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THE ENVIRONMENTAL ECONOMICS OF MULTI-COMPARTMENT SEPTIC TANKS

The paper compared the economics of 1-, 2- and 3-compartment septic tanks in terms of the incremental benefit–cost ratios which took into account the equivalent worth of differential percentage suspended solids and biochemical oxygen demand removal intangible benefits, maintenance cost and capital recovery cost at interest rate of 21%. The sensitivity test for the effects of inflation and interest rate on incremental benefit–cost ratio were done.

The result showed that the 3-compartment septic tank is the best alternative to the 2- and 1-compartment septic tanks since it offers the highest benefit potential followed by 2-compartment septic tank in preference to 1-compartment septic tank in that order. But the choice between 2- and 3-compartment septic tanks in preference to single compartment septic tank depends on the prevailing rate of capital recovery.

1. INTRODUCTION

In most urban and semi-urban areas of developing countries and countryside of developed countries, sewage disposal is done by the use of septic tank system at the individual households or corporate buildings. The state and local government authorities ensure through the Housing Corporation that septic tanks approved alongside household building designs conform to guideline or code of practice.

Septic tank, a buried watertight tank designed for a retention time of between 1–3 days (PICKFORD [9]) and made of either bricks, cement/concrete or synthetic materials, receives wastewater from household, remarkably, sewage for its storage and natural treatment prior to flow of the liquid fraction (effluent) to a soakaway. There are three types of septic tanks. These are single-compartment (tank without partition but with or without baffle) and the multi-compartment (LAAK [4]; FEACHAM and CAINCROSS [2], OKEREKE and COTTON [6]; COTTON et al. [1]) notably, the 2-compartment (tank with a partition) and 3-compartment (tank with two partitions) systems (figure 1). The first type is popular in Nigeria, whereas others, particularly the 2-compartment type, are

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used in Asia and countryside of Europe, America and Canada devoid of central sewerage connection to treatment works (OKEREKE [8]). Nevertheless, the sociological economic appraisal of these septic tanks to determine their preferential sequence is not available.

Though septic tank cannot be said to be a public good or project, it is of interest to the local and state governments in so far as it concerns the public health and environmental safety. The engineering economy study of septic tank shall therefore be seen from the perspective of a privately owned project with greater emphasis on the environmental or intangible (social) benefits and costs.

The term *intangible* refers to things such as pollution of environment or groundwater by, say, septic tank discharges, standards of health, comfort and amenities which affect the satisfaction or well-being of individuals, but for which no economic market value exists, and are traditionally not reflected, like the economic goods and services, in the profit and loss account or balance sheet of company or government. There is a strange paradox about peoples' attitude to intangibles considered on some occasions as very important human valuables or requirements not from monetary standpoint but from socio-psychological value yet on another occasion it is often taken for granted. The incremental benefit–cost analysis is used to reconcile these attitudes by introducing realistic system of valuation of items of this kind experienced in appraisal of building projects such as replacement of one type of septic tank for another type.

In incremental benefit–cost analysis, the incremental benefit–cost ratio ($\Delta B/\Delta C$) is used to find the alternative with the maximum profit (benefit) potential from a group of mutually exclusive investment alternatives which may not necessarily be the alternative having the largest overall benefit–cost ratio. The mutually exclusive investment alternatives are those projects in which at most one project (or option) out of the group of alternatives (or options) can be chosen under the premise that the selection of one of the alternatives excludes consideration of any other alternative including the "do-nothing" alternative.

The distinctive definitive equations of benefit–cost ratio (the ratio of the equivalent worth of benefits to equivalent worth of costs of a proposed project) and incremental benefit–cost ratio are as follows (OKEREKE [8]).

Equation 1.1

$$B/C = B/((CR + (0 + M)), \tag{1}$$

where B is annual worth of benefits of the proposed project, CR is the capital recovery cost (that is the equivalent annual cost of the initial investment including allowance for salvage value if any), 0 and M represent the equivalent annual operating and maintenance costs of the project or system.

Also

$$CR = (P - Sv)\,CR_nF_n + Sv, \tag{1a}$$

P is the present sum of money (initial investment cost), Sv is salvage value which is zero for septic tank, CR_nF_n is the capital recovery factor over n years at going interest rate of i.

