5	30°	(11)
Sanitary wastewater	COD - 288 mg/L	upflow	laboratory	0.32 kg COD/m^3.day	24	73	25-35	(12)
Diluted city wastewater (Durban, SA)	BOD-300-400 mg/L COD-1100-1300 mg/L	contact digestor	pilot	0.64 kg BOD/m^3.day		80 (BOD)		(13)

TABLE 1. Anaerobic Treatment of Sanitary Wastewater and Dilute Wastewaters - continued

Nature of Wastewater	Characteristics of Wastewater	Process	Type of Study	Loading Rate	HRT (h)	% Removal	Temp °C	Reference
Synthetic wastewater	COD - 780 mg/L	two stage anaerobic filter	laboratory	0.5 kg COD/m^3.day	15	83	21-26	(14)
				1.0 kg COD/m^3.day	8	79	21-26	
				2.0 kg COD/m^3.day	4	71	21-26	
Dilute synthetic wastewater	COD-50-600 mg/L	anaerobic attached film expanded bed	laboratory	up to 8 kg COD/m^3.day	6-0.33	80	10-30	(15)
Raw wastewater (USA)	BOD - 220(mean) mg/L	upflow filter	pilot scale	0.24 kg BOD/m^3.day	10	55	10-25	(16)
Raw wastewater (India)	BOD - 175 mg/L	upflow filter	pilot	0.26 kg BOD/m^3.day	5	73	28	(17,18)
	- 210 mg/L			0.23 kg BOD/m^3.day		80	31	
Raw wastewater (Washington State)	BOD - 120 mg/L SS - 140 mg/L	upflow filter	bench			BOD 61 SS -64		(19)

Pretorius (9) investigated the applicability of the anaerobic process for raw wastewater pretreatment. He observed that about 90 percent of the raw wastewater COD was reduced after a detention time of 24 hours at a temperature of 20°C. He further stated that the hydraulic loading rate could be a better parameter for design purposes than waste concentration.

Khan and Siddiqui (10) using both low and high strength raw wastewater found that the filter depth was optimized at 1.2m.

Witherow et al. (20) were unable to improve the efficiency of the filter by doubling the depth of media from 1.22 to 2.45 m sufficiently enough to recommend this modification.

Raman and Khan (11) recommended that the raw wastewater should be free from grit and preferably homogenized prior to anaerobic upflow treatment. They also reported the effluent to be relatively odour free and that overland grass filtration was a useful adjunct for further polishing.

Kobayashi et al. (12) used a laboratory scale anaerobic filter packed with synthetic high surface area media to treat domestic wastewater finding that effluent quality declined as the temperature decreased from 25°C to 20°C but that performance at 25°C and 35°C degrees was not significantly different. It was further noted that the filter was relatively insensitive to daily fluctuations of influent wastewater quality.

4.3 Septic Tank Effluent Treatment Using an Anerobic Filter

A summary of anaerobic filter performance while treating septic tank effluent is presented in Table 2.

Raman and Chakladar (1,18) found that the high efficiency of the anaerobic filter can be maintained even at low influent concentrations of

TABLE 2. Performance Summary for Anaerobic Filters Treating Septic Tank Effluent

Location of Study	Characteristics of Wastewater	Process	Type of Study (scale)	Loading Rate	HRT (h)	% Removal	Temp (°C)	Reference
India	BOD-240 mg/L	Upflow	full scale	0.02Kg BOD/m^3d	6 d	71		(18)
India	BOD-210 mg/L	Downflow and upflow	full scale	Low loading	high	75		(18)
Washington State	BOD-241 mg/L COD 486 mg/L	Upflow	full scale			26 28	12.4	(3)
India	BOD-290 mg/L	Upflow	laboratory	0.34Kg BOD/m^3.d		76	23-33	(18)
Thailand	COD 310 mg/L SS 170 mg/L	Upflow	full scale	0.5 Kg COD/m^3.d	24	60 70		(21)
Washington State	BOD 103 mg/L SS 67 mg/L COD 305 mg/L	Upflow	full scale	0.04 Kg BOD/m^3.d	38.4	28 42 23		(22)
Washington State	BOD 217 mg/L SS 33 mg/L COD 542 mg/L	Upflow (trench)	full scale	0.027 kg BOD/m^3.d		39 33 21		(22)
Washington State		Upflow	Bench scale			85(BOD) 90 (SS) 80 (COD)	7 and 14	(22)
Washington State	BOD-120 mg/L	Upflow	full scale	0.19 kg COD/m^3d	19	28 (COD)	11.8	(23)
Washington State		Downflow Sand filter				60 (COD) 28 (SS)		(8)

125 to 120 mg/l BOD, with either continuous or intermittent flow. They noted that although temperatures varied from 12.5 to 26°C during the winter and 25 to 36°C during the summer, the treatment efficiencies did not vary appreciably. It was further noted that it may not be practical to reduce the effluent BOD below 30 mg/L with the reported sizes of filter and media, and recommended that further effluent polishing could be accomplished by aeration.

Polprasert and Hoang (5) reported that after a four day retention period in the anaerobic filter, the effluent was almost free of bacteria. However, five of eight samples still contained 10^2 to 10^3 MPN/100ml of bacteriophages and may not be safe for disposal to areas where viral infection is prevalent.

Raman and Khan (17) found that the removal of helminthic ova (Ascaris eggs) was almost 100 percent in most of the field and laboratory units. After two years of field observations, BOD removal was 70 to 78 percent based on an influent concentration of 170 to 250 mg/l at an average loading of 0.9 kg BOD/m^3.day.

Hoang (24) found that, although there was no direct relationship between organic loading and viral removal in an anaerobic upflow filter, at the same retention time, bacteriophage reduction increased with lower level organic loading to the filter. Greatest reductions were found at a retention time of four days.

Satharkar (21) reported that a one day retention time, corresponding to a 0.43 m^3/m^2/day hydraulic loading, was optimal for the reductions of organic components.

