

# Performance Evaluation of Fluidised Bed Biofilm Reactor using Kaldnes K1 for Domestic Wastewater

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**Abstract**— The removal of pollutants is an increasingly important goal in Sewage Treatment Plant. Practical and cost-effective biological pollutant removal technologies are needed, especially in older plants with limited space for expansion and in constructions exceeding 20,000m<sup>2</sup> should have on-site facilities in their premises for collection, treatment and facilities for reuse or safe disposal of sewage. Treating wastewater using Fluidised Bed Biofilm Reactor (FBBR) is a technique that has hailed as the most important significant development in wastewater treatment. The application of FBBR technology for wastewater treatment is a breakaway from traditional technology since it combines the best features of activated sludge process and trickling filter. FBBR, which combines suspended growth and attached growth processes by adding free floating biofilm carriers into the aeration tank is highly an effective biological treatment process and has attracted significant interest in the field of wastewater. This paper presents removal of organics, suspended solids and nutrients from domestic wastewater with Kaldnes K1 in FBBR. A laboratory scale FBBR model was fabricated in order to study the performance of FBBR in treating domestic wastewater with respect to operational parameters such as percent filling and HRT. The study was carried out, the biological treatment process by optimizing the percent filling of 10%, 20% and 30% to the reactor volume at HRT 3hours, 4hours and 5hours. The operation of the reactor was operated in a continuous mode. Samples were collected at regular intervals and test for removal efficiency of pollutants were analyzed. Monitoring the results, it was found that 30% filling rate at 5hr, Kaldnes was efficient. Classical nitrification and denitrification and the typical enhanced biological phosphorus removal process were achieved in the reactor with 30% Kaldnes filling rate at 5hr, which operated with a volumetric organic loading of 0.84gCOD/L/d. The removal efficiencies for BOD, COD, TSS, Total Nitrogen and Total Phosphorus were found to be 87%, 80%, 84%, 51% and 61% respectively. Kaldnes media's removal efficiency was practical and a cost-effective carrier for organics, suspended solids and nutrients removal in domestic wastewater.

**Key words:** Fluidised Bed Biofilm Reactor, Domestic Wastewater

## I. INTRODUCTION

The problem of sewage disposal and waste management has become increasingly critical due to the increase of worldwide population. Catastrophic impacts on human health and on the environment could result if pollution of receiving waters is allowed to continue. Therefore to preserve water quality for future generations, an effective means of solving this problem must be developed. Wastewater treatment technology has been improving and currently it is possible to treat wastewater to a highly usable level efficiently and in a cost effective way.

Domestic wastewater is also one of the major points of pollution sources, which is discharged from residential and commercial areas into the rivers without any treatment. There are many ways to treat domestic wastewater so that it can be reused. The various methods must be safe from a health point of view and not harmful to the environment.

Domestic wastewater treatment systems exist in many forms, varying in their complexity, treatment method, and location within or outside the home and should be designed in accordance with source, quality, site specifications and reuse patterns. Treatment systems range in sophistication from simple branched drain garden irrigation networks to full tertiary treatment systems that can filter water to nearly potable levels of quality.

Different types of biofilm treatment processes are in use, such as Trickling Filter, Rotating Biological Contactors, Fixed Media Submerged Biofilters, Granular Media Biofilters, Fluidized Bed Reactor etc. To overcome the demerits of the above processes, a new technology was developed known as Fluidised Bed Biofilm Reactor (FBBR). FBBR is an effective biological treatment process and it was developed on the concept of conventional activated sludge process (ASP) and trickling filter.

The efficiency of FBBR is 10 times than ASP and it typically occupies about 10% of the space required by stirred tank reactors of similar capacities (Burghate et al., 2013).

### A. Fluidised Bed Biofilm Reactor

The Fluidized Bed Biofilm Reactor (FBBR) is a process innovation in wastewater treatment, which utilizes small, fluidized media for cell immobilization and retention (Burghate et al., 2013). Main application of the fluidized bed biofilm reactor is in the field of biological treatment of wastewater. The typical diagram of FBBR is shown in Figure 1. Aerobic as well as anaerobic FBBR have received increasing attention for being an effective technology to treat water and wastewater.