And

$$CR_nF_n = i/((1+i)^n - 1) + i, \quad i = i\%/100, \tag{1b}$$

at $n = 1$, CR_nF_n is i, the minimum attractive rate of return on capital (that is the opportunity cost of capital).

Equation 1.2

$$\Delta B/\Delta C = (B_1 - B_m)/((CR_1 + (O_1 + M_1) - (CR_m + (O_m + M_m)), \tag{2}$$

where $\Delta B/\Delta C$ is the incremental benefit–cost ratio, B_1 is the equivalent worth of benefits of alternative one septic tank, B_m is the equivalent worth of benefits of alternative two septic tank and CR_1, O_1 and M_1 are the capital recovery cost, operation and maintenance costs of the alternative one septic tank. CR_m, O_m and M_m are the capital recovery cost, operating and maintenance costs of the alternative two septic tank. The ratio is a veritable instrument in economic appraisal of projects to determine preferences.

In this study, single and multi-compartment septic tanks were compared to establish the preferential sequence of the mutually exclusive alternatives in socio-economic terms.

2. MATERIALS AND METHOD

2.1. SEPTIC TANK EXPERIMENTATION

Three different 1-, 2- and 3-compartment septic tanks made based on the same design retention time of 24 hours and capacity in cement/concrete materials were studied. The features and characteristics of the septic tank were as presented in figure 1 and table 1. Each of the septic tanks had an inlet that received sewage from toilet and outlet for the effluent to a soakaway. The sizes of the delivery pipes were the same (dia 100 mm, polyvinyl chloride (PVC)) with 100 mm diameter inlet and outlet Tee. Inter-tank wastewater transfer H-PVC pipes (double Tee) were installed at the partitions of the multi-compartment septic tanks. At the inlet manhole of each of the septic tanks, a 0.1 m diameter by 0.2 m deep sump was made for placing a 300 cm^3 thermosetting plastic container for collection of representative samples. At the outlet manhole also the outlet pipe was installed to make a water-fall for easy collection of effluent samples.

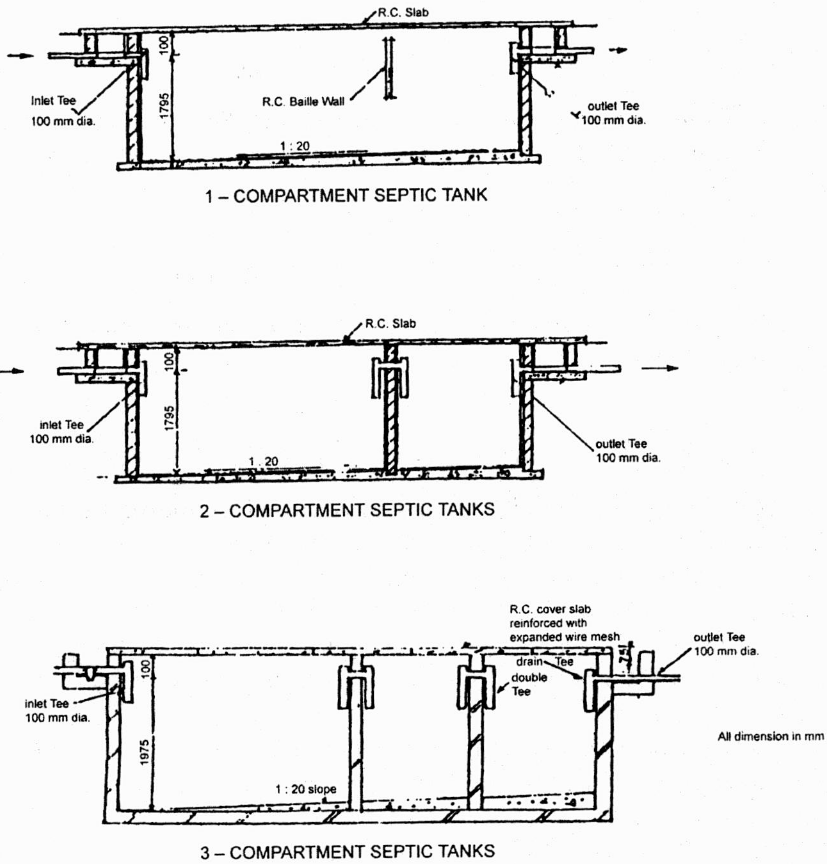

Fig. 1. The features of the 1-, 2- and 3-compartment septic tanks

Table 1

Characteristics of the septic tanks

Parameter	Septic tanks*		
	1-c	2-c	3-c
Volume (m^3)	17.71	17.71	17.71
Depth (m)	1.89	1.89	1.89
Flow rate (m^3/d)	8.64	10.45	8.76
Mean % BOD removal	56.74	65.15	69.99
Mean % SS removal	79.18	87.72	92.78
Desludging time at tank full of sludge (yr)	0.75	1.02	0.84
Desludging time on assumption of equal flow rate of 8.64 m^3/d (yr)	0.75	0.86	0.83