Hamilton (22) reported findings from two full scale studies treating septic tank effluent from single family dwellings in Washington State. At the first site the following removal rates were observed after a 1.6 day retention time:

SS - 42% BOD - 28%

COD - 23% COD_f - 28%

The second site produced the following removal rates after acclimatization:

BOD - 39% COD - 21%

SS - 33%

It was further reported by Hamilton that Haukon Thaulow at the University of Washington, using a bench scale model at both 7 and 14° C, had found BOD removals averaging 80 percent and suspended solids removals averaging 90 percent.

4.4 Start-up of an Anaerobic Filter

The start-up time of an anaerobic filter is directly proportional to the concentration of the microbial population. Lag times may be reduced by seeding. Young and McCarty (25) noted microorganisms in an unseeded filter remained dispersed and a significant fraction washed out with the filter effluent, whereas in a highly seeded filter, rapid flocculation was observed, causing the biomass to remain in the filter. Foree and Lovan (26) found 90 percent COD removal after 25 days of operation when the filter was seeded with anaerobic digester supernatant.

Raman and Chakladar (1), and Raman and Khan (17) reported, that without seeding, four to six weeks of continuous operation at temperatures between 25 and 32 degrees, were required for start-up, and three months were required before the filter became mature.

4.5 Filter Clogging

In full scale studies(1,10,17,18) filter clogging has been reported after 18 months of continuous operation. Wasting of sludge from the filter can be accomplished by flushing water from the top through an idle filter and removing the solids (1).

4.6 Removal of Nutrients

The anaerobic upflow filter generally does not remove or reduce nutrients such as nitrogen and phosphates. Investigators (11,12,23) report both ammonia-nitrogen and phosphate levels increasing in the effluent. Their results are summarized in Table 3.

Kennedy (4) states that the anaerobic filter can be used as a denitrifying chamber if preceded by aerated pretreatment, rather than primary settling. An additional source of carbon is normally required to complete the denitrification. The carbon source could either be the traditional methanol, or greywater could be used (27).

4.7 Advantages of an Anaerobic Filter

The main advantages are as follows:

(a) simplicity in construction, operation and maintenance;

(b) more efficient waste stabilization since organics are removed from the wastewater as methane and carbon dioxide gases, rather than fixed cells, resulting in a low production of waste biological sludge;

(c) low loss of head - less than 15 cm in normal operation;

(d) low nutrient requirements;

(e) clear, odour and nuisance-free effluent;

(f) efficiency is not affected by intermittent or transient nature of flows;

TABLE 3. Ammonia-Nitrogen and Phosphates in Anaerobic Filter Effluent

Parameter	Influent (mg/L)	Effluent (mg/L)	Increase (%)	Reference
NH_3-N	25.4	34.8	37	23
NH_3-N	41	52	27	11
NH_3-N	33	44	33	12
Ortho-PO_4	6.4	7.5	17	23
Total PO_4	3	5	67	12

(g) is more efficient than a septic tank alone;

(h) the filter can be used alone or in conjunction with a septic tank;

(i) when used in conjunction with a septic tank, the filter prevents most of the solids discharged from the septic tank from entering the tile field;

(j) requires only occasional cleaning;

(k) provides excellent removal of microorganisms;

(l) the filter requires no energy to operate;

(m) the anaerobic filter may be used for denitrification;

(n) long solids retention times afford a high level of treatment without long hydraulic retention times; and,

(o) extreme actions such as passing air through the unit or permitting the pH to drop as low as 5.5 or letting the filter stand for weeks or months with zero loading, do not affect the ability of the filter for rapid recovery.

4.8 Disadvantages of an Anaerobic Filter

(a) Longer periods are required for starting the process than with an aerobic process.

(b) Filter clogging may occur after one to two years of continuous operation.

(c) The process is not likely to achieve effluent quality better lthan 30 mg/l BOD.

(d) Long solids retention times are required thereby allowing the filter to adjust less readily to environmental changes.

4.9 Design Guidelines

Raman and Khan (11) provide the following design guidelines for an anaerobic upflow filter treating either raw sewage or septic tank effluent:

Media	gravel, broken stone
Size of media	1.9 cm to 2.5 cm
Depth of media	115 cm to 125 cm
Hydraulic loading rate	3.4 m^3/m^2/day
Temperature	23 to 33°C
BOD removal Efficiency	70 to 80 percent for influent BOD concentration of 110 to 300 mg/l

4.10 Mathematical Models

Young and McCarty (28) proposed the following relationship to describe the performance of an anaerobic filter:

$$\%E = 100\left(1 - \frac{e}{t}\right)$$

where %E = ultimate soluble BOD removal efficiency

t = hydraulic retention time (hours)

e = experimentally determined coefficient

Young and McCarty found e to be 1.8. Kobayashi et al. (12), using COD to approximate ultimate BOD, reported e to compare favourably with an approximate value of 2.0 .

DeWalle et al. (8) reported a statistical evaluation of performance data of laboratory scale anaerobic filters treating sanitary wastewater and proposed the following equation:

$$\%\,BOD_{removal} = b_0 + b_1(\ln bod_{inf}) + b_2(\ln SS_{inf}) + b_3(time^{-1})$$

where BOD and SS are in mg/L, time is in days and ln represents natural logarithm. b_o, b_1, b_2 and b_3 are dimensionless coefficients. He stated that the model accounted for more than 90 percent of the variability for four of the five filters studied. Coefficient b_1 was significant at the five percent level for four of five filters, and b_3 significant for two of five filters, while b_2 was not significant. A similar equation for suspended solids removal could not account for any of the variability, indicating the suspended solids effluent concentration is independent of the influent concentration.

Polprasert and Hoang (5) reported that the removal of bacteria and bacteriophages followed a first-order reaction shown below:

$$C_b = C_{bo}\, e^{-k\theta_{AF}}$$

where C_b = concentration of enteric microorganisms in liquid phase (effluent) of AF

C_{bo} = influent concentration of enteric microorganisms

k = removal rate coefficient

θ_{AF} = hydraulic retention time of the solution in AF

k values suggested are:

0.92 for fecal coliforms; and,

0.54 for bacteriophages.