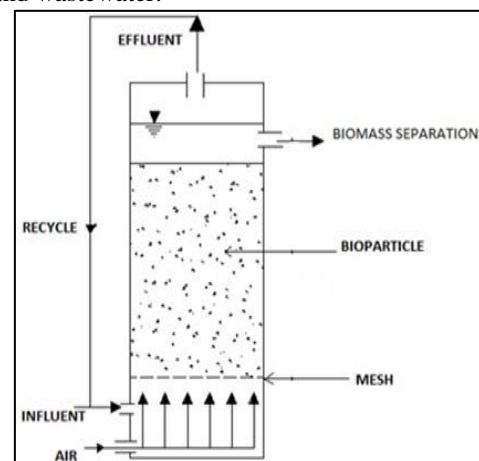


Fig. 1: Typical diagram of fluidised bed biofilm reactor

The most important features are the fixation of microorganisms on the surface of small sized particles, leading to high content of active microorganisms and large surface area available for reaction with the liquid the high flow rate low residence time which can be achieved, leading to high degree of mixing decreased external mass and to large reduction in size of the plant and the removal of risk of clogging.

Fluidised beds combine the best features of activated sludge and trickling filtration into one process. Offering a fixed film and a large surface area, fluidised bed systems offer the stability and ease of operation of the trickling filter as well as the greater operating efficiency of the activated sludge process.

### B. Fluidised Bed Technology

In 1922, Fritz Winkler made the first industrial application of fluidisation in a reactor for a coal gasification process. In 1942, the first circulating fluid was built for catalytic cracking of mineral oils, with fluidisation technology applied to metallurgical processing in the late 1940. A fluidised bed is a physical phenomenon occurring when a quantity of a solid particulate substance is placed under appropriate conditions to cause a solid or fluid mixture to behave as a fluid. The ability to free flow under gravity or to be pumped contacting methods is used in a number of processing units. The resulting phenomenon is called fluidisation.

Fluidised beds promote high level of contact between gases and solids. It has extremely high surface area contact between fluid and solid. Fluidised bed technology increases efficiency by allowing entire surface of the biofilm to be suspended and therefore exposed to air.

### C. Biocarriers

Biocarriers are referred as bed in the fluidised bed biofilm process. They shall provide sufficient bacterial population which requires sufficient surface area to stick to reproduce and does its microbial team work. The carriers carry the microorganisms throughout the reactors. The biofilm carrier elements are kept suspended in the water by means of diffusing air. As the biocarriers move throughout the reactor they provide rapid wet ability, fast bacterial colonization, high internal porosity and effective water binding. The benefits include better treatment of wastewater which is reflected by reduction of main parameters such as COD, BOD, TSS and most importantly a huge reduction of sludge generation. The dimensions of some standard biocarriers are as shown in Table 1.

Model	Length (mm)	Diameter (mm)	Internal surface area (m <sup>2</sup> /m <sup>3</sup> )
K3	12	25	500
Natric C2	30	36	220
Biofilm chip-M	2,2	48	1200
Ceramic ball	3,0	45	900

Table 1: Dimension of Bio carrier Element

## II. NEED FOR THE STUDY

The purpose of this study is to develop a high rate, effective and low cost biotechnological process for pollutants removal. The proposed process intends to treat domestic wastewater and reuse the treated water for toilet flush, garden and for

backwashing the treatment plant by reducing the organics, suspended solids and nutrients present in domestic wastewater. The advantages of the process are, no use of catalyst or oxidants except air, no chemical sludge to be disposed and low energy consumption.

## III. SCOPE OF THE STUDY

This study was to provide a cost effective media for the removal of organics, suspended solids and nutrients in accordance with the percent filling and hydraulic retention time, which may provide compact treatment plant and a technology to evaluate the performance efficiency in the removal of BOD, COD, TSS, Phosphates and Total Nitrogen in order to meet the standards of MOEF(2015).

## IV. OBJECTIVES

The objectives of this study are

- 1) To evaluate the performance of Kaldnes K1 biofilm media in a fluidized bed biofilm reactor for domestic wastewater treatment process for the removal of organics, suspended solids and nutrients.
- 2) To optimize the operational parameters such as different percent filling of biocarriers and Hydraulic Retention Time (HRT).

## V. MATERIALS AND METHODS

### A. Packing Material for Fluidisation Process

Various materials have been tried by researchers as biofilm carrier media. Some of them are sand, glass beads, activated carbon, cement ball, plastics, ceramic tiles, electric corrugated pipe, etc. In this study Kaldnes K1 media was used as a packing material for fluidisation process.

### B. Kaldnes K1

Kaldnes, wheel shaped is made up of polyethylene which has the density slightly less than water and shaped like small cylinders. Internal cross members installed in each biocarrier increase the available interior surface area for biofilm attachment. Longitudinal fins are incorporated on the external surface of the biocarrier which increase the external surface area available for biofilm growth. Anoxkaldnes has developed a complete range of FBBR biocarriers to suit different processes and wastewaters (Hewell et al., 2006). It has been designed to provide the best habitat for both young and matured beneficial bacterial. The properties of bio ball are listed below in Table 2.