* 1-c, 2-c, 3-c represent 1-compartment, 2-compartment and 3-compartment, respectively.

Table 2

Incremental benefit and cost analysis

	Benefits	Equivalent worth ($)
(i)	ΔB_{12} of %SS removal	55.54
	ΔB_{12} of % BOD removal	0.39
	Total ΔB_{12}	55.93
	ΔB_{23} of % SS removal	32.91
	ΔB_{23} of % BOD removal	–0.25
	Total ΔB_{23}	32.66
	ΔB_{13} of %SS removal	88.40
	ΔB_{13} of % BOD removal	0.15
	Total ΔB_{13}	88.55
(ii)	Cost ($)	
	CR_1	109.38
	CR_2	115.79
	CR_3	123.02
	M_1	8 (present worth $6.93)
	M_2	8 (present worth $6.56)
	M_3	8 (present worth $6.82)
	ΔCR_{12}	6.41
	ΔM_{12}	–0.37
	Total ΔC_{12}	6.04
	ΔCR_{23}	7.23
	ΔM_{23}	0.25
	Total ΔC_{23}	7.48
	ΔCR_{13}	13.64
	ΔM_{13}	0.11
	Total ΔC_{13}	13.75
(iii)	$\Delta B/\Delta C$ ratios	
	$\Delta B_{12}/\Delta C_{12}$	9.26
	$\Delta B_{23}/\Delta C_{23}$	4.36
	$\Delta B_{13}/\Delta C_{13}$	6.44

Sampling of influent sewage (from inlet manhole) and effluent (from outlet manhole) were done hourly, initially to obtain daily composite samples for laboratory analysis for suspended solids (SS) and biochemical oxygen demand (BOD) parameters by standard methods for one year. Subsequently, sampling once a day was done for another 3 months including after desludging by manual method for the diurnal physicochemical analysis by standard procedure used to determine the average percentage suspended solids (% SS) and biochemical oxygen demand (% BOD) removal efficiencies of the septic tanks given in table 2. The mean flow rates of sewage effluent at each sampling time were determined quantitatively. The sludge accumulation rates (SAR) in the septic tanks were determined by standard procedure (OKEREKE [7]). The performance result of the septic tanks after statistical *t*-test (IYAMA and IHEAGWAM [3]) for difference of mean % SS and BOD removal between 1- and 2-compartment septic tanks and 2- and 3-compartment septic tanks at 5% level of significance were as included in table 2.

2.2. METHOD OF INCREMENTAL BENEFIT–COST ANALYSIS

Based on information from the experimentation obtained at this stage, incremental benefit and cost of the septic tanks were determined as presented subsequently in sections 2.2.2 and 2.2.3 taking into account the assumptions in section 2.2.1. Before comparing the mutually exclusive alternatives, they were first ranked in order of increasing total equivalent worth of costs, starting with the lowest equivalent cost alternative (1-compartment septic tank) to the highest equivalent cost alternative (3-compartment septic tank). The incremental benefit–cost ratio ($\Delta B/\Delta C$) between 1- and 2-compartment septic tanks was calculated and then $\Delta B/\Delta C$ between 2- and 3-compartment septic tanks as well as 1- and 3-compartment septic tanks were also calculated using equation (1). If the $\Delta B/\Delta C$ was greater than or equal to 1, then the higher equivalent cost alternative was chosen since it represented greater benefit potential.

2.2.1. ASSUMPTIONS IN THIS STUDY

In order to associate monetary value to the intangible benefits of the septic tanks such as increased SS removal efficiency achieved by multi-compartment septic tanks over the single compartment system, it was necessary to make some assumptions and presumption of facts as follows:

(i) Overall inflation rate in the study area was negligible and prices of goods and services did not change with time over the study period.