Pfeffer (29) states that the Monod model has been widely used for suspended growth systems, although the application of this model to a supported growth system may be debatable. The two key equations are as follows:

$$S = \frac{K_s\,[1 + k_d \theta_c]}{\theta_c\,[Y_k - k_d] - 1}$$

$$X = \frac{\theta_c Y\,[S_o - S]}{\theta\,[1 + k_d \theta_c]}$$

where S = substrate level in complete mix effluent (mg/l)

S_o = influent substrate level (mg/l)

K_s = half velocity coefficient (mg/l)

k = maximum specific substrate utilization rate ($time^{-1}$)

k_d = organism decay rate ($time^{-1}$)

X = organism mass concentration (mg/l)

θ = hydraulic retention time

θ_c = mean cell residence time

Y = yield coefficient

The coefficients, K_s, k, k_d, and Y are reported as follows (O'Rourke, "Kinetics of Anaerobic Treatment at Reduced Temperatures", Ph.D. Thesis, Stanford University, 1968);

Kinetic Coefficients

	30°C	25°C	20°C
K_s	333	869	2130
k	4.8	4.7	3.6
k_d	0.037	0.011	0.015
Y	0.058	0.054	0.040

The K_s value is the most important, highly temperature sensitive and dominates the kinetics in relationship to effluent substrate. For example, an effluent level of 20 mg/l COD shows O_c to be negative 73 days, suggesting that it may not be possible to achieve COD levels in this low range. This was previously alluded to by Raman and Chakladar (1).

Young (30) further refined the model presented by Young and McCarty (28), stating that the coefficient, e, would be expected only to apply to experimental filters.

Since $E = 100\ (S_o - S_e)/S_o$

and, $T = \varepsilon V/Q$

where, S_o = influent BOD concentration

S_e = effluent BOD concentration

ε = porosity of the filter media

V = volume of the reactor tank

Q = flow rate

the original model than can be rearranged as follows:

$$S_e = \frac{e\ S_o\ Q}{\varepsilon\ V}$$

$$= e'\ L$$

where, L = mass of BOD_L/day/unit total volume.

5. ANAEROBIC FILTER FOR SEPTIC TANK EFFLUENT TREATMENT

5.1 Suitability for Use in Canada

5.1.1 Influence of Temperature

In a study conducted by the Manitoba Department of Health, it was observed that under severe winter conditions, temperatures in the septic tank remained at or about 10°C, and in the siphon chamber around 4.4°C in a atisfactory installation (31). Laak reported that Professor Graham's observations revealed that septic tank temperatures varied between 7° to 22°C in the first chamber and 2° to 14°C in the second chamber while the air temperatures varied between -20°C and 6°C in an installation in Ontario (32). Studies conducted by Hickey and Duncan on 20 septic tank installations in Anchorage and Fairbanks in Alaska revealed that the average temperatures of septic tank contents during the coldest months ranged between 11.1°C and 12.2°C for Anchorage and 8.9°C and 10°C for Fairbanks, while the average nearby ground temperatures remained below 1.7°C for several months in both areas (33). In a study conducted near Ottawa, it was observed that even during colder months, when air temperatures were below the freezing point, the septic tank liquid temperatures were close to 16°C (34). Studies conducted by the University of Washington revealed that there was an average drop of 1.9°C (14.3°C to 12.4°C) from the septic tank temperature to the anaerobic filter temperature (3). Therefore it is not unreasonable to assume average temperatures of 12°C and 10°C for the septic tank and anaerobic filter respectively during the colder months in most parts of Canada except the northern parts.

In this connection, it is of interest to examine how the anaerobic filter functions under low temperature conditions such as 10°C. While a laboratory study 1indicated an average BOD removal of approximately 80% or more through an anaerobic filter treating septic tank effluent at temperatures of 7°C to 14°C, studies of field anaerobic filter units showed average COD removals of only about 30% at approximately 12°C (23). The reasons for the wide difference in organic matter removal efficiency are not apparent. Recent studies conducted with potato wastewater showed that anaerobic treatment is also effective at sub-optimal temperatures, although at lower loading rates. In these experiments with suspensions of solid material from potatoes, the system was found to be very adaptable to temperature variations in the range 10-45°C (35). Lin et al in his study on anaerobic lagoon-filter system treating potato wastewater observed removals of 85% of COD and 93% of SS even when the system temperature was brought down to 4°C; the total methane production was however lower (36). These studies show that although removal efficiencies may not be high, the anaerobic filter unit is capable of adapting to low temperatures without failure. Therefore it may be possible to obtain 30 to 50% BOD removal through the anaerobic filter even during the colder months; higher BOD removals can be anticipated at other periods of the year. Thus the anaerobic filter treatment of the septic tank effluent is suitable under Canadian conditions as a treatment step especially to reduce the BOD and SS level in the effluent discharged for disposal through the tile field system. It is difficult to answer the question whether the anaerobic filter effluent will be able to meet consistently effluent standards of BOD = 20 mg/L and SS = 20 or 30 mg/L all through the year under Canadian conditions, for surface discharge option with the available data which are conflicting. Long term field studies would be necessary to answer this question.

5.1.2 Questionnaire Survey Results

A questionnaire was sent to all provincial health/environmental agencies to obtain their reaction to the use of anaerobic filter for septic tank effluent trteatment. A copy of the questionnaire is included in Appendix B. Replies to the questionnaire were received from all provinces/territories. Septic tank effluent treatment using an anaerobic filter is not in use in any province or territory of Canada except for an isolated unit in one province many years ago and for an experimental system in another province for denitrification studies. There are no specific regulations governing the use of anaerobic filters for onsite disposal in any province or territory of Canada. Some of the provinces would permit the use of anaerobic filter as an experimental system; some would require more information on the process and performance for permitting its use; one would permit its use essentially in nitrate removal systems. Some of the provinces would permit surface discharge of anaerobic filter effluent it if meets their established criteria for permitting effluent discharge into surface waters; a few provinces would not permit discharge of anaerobic filter effluent into surface waters, especially when used in onsite disposal schemes. Most of the provinces require more information on the system and would probably approve such a system if enough data are presented and especially only subsurface disposal of effluent is proposed. Some provinces would probably allow lesser tile field area if an anaerobic filter is used in conjunction with a septic tank. With the data available from literature, it is not possible to recommend discharge of the anaerobic filter effluent to a surface water course especially when effluent criteria based on BOD and SS are stipulated. It may be possible to do this only when an acceptable dilution is indicated to the exclusion of any other criteria.