Properties	Unit	Value
Specific surface area	m <sup>2</sup> /m <sup>3</sup>	840
Height	cm	1.5
Diameter	cm	2.5
Material	-	HDPE
Density	gm/cm <sup>3</sup>	0.94

Table 2: Properties of Kaldnes K1 Media

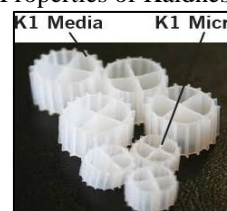


Fig. 2: Kaldnes K1

### C. Equipments

The equipments which was used to carry out the experimental work for this present study in evaluating the performance of the Fluidised Bed Biofilm Reactor are as listed in Table 3.

S. No.	Equipments
1	BOD incubator
2	Hot plate
3	Compressor
4	Oven
5	Water Bath
6	Air pump
7	Diffuser
8	Electronic weighing machine
9	Desiccator
10	COD digester
11	Feed and settling Tank
12	pH meter

Table 3: Equipments to Be Used for This Study

### D. Experimental Methodology

First the reactor was set up as designed reviewing the literatures. At the mean time the collected domestic wastewater sample was characterized and acclimatization of sludge was done followed by optimization studies which were HRT and percent filling of biocarriers. Finally analysis of the biologically treated domestic wastewater was carried out by appropriate standard methods, thus evaluating the performance of biological treatment process. This study was to find a cost- effective, advantageous an efficient media for greater removal of pollutants in domestic wastewater.

### E. Fabrication and setup of fluidised bed biofilm reactor

The laboratory scale Fluidised Bed Biofilm Reactor was fabricated with dimensions arrived based on the literature and standards. The reactor is a circular column made up of acrylic material of total volume 3.5litre. The reactor is 45cm in height and has an outer diameter of 11cm and inner diameter of 10cm and 5mm thick. The dimensions of the reactor are tabulated in Table 4. At the top an inlet was provided using a feed tank of 10litre capacity which was fitted with pump to supply influent to the reactor. An outlet for effluent was provided at the bottom of the reactor.

S. No.	Reactor dimensions	Value
1	Outer diameter	11cm
2	Inner diameter	10cm
3	Height	45cm
4	Thickness	5mm
5	Working volume	3.5litre

Table 4: Dimensions of the Fabricated Lab Scale Reactor

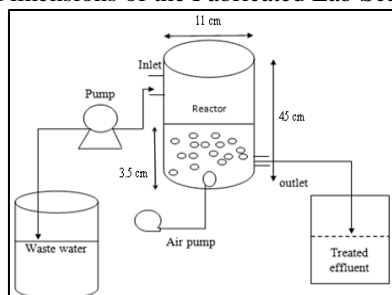


Fig. 3: Schematic diagram of Fluidised Bed Biofilm Reactor

At the inlet of the reactor, a regular cock was provided to regulate the flow as well as fluidisation of media in the reactor. A screen was provided at the top end to avoid

escape of media from the reactor and also to distribute the flow uniformly in the reactor.

The basic schematic diagram of FBBR is shown in Fig 3. In order to study the performance of the reactor with Kaldnes K1 media, a laboratory model was fabricated and set-up at the lab scale as shown in Fig.4



Fig. 4: Fabricated lab scale Fluidised Bed Biofilm Reactor

### F. Operational Parameters

The efficiency of organics, suspended solids and nutrients removal in the reactor was studied by optimizing the operating parameters such as percent filling of biocarrier to the reactor volume and HRT.

### G. Optimisation of percent filling of biocarriers

The purpose for this study was to determine the optimum percent filling of biocarriers that was most effective and efficient in aiding the treatment of domestic wastewater. The percent filling was calculated and obtained by reviewing literatures.

### H. Percent filling of biocarriers to reactor volume

Biocarriers was also a factor that influenced the rate of biodegradation. The bed here was fluidized hence the biocarriers was filled accordingly to make it act as a fluidised particle. The percentage filling of biocarriers is defined as the volume of carrier material which includes voids to the reactor working volume. The volume of carrier material in litres and number of pieces required for percent filling was calculated as below and the values are presented in Table 5.