(ii) The 1-compartment, 2-compartment and 3-compartment septic tanks were different and mutually exclusive technical solutions to sewage disposal in developing countries or isolated household buildings not connected to central sewage treatment plant system. In other words, the selection of one alternative did not depend on any other alternative and only one alternative must be chosen.

(iii) There was no room for choosing none alternative.

(iv) Salvage value of septic tanks was zero.

(v) The cost of removal of 1% SS and 1% BOD were \$ 6.50 and \$ 9.08, respectively (US\$1= N125).

(vi) BOD removal efficiency of septic tank is a function of the clear space (OKEREKE [7]) required for the storage of accumulated solids (sludge) which in turndetermines the desludging (sludge removal) time interval. In other words, the more efficient septic tank required longer desludging time interval, which invariably meant some savings on maintenance cost.

2.2.2. DETERMINATION OF DIFFERENTIAL BENEFITS OF THE SEPTIC TANKS

The benefits of environmental projects such as septic tanks are priceless and not measured by the willingness of the individual beneficiaries to pay. The estimations therefore were done indirectly. For example, a person who owns a water borehole besides his residence or property may not know the benefit of a functional or efficient septic tank system in so far as the borehole water is not polluted by sewage effluent from the septic tank. But if there is awareness of eminent danger or threat of pollution of the water source, the benefit or willingness to pay for maintenance of the status quo or efficient sewage treatment system to protect the borehole becomes glaring. LEWIS et al. [5] gave the risk of groundwater pollution by onsite sanitation. Though amenity benefit is often difficult to measure, a promising line of approach for septic tanks is by the use of effluent quality or its impact on groundwater treatment or quality.

Septic tank irrespective of the type if properly designed, constructed and maintained avails certain common intangible benefits associated with replacing unsanitary excreta disposal (defecation in the bushes or bucket latrine) with septic tank. Therefore, the differential benefit between the 1-compartment, 2-compartment and 3-compartment septic tanks lies only mainly on the differences in effluent quality or contaminant removal efficiency. To associate monetary value to the benefit arising from the differential performance of the septic tanks in terms of % SS removal, assumption (v) of section 2.2.1 was applied by multiplying the cost of removal of unit percent of SS with the corresponding differential % SS removal between the septic tanks being compared as given in table 1. The equivalent worth of the incremental benefit was as given in table 2.

In order to assign monetary value to the incremental benefit between the septic tanks due to differences in their BOD removal efficiency, it was necessary to make the following presumption of facts that BOD was equivalent to organic matter. That was to say that the destruction or volatilization of organic matter, particularly, fresh sludge during digestion process implied removal of BOD that resulted in smaller volume of sludge accumulation in that septic tank that gave higher BOD removal efficiency. That provided more clear space relative to that of the less efficient septic tank which translated into differences in desludging time (that is the time interval between successive sludge removal from the tank). Desludging time of the 1-, 2- and 3-compartment septic tanks were 0.75 year, 1.02 years and 0.84 year, respectively (table 2). Desludging was done by manual method usually common at a normal cost of $8 per tank. Due to the improved performance of 2-compartment septic tank over the 1-compartment type by 8.41% BOD removal, desludging was done at 1.02 year instead of 0.75 year of the 1-compartment septic tank. The incremental benefit of extended desludging time by 0.27 year was translated into monetary value (equivalent worth) if we considered the return on borrowed capital ($8) for 0.27 year at the going interest rate (21%). Similarly, the incremental benefit (equivalent worth) of 3-compartment in comparison with 2-compartment septic tank due to the difference in performance by 4.84% BOD removal that resulted to desludging program at 0.18 year earlier than should have been the case if 2-compartment septic tank was used was also calculated (table 2).

2.2.3. COST OF SEPTIC TANKS

The determination of the cost of the respective septic tanks examined in this study was guided by the basic principle that financial cost does not really measure opportunity cost. Only the costs which would be avoided if the scheme were not to go ahead were included. Indirect costs due to intangibles such as displeasure or discomfort to neighbours or people due to say odour nuisance, particularly during desludging and incommensurable loss of a worker (desludger ruined inadvertently for ignorantly using naked light) in the septic tank during its manual desludging, were not considered.