5.2 System Design and Configuration

5.2.1 System Configuration

Winneberger's concept of an anaerobic filter for the treatment of septic tank effluent is presented in Figure 4 (37). It may be observed that the filter is relatively shallow and it is operated essentially in a horizontal flow mode. Hamilton's system (Figures 5,6,7) consisting of two rock filters connected in series with a septic tank is reported to have operated for almost four years without clogging or solids removal (22). Raman and Chakladar's device shown in Figure 1, contained a single compartment septic tank followed by a rock filled upflow filter. A cleaning chamber ahead of filter was used to remove the sludge collected during the cleaning of the filter achieved by opening the plug at kthe bottom (2). Polprasert and Hoang constructed two full-scale septic tank-anaerobic filter units shown in Figure 8 at the Asian Institute of Technology (AIT) Campus, Bangkok, Thailand (5). The units are similar to the units used by Raman and Chakladar except that the septic tank is contiguous to the filter unit in the AIT design. Each unit built at AIT consisted of three rectangular chambers; the first was a single chamber septic tank; the second, relatively small in configuration, housed a 12 cm diameter polyvinyl chloride pipe to convey flow of septic tank effluent to the anaerobic filter; and the third is the anaerobic filter chamber.

A very practical design requiring only slight modification of the current standard septic tank installation practices was developed by Green who has applied for a patent of this design shown in Figures 2 and 3 (3). Gravel is filled in around the annular excavation space to the depth of the septic tank and the effluent is piped around the tank to the influent side of the excavation. The waste stream filters upwards through the rock