Percentage filling =

$$\frac{\text{Volume of biocarrier including voids (Litre)}}{\text{Reactor working volume (Litre)}} \times 100$$

1) For 10% filling

Reactor working volume = 3.5Litre

Volume of biocarrier material = Reactor working volume x percent filling = 3.5Litre x 10/100 = 0.35Litre

2) For 20% filling

Volume of biocarrier material = Reactor working volume x percent filling = 3.5Litre x 20/100 = 0.7Litre

3) For 30% filling

Volume of biocarrier material = Reactor working volume x percent filling = 3.5L x 30/100 = 1.05Litre

S. No	% Filling of biocarriers	Volume of biocarrier (L)	Depth (cm)
1.	10	0.35	4.5
2.	20	0.7	9

3.	30	1.05	13.5
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Table 5: Percent Filling of Biocarriers

I. Optimisation of hydraulic retention time

The effect of HRT on removal of organic, suspended solids and nutrients was evaluated by varying HRT. The reactor was operated continuously and flow rates were adjusted to 1litre/hour, 0.8litre/hour and 0.7litre/hour with the respective HRT of 3hour, 4hour and 5hour. The values are tabulated in Table 6. The removal efficiency was calculated for every HRT value. The effective HRT was based on the maximum pollutant removal for the optimum percent filling of biocarrier to reactor volume.

Flow rate (l/hr)	HRT (hr)	OLR (kg/m <sup>3</sup> .d)
1.16	3	3.99
0.875	4	3
0.7	5	2.4

Table 6: Operational Parameters

VI. RESULTS AND DISCUSSION

A. Characterization of Collected Domestic Wastewater Sample

Samples were collected for initial characterization of domestic wastewater from Anna University STP. The collected domestic wastewater was analyzed for the parameters pH, TSS, BOD<sub>3</sub>, Alkalinity, COD, Nitrogen, Total Phosphates and Total Nitrogen and the results found are tabulated in Table 7.

Parameter	Value
pH	6.6
Total Phosphate	6.5
COD	445
BOD <sub>3</sub>	285
TSS	316
TDS	725
TOC	83
TN	37
TKN	39

Table 7: Characteristics of Collected Domestic Wastewater from STP, Anna University

All units except pH are in mg/L

B. Acclimatization Process

Before start up, acclimatization was started by inoculating 3L of fresh collected sludge taken from STP, Anna University in the reactor. The reactor was filled with media and the contents were allowed to stabilize at the required temperature. Its contents were aerated continuously at 9lpm using three air pumps. The nutrients were added in calculated amounts regularly.

The sludge was replaced by raw domestic wastewater in calculated quantity to bring in the required MLSS concentration to start the treatment process. MLSS was regularly tested at an interval of two days. The concentration of active biomass in the FBBR system reported is in the range of 3200mg/L to 4500mg/L for domestic wastewater. (Feng Quan, 2012). As MLSS concentration reaches accordingly, it is observed that microorganisms have attached to the media. As 4570mg/L MLSS concentration was reached, the biological treatment was started.

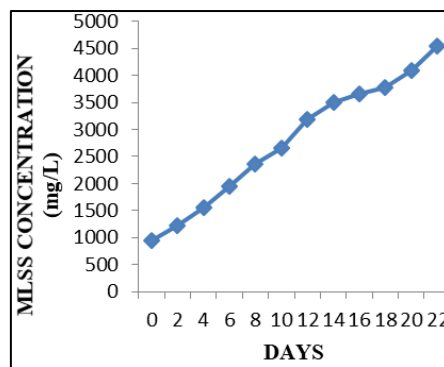


Fig. 5: Mixed Liquor Suspended Solids concentration of acclimatization process

C. Effect of kaldnes k1 media for removal of organics in FBBR

The results for the average effluent COD concentration from the reactor showed that the denitrification process can consume most of the biodegradable organic matter. Other studies have shown that COD removal in the aerobic phase in the FBBR system was at the 75–80% level (Manoj Kumar and Chaudhari, 2013). COD removal depends on the volumetric organic loading rate. The highest COD removal efficiency was obtained at an OLR of 0.86–0.89 gCOD/L/d.