The cost included were the land resource costs for each of the septic tanks based on the current market value. The slight variation in the land area involvement and consequently in the cost of land arose from the partitions in the multi-compartment septic tanks since they had equal volumetric capacity and depth. The other cost considered was that involved in building the septic tanks which was determined from the summation of all the elements of costs (materials and labour) amounting to $515.21, $545.59 and $579.81 for the 1-, 2- and 3-compartment septic tanks, respectively. The cost of land resource was excluded in this aspect of cost (materials and labour) to avoid "double counting" of cost already included. The differences in the construction costs were due to essentially the differences in the material requirements arising from inclusion of partitions in the multi-compartment septic tanks.

Another aspect of cost was the annual cost of maintenance of the septic tanks (desludging or removal of accumulated sludge in the tanks to avail clear space in the tanks) for their continued usage. The frequency of desludging among other factors depended on the efficiency of the septic tank (OKEREKE [7]). For the 1-compartment, 2-compartment and 3-compartment septic tanks studied, the desludging times were 0.75 year, 1.02 years and 0.84 year, respectively. The usual cost of desludging septic tanks was $8 each payable at the different times of the desludging exercise. The equivalent worth of the $8 capital at 21% rate of return on capital were $6.93, $6.56 and $6.82 for the 1-, 2- and 3-comparment septic tanks, respectively, at the time of depositing the maintenance cost in the savings bank account.

The capital recovery cost (CR) of the land resource cost and construction cost used in the incremental benefit–cost ratio analysis were calculated using equation (1a) based on the rate of return on capital of 21% applied in the banking industry at the time of study for a 30-year capital recovery period. The values of incremental benefit–cost ratios between 1- and 2-compartment septic tanks, 2- and 3-compartment septic tanks and 1- and 3-compartment septic tanks calculated using equation (2) were as presented in table 2.

2.3. SENSITIVITY TEST

2.3.1. THE EFFECT OF INFLATION

The null effect of inflation on the equivalent worth calculation and invariably on the incremental benefit–cost ratio was proved mathematically as follows:

If C_{ui} is the equivalent cost (uninflated cost), C_i is inflated cost, inf is inflated interest rate, i is uninflated interest rate, f is the inflation rate and n is number of years, then, equivalent worth (uninflated cost)

$$EW_{ui} = (1 + i)^{-n} . C_{ui}.$$

Equivalent worth (inflated cost),

$$EW_i = (1 + \text{inf})^{-n} . C_i$$

or

$$EW_i = C_i/(1 + i)^n (1 + f)^n.$$

Also,

$$C_i = C_{ui} (1 + f)^n \quad \text{and so,} \quad EW_i = EW_{ui}.$$

(The equivalent worth of uninflated cost and inflated cost are equal).

Thus, in general terms, the equality of equivalent worth of uninflated and inflated prices at any rate implies that inflation would make no difference in calculations for the incremental benefit–cost ratio.

2.3.2. THE EFFECT OF INTEREST RATE

In order to check the effect of interest rate on the incremental benefit–cost ratio of the alternatives, various interest rates within the range of 0–100% were used to calculate capital recovery cost and equivalent worth of incremental costs. This range covered the rates in the banking industry in developed and developing economies including those of the private sector money marketing (lenders). The trend of incremental benefit–cost ratios between 1- and 2-compartment septic tanks and 2- and 3-compartment septic tanks at various interest rates were as presented in figure 2.