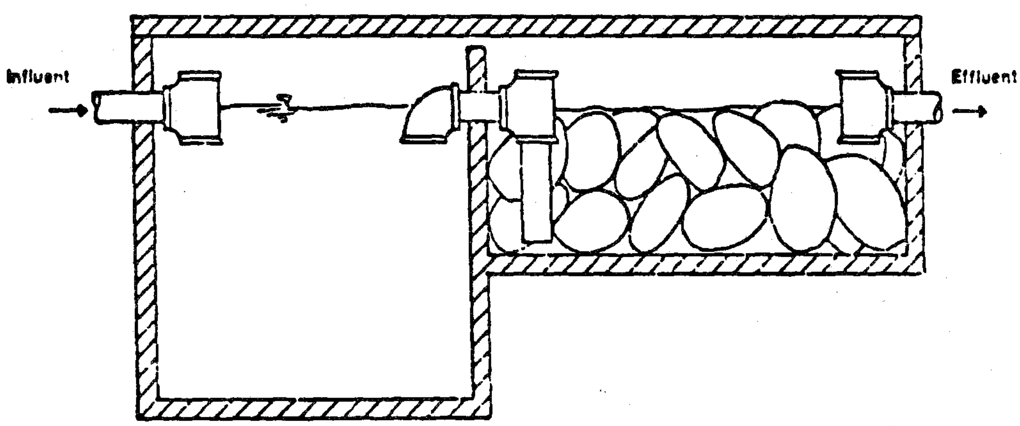

Figure 4 Anaerobic Filter Combined with Septic Tank

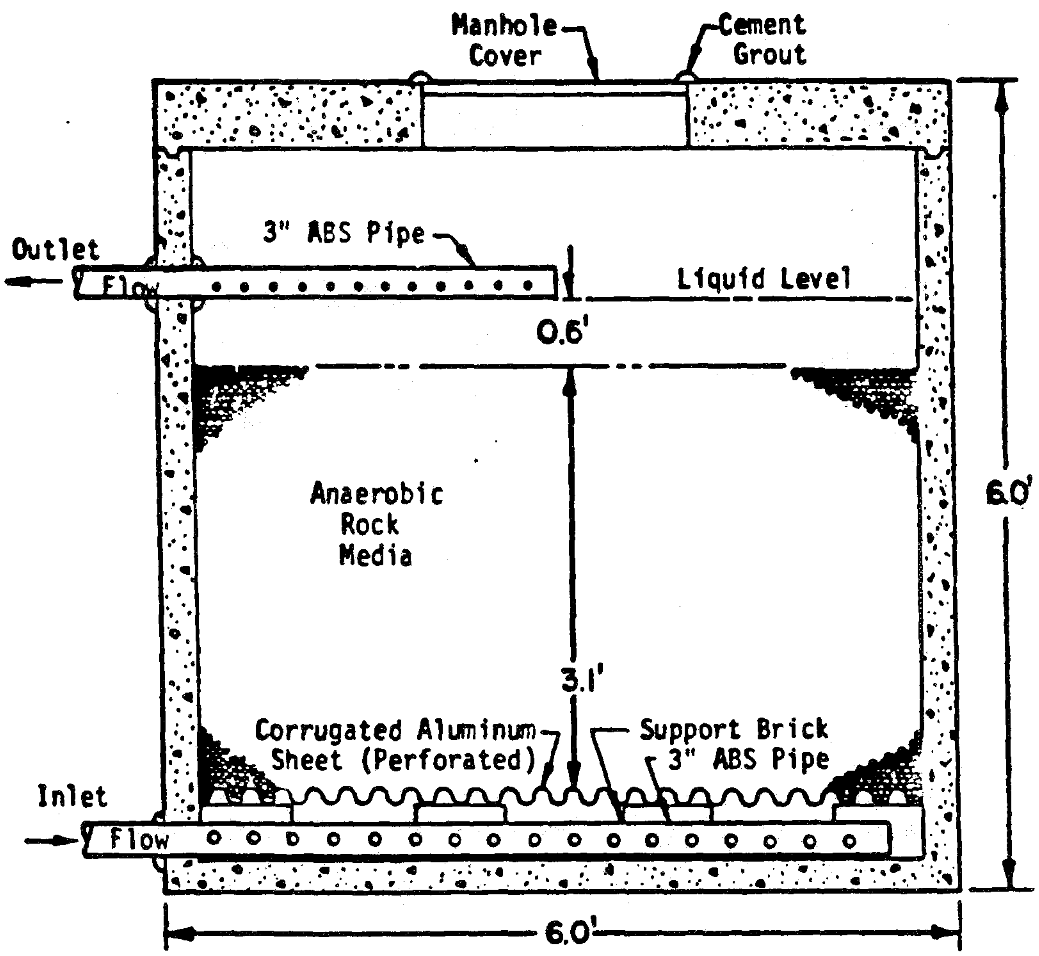

Figure 5 Anaerobic Filter Detail

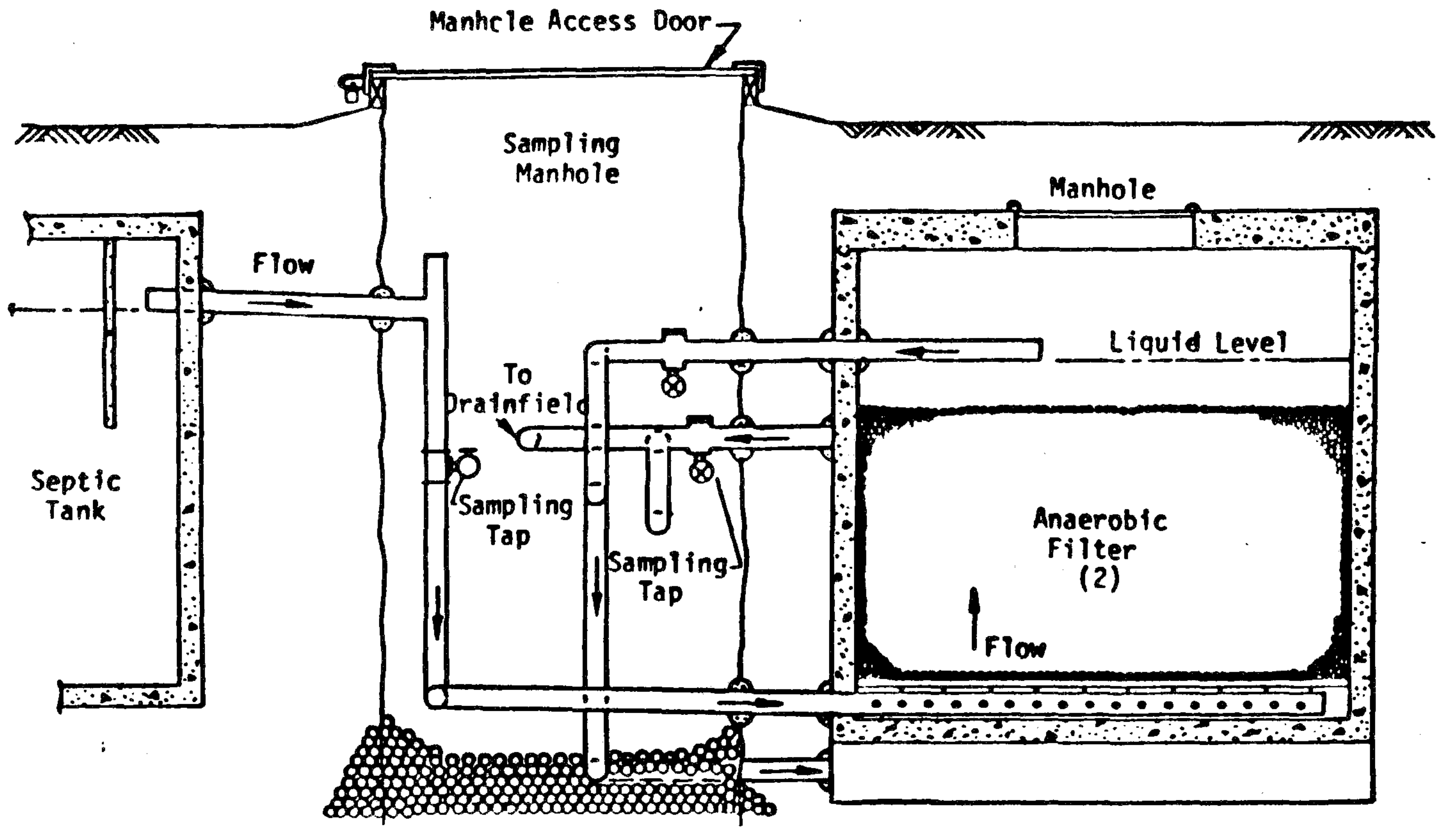

Figure 6 Septic Tank, Manhole, and Anaerobic Filter (Profile View)

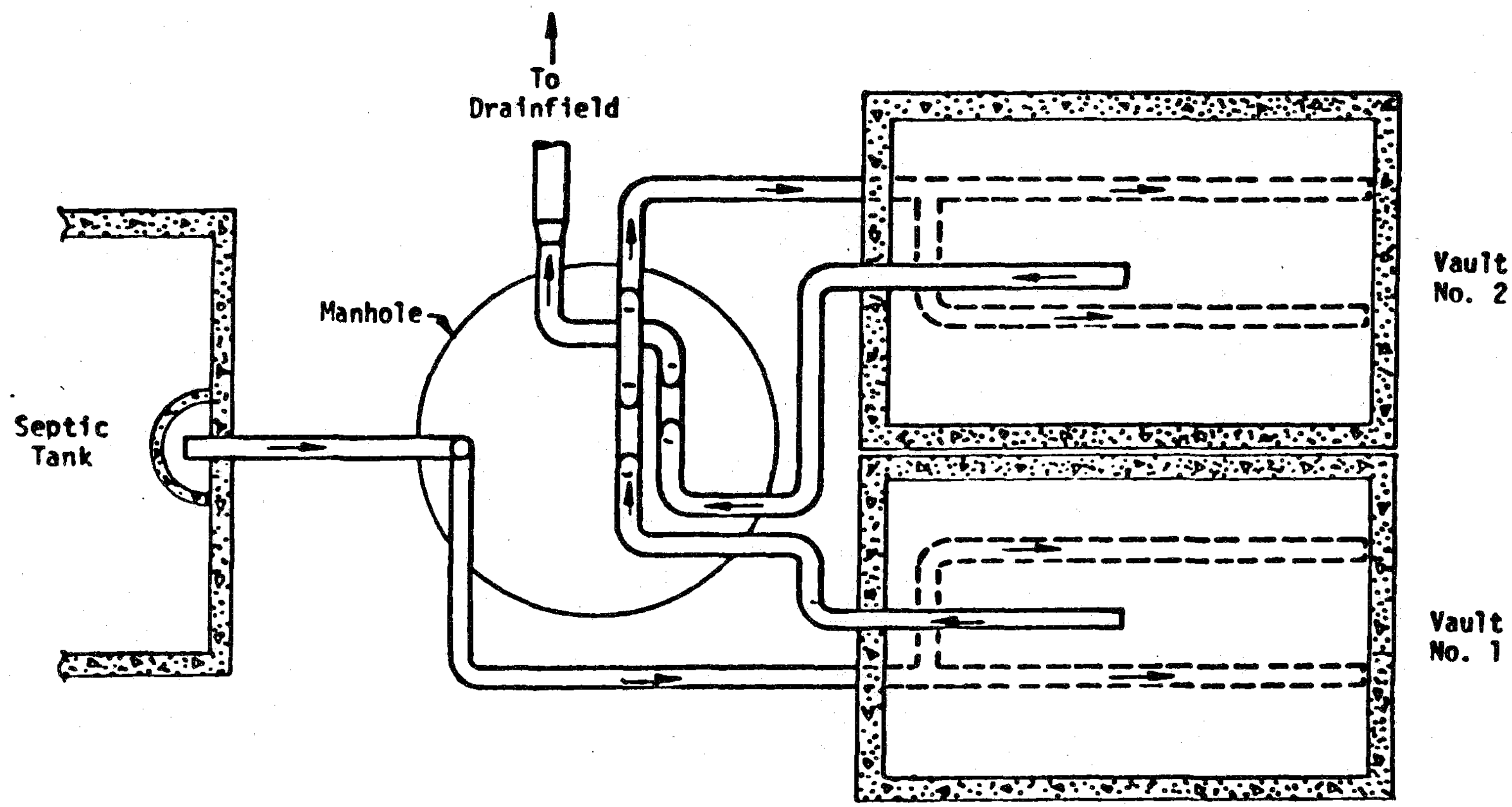

Figure 7 Septic Tank, Manhole and Anaerobic Filter (Plan View)

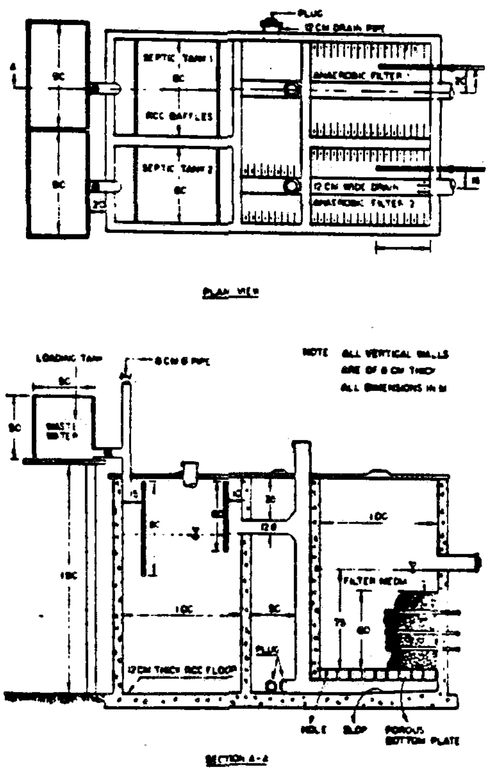

Figure 8   Septic Tank-Anaerobic Filter Units

medium and towards a perforated resin located near the original septic tank outlet. Two of these "wrap around"filters had been experimentally installed and were reported to be operating satisfactorily for almost three years.

A configuration shown in Figure 9 is proposed in a recent publication of the World Bank as an alternative design (38). It shows two-compartment septic tank with an anaerobic upflow filter. Mara proposes a similar design and states that the filter effluent may be discharged into a stream or disposed of in drain field trenches or evapotranspiration beds (39). He also suggests that the effluent may be used for small flood irrigation schemes.

It may be observed that all the anaerobic filters discussed earlier except the one operated by Winneberger were operated in the upflow mode. The downflow stationary fixed film reactor is reported to be not suitable for the treatment of very dilute waste streams (e.g. less than 2000 mg COD/L). (40).

Thus a typical design for a household would involve generally a septic tank constructed with an anaerobic upflow filter, allowing room for a small cleaning chamber to remove sludge from the anaerobic filter at some regular intervals. The design will be similar to the AIT design. The 'wrap around' filter, although more economical compared to other designs, would be less preferable for installation in a household.

5.2.2 <u>System Design - Size and Medium</u>

The hydraulic retention time governs the design of the anaerobic filter. Based on the published literature value, a minimum hydraulic retention time of approximately 24h is suggested to provide an adequate performance. It may be desirable to use an anaerobic filter of capacity

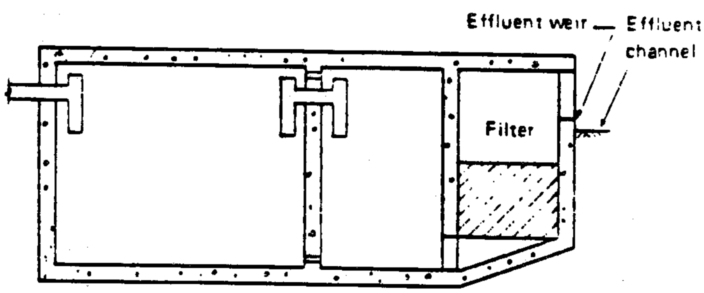

Figure 9 Two-Compartment Septic Tank with Upflow Filter

(empty tank capacity) equal to that of the septic tank, although in most cases it would provide a hydraulic retention time greater than 24 hours. Assuming a septic tank of 2700L (600 imperial gallons) capacity to meet the needs of a three-bedroom house, the anaerobic filter would have a capacity of 2700 L also.

All the laboratory scale and full scale anaerobic filters used so far to treat septic tank effluent have used only rock medium, although different types of media have been tried or used in anaerobic filters treating other wastewaters. Frostell studied the influence of media on the loading capacity of anaerobic filters (41). Three different types of filter media as given below were examined by him.