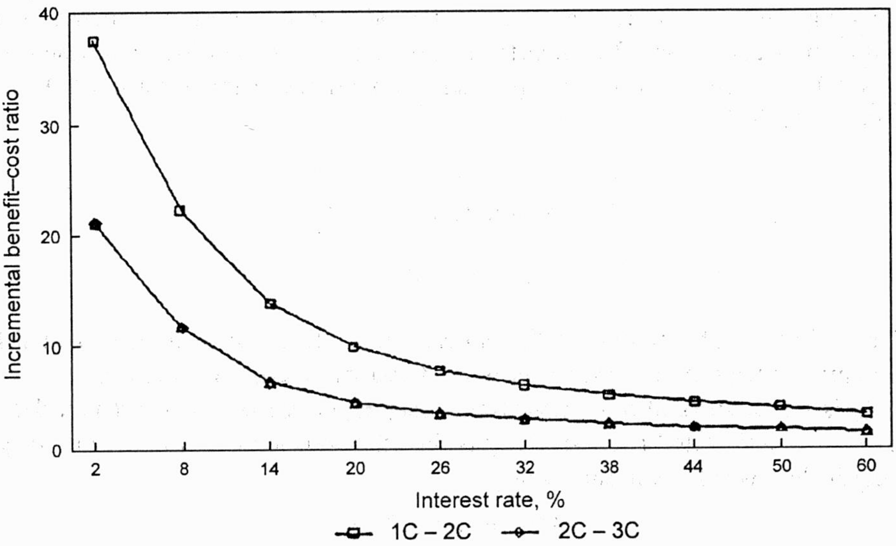

Fig. 2. Changes in incremental benefit–cost ratio at various interest rates

3. RESULTS AND DISCUSSION

The results of the experimentation and economic analysis of the septic tanks were as shown in tables 1 and 2 and fig. 2.

At the going interest rate of 21% on borrowed capital, the incremental benefit–cost ratio of 1-compartment and 2-compartment septic tanks was 9.26 (table 2). This ratio is greater than unity which therefore suggests that the higher equivalent cost alternative, the 2-compartment septic tank offers greater benefit potentials than the 1-compartment septic tank. The comparison of the 2-compartment and 3-compartment septic tanks gave incremental benefit–cost ratio of 4.36 implying that the 3-compartment septic tank is a preferred alternative to the 2-compartment septic tank in terms of the greater benefit it offers relative to the 2-compartment septic tank.

In the overall project appraisal program, the 3-compartment septic tank gave the greatest benefit potential even though it was the most costly alternative. These inferences followed from the incremental benefit–cost analysis predicated on the assumption that inflation rate was zero.

The sensitivity test to check the effect of inflation of cost and rates on incremental benefit–cost ratio calculations showed from a generalized mathematical proof (#2.3.1) that inflation had no effect on the ratio since the equivalent worth of uninflated cost was equal to the equivalent worth of inflated cost at any inflation rate. Therefore, the earlier inferences were unaffected.

From figure 2, it could be said that for all the mutually exclusive alternatives, the ratio decreased as the interest rate increased. No matter the interest rate, the incremental benefit–cost ratio of the 1- and 2-compartment septic tanks never got to below unity. In other words, at any interest rate on borrowed capital, 2-compartment septic tank is superior to the 1-compartment septic tank because of its greater benefit potential. However, this argument might not hold for 3-compartment septic tank in comparison with 2-compartment septic tank. At high interest rate above 85%, sometimes used in a money market (monetizing) economy, the incremental benefit–cost was less than unity which therefore made the 2-compartment septic tank a preferred alternative to the 3-compartment and 1-compartment septic tanks.

Furthermore, the practical flow rate and unit cost of contaminant removal did not alter the inferences.

4. CONCLUSIONS

Based on the average performances of septic tanks and incremental benefit–cost analysis at any normal rate of return on capital, the 3-compartment septic tank is the best alternative to 1- and 2-comparment septic tanks since it offers the highest benefit potential. However, in the event of abnormal interest rate above official rates sometimes experienced in private project financing through moneylenders in some developing countries, the incremental benefit–cost ratio is less than unity in favour of the 2-compartment septic tank alternative in preference to the 3- and 1-compartment alternatives. At all interest rates, the 2-compartment septic tank gave incremental benefit–cost ratio greater than unity which therefore suggests that it is always superior to the 1-compartment septic tank. But the choice between the 2- and 3-compartment septic tanks in preference to the single compartment septic tank depends on the prevailing rate of capital recovery.

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OPŁACALNOŚĆ WIELOKOMOROWYCH OSADNIKÓW GNILNYCH W ASPEKCIE OCHRONY ŚRODOWISKA

Porównano opłacalność inwestowania w jedno-dwu- i trójkomorowe osadniki gnilne. Analizę porównawczą przeprowadzono, opierając się na wskaźnikach zysku do kosztów, w których uwzględniano niematerialne korzyści (procentowe obniżenie zawiesin i biochemicznego zapotrzebowania tlenu), koszty eksploatacyjne oraz amortyzację przy stopie zysku 21%. Przeprowadzono testy czułości, określające wpływ inflacji i stopy zysku na wielkość wskaźników zysku do kosztów.

Badania wykazały, że trójkomorowy osadnik gnilny jest najlepszym rozwiązaniem, gdyż pozwala uzyskać największy potencjalny zysk. Jednakże wybór między osadnikiem gnilnym dwu- a trójkomorowym zależy też od korzystniejszej stopy amortyzacji.