(1) Approximately spherical hard rock particles (porosity 0.42)

(2) Ceramic Raschig rings (porosity 0.68)

(3) Plastic berl saddles (porosity 0.91)

A soluble synthetic wastewater with a COD of 1200 mg/L was used and responses to different loading rates were quite similar in all filters. A COD reduction of slightly below 90% was achieved at 0.5 kg COD/m^3.d, decreasing to 69% in the plastic, 76% in the ceramic and 77% in the rock filters at 1.8 kg COD/m^2.d; no improvement in sludge retention was observed with the more porous ceramic and ~~porous~~ plastic media.

However studies by van den Berg and Lentz (42), van den Berg and Kennedy (43) and Young and Dahab (44) showed quite different results when using different media. van den Berg and Lentz (42) found that area loading rates were up to 20% higher with baked clay than with glass or PVC plastic as film support material. They also found that active films formed faster on clay than on glass or plastic and that clay support provided for greater process stability than glass or plastic. van den Berg and Kennedy (43) tested needle punched polyester construction material and red draintile clay. They found that rates of film development were very fast on these two material in comparison with potters clay and especially polyvinyl chloride tested earlier by their group. Both the needle punched polyester and red draintile clay were very effective. Red draintile clay is easily available and cheap. Investigations conducted by Young and Dahab (44) using four different media showed the importance of medium type, size and shape on wastewater treatment performance. Corrugated modular blocks were used as medium in two reactors, while the other two contained cylindrical Pall rings and polypropylene spheres as medium respectively. Figure 10 shows the effect of various media on COD removal at different hydraulic retention times.

In the case of anaerobic filter treating septic tank effluent, it is preferable to use a medium which is relatively inexpensive and which is sturdy in comparison. In this treatment application, high organic matter removal efficiences or high loading rates may not be the criterion, although higher treatment efficiency would always be of advantage. Rock medium and to some extent clay support media either burnt clay or red draintile clay would be desirable in the present application. Rock has been extensively tried and would be a logical choice. Studies using other inexpensive and less brittle media are indicated.

5.3 Public Health Aspects

Studies done at the University of Washington showed fecal coliform removals of approximately 43% (from 2.1×10^6 org/100 mL to 1.2×10^6 org/100mL) through the anaerobic filter (3). Kobayashi et al (12) working on an anaerobic filter treating low strength sanitary wastewater reported fecal coliform reductions of approximately 66% through the filter (from 1.2 x 106 organisms/100 mL to 45 x 105 organisms/100 mL).

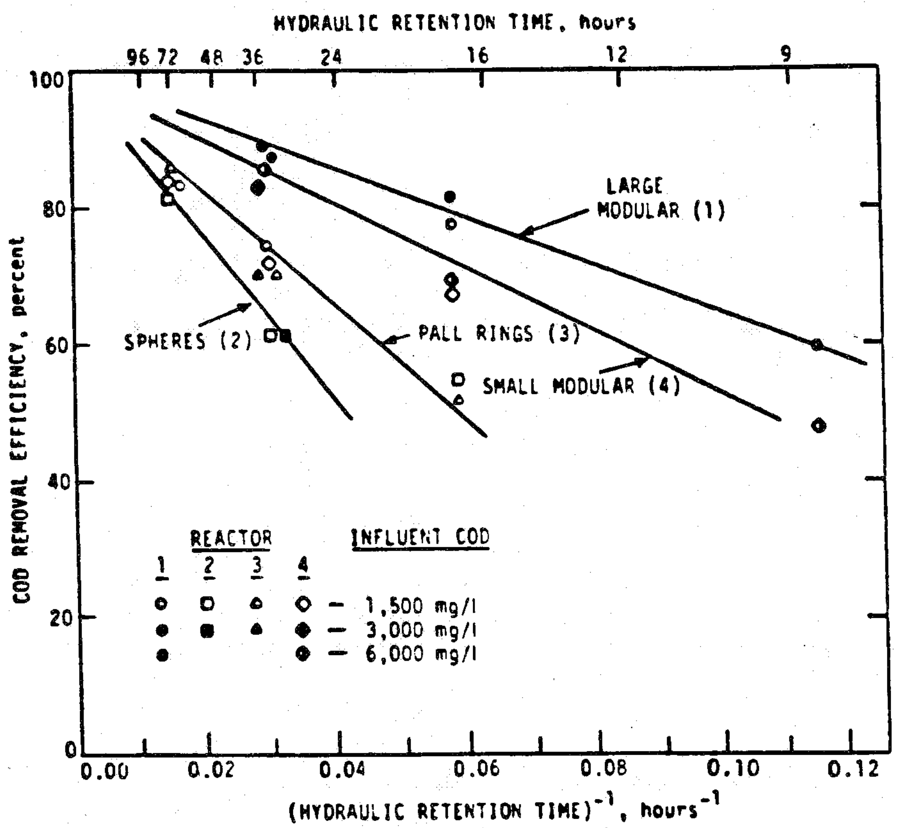

Figure 10 COD removal efficiency versus the inverse of the theoretical hydraulic retention time when operating at a number of influent concentrations.

Studies on anaerobic filter treatment of septic tank effluent carried out at AIT, Bangkok, Thailand (5) showed that the average fecal coliform removal through anaerobic filter 1 were approximately 65%, 75%, 79% and 100% at hydraulic retention times of 1d, 2d, 3d and 4d respectively; fecal coliform removals through anaerobic filter 2 were approximately 53%, 75%, 84% and 97% respectively for hydraulic retention times of 1d, 2d, 3d and 4d. Bacteriophage removal was less effective in comparison to fecal coliform removals. At hydraulic retention times of 1d, 2d, 3d and 4d, average bacteriophage removals in anaerobic filter 1 were approximately 41%, 60%, 84% and 85% respectively, while in anaerobic filter 2, removals were 45%, 60%, 83% and 85% respectively. Based on these data, the anaerobic filter should be operated at a hydraulic retention time of at least four days to reduce the chance of microbial pollution especially that of enteric bacteria. In areas where viral contamination is prevalent, the anaerobic filter effluent should be further treated to inactivate the remaining viruses. Of course, these requirements for increased hydraulic retention time and further treatment for removal of viruses in such an environment would be more indicated in the case of surface discharge of effluent. It may be observed that even with a hydraulic retention time of two days, approximately 75% fecal coliform removal and 60% bacteriophage removal occurred, thus providing a better effluent for further treatment through soil.

5.4 Effluent Disposal

There are two essential questions that need to be answered in respect of the disposal of anaerobic filter effluent; these are indicated below.

(1) Can the effluent be discharged to a surface water course? If so, under what conditions?

(2) If the effluent is to be disposed of through soil (subsurface disposal systems), can the extra treatment afforded by the anaerobic filter be reflected in reduced size of the subsurface disposal system?

Under Canadian climatic conditions, it is expected that BOD removals will be much lower especially during the colder months with the result that it will be difficult to meet effluent BOD and SS levels of 20 mg/L and 20 or 30 mg/L respectively usually stipulated by the regulatory agencies for effluent discharge to surface waters. Two provinces in Canada specifically would not allow surface discharge to receiving waters from individual onsite systems. The problem is not only one of regulatory control, but also it is quite possible that with numerous multiple discharges it could create aesthetic problems, visually offensive. Although World Bank believes that anaerobic filter could be substituted for subsurface systems for disposal, and the filter effluent diverted for surface discharge, the anaerobic filter effluent could pose public health risks at the usual hydraulic retention time provided in the anaerobic filter, unless very large dilution is available.

In the case of septic tank - anaerobic filter system installed in institutions such as prisons, schools and others, surface discharge of the anaerobic filter effluent could be permitted provided any one of the following is available with proper operation and maintenance of the system.

(1) adequate dilution

(2) further treatment through sand filter disinfection or grass plots.

In the case of anaerobic filter effluent disposal through soil, most of the provinces would not permit any reduction in the area provided for soil, although one would accept 20% reduction in drainfield size. With significantly reduced removals of BOD through the anaerobic filter during colder months, it is not prudent to lower the usual size requirements. With the additional treatment obtained in the filter, chances of tile field clogging would be reduced; the additional treatment would thus enhance the longevity of the subsurface system.

5.5 Costs

The cost of 2700 L (600 imp. gallons) septic tank installed would be approximately $1000-$1500 depending on the location and the material of construction of tank. An equal size anaerobic filter with rock media and a small concrete partition (baffle) for a cleaning chamber would cost approximately the same amount. The tile field system for a three-bedroom house would approximately cost $1000-$1500 as installed. Thus the introduction of an anaerobic filter unit would increase the cost approximately by 50%, if disposal through subsurface system is adopted. A septic tank - anaerobic filter system would cost the same as a septic tank - soil absorption system in the case of the individual household, only when surface discharge is permitted. In the case of institutional treatment systems, site-specific costs for the alternatives would have to be worked out.

No anaerobic filter system will be completely free of maintenance, as sludge accumulation must be removed periodically, similar to septic tanks. The rate of solids accumulation, a function of the loading rate and influent solids concentration, plus the ability of the filter to store solids, could be factors in determining the maintenance costs. It is likely that such costs will be similar to those for septic tanks.

6. RESEARCH NEEDS

Research is needed either to develop technologies further, to measure their effects or to find new, more efficient techniques suitable for Canadian conditions. The areas for further research are the following:

(i) laboratory studies at a low temperature such as 10°C to examine the performance of an anaerobic filter treating septic tank effluent;

(ii) long-term field studies to monitor the performance of a septic tank-anaerobic filter system with respect to BOD, SS, nitrogen, phosphorus, indicator microorganisms and virus removals;

(iii) anaerobic filter treatment of grey water;

(iv) field studies on further treatment of septic tank-anaerobic filter system effluent using grass plots and other simple techniques;

(v) laboratory studies on the effect of different media such as rock, burnt clay and red draintile clay on anaerobic filter efficiency; and

(vi) studies to determine the relationship between effluent quality and subsurface disposal system area.

APPENDIX A

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APPENDIX B

QUESTIONNAIRE

QUESTIONNAIRE

The anaerobic filter is a submerged filter (upflow, downflow or horizontal flow). A typical anaerobic upflow filter is shown in Figure 1. When treating septic tank effluent the filter has been shown to produce an effluent almost of secondary quality. The anaerobic filters are generally suitable for treating the effluent from septic tanks installed in institutions, small communities and single and multi-family dwellings.

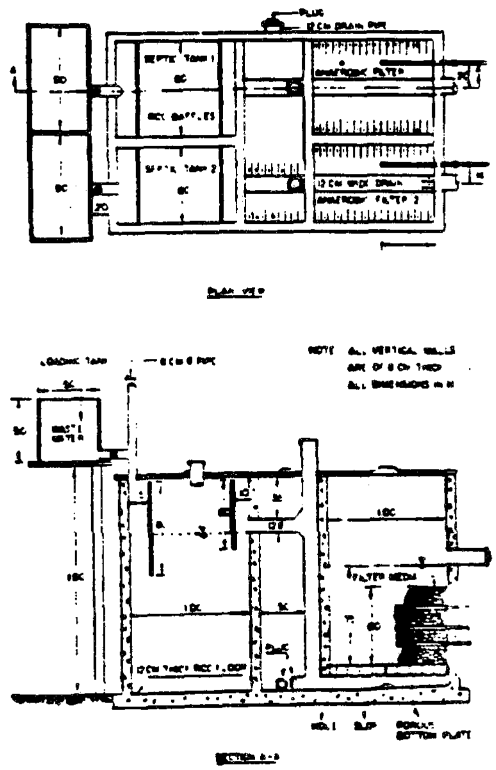

Figure 1—Septic tank-anaerobic filter units.

(Continued...)

1. Has an anaerobic filter been used in your province? If yes, are there any in-house studies available or could you provide an idea of the performance of such a unit?

2. Are there any regulations specifically governing the use of anaerobic filters in your province and if so, would you please outline those regulations or send a copy.

3. If anaerobic filters are neither used nor regulated in your province, under what conditions would you permit the use of such a system?

(continued...)

4. Would you allow anaerobic filter effluent to be discharged directly to a water course? Please comment.

5. Do you have any further comments?

END