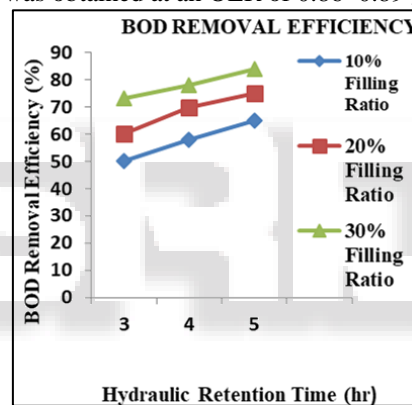


Fig. 6. Effect of BOD removal efficiency by Kaldnes K1

The COD removal rate was in turn an observed 0.824–1.33 gCOD/L/d, and a linear relationship was recorded between COD removal rate and OLR. The load of COD removed was also proportional to the COD load fed into the reactor, and such behavior was observable over large ranges of influent COD loading rates. The highest values for COD removal rate were recorded at COD load levels exceeding 0.8gCOD/L/d. The same conclusion has been reported by other authors (Podedworna et al., 2009; Masłon´ and Tomaszek, 2015).

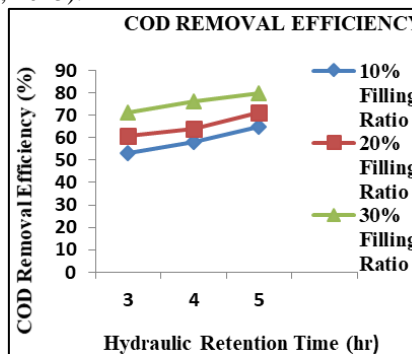


Fig. 7: Effect of COD removal efficiency by Kaldnes K1

**D. Effect of kaldnes k1 media for removal of nutrients in FBBR**

A high degree of removal of nitrogen from wastewater was demonstrated with the analysis cycle for the system indicating removal by the classical nitrification under aerobic conditions, as well as denitrification conditions. The total phosphate and total nitrogen removal efficiencies amounted to 61% and 53% were dependent on the OLR and COD/TN ratios in the influent.

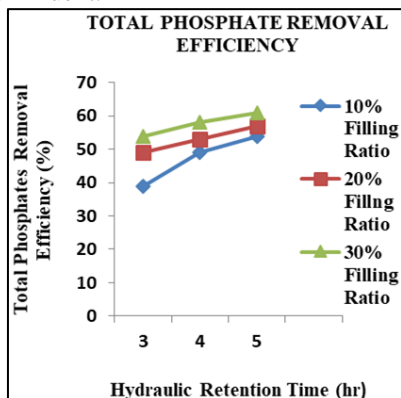


Fig. 8: Effect of Total Phosphate removal efficiency by Kaldnes K1

In this experiment maximum TN removal was achieved at COD/TN ratios in the range 10–11 (Maslon’ and Tomaszek, 2015) obtained fullest total nitrogen removal in FBBR reactors at COD/TN ratios above 9.0.

The amounts of nitrogen removed correlated positively with influent COD/TN (Gen et al., 2010). (Ding et al, 2011) achieved a best TP removal efficiency of 87% in an FBBR reactor where the COD/N ratio was 12.5 and a simultaneous nitrification and denitrification process was ongoing.

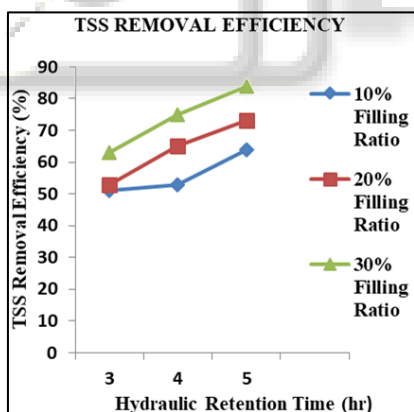


Fig. 9: Effect of Total Nitrogen removal efficiency by Kaldnes K1

The high degree to which total phosphate could be removed from wastewater possibly reflected high nitrification peaking at 99.7%. The C/N ratios of 11.1 and 11.2 were the optimal values for an FBBR system, leading to the most effective removal of both nitrogen and organic carbon. For comparison, in other studies (Lim et al, 2011) obtained a

maximum percentage nitrogen removal with 84% TN removal using a polyurethane foam carrier packing volume of 40% in an FBBR system.

**E. Effect of kaldnes k1 for removal of TSS in FBBR**

Biofilm formation on MBBR carriers commonly follows the four stages of attachment, accumulation, re-generation and maturation (Zhu et al., 2015).

Assuming that the biofilm system is at steady state, the detachment rate of biomass can be considered equal to biofilm growth. However, for most FBBR systems the shear forces will vary over time, and detachment will vary accordingly and contribute to higher suspended solids content (Horn et al., 2013). However, due to detachment, the FBBR always contain some suspended biomass, which is not attached to the carriers but may still contribute to the overall performance. The importance of this contribution will vary depending on the specific growth rate and the activity of the microorganisms in the process, as well as in response to loading rate, substrate concentrations and HRT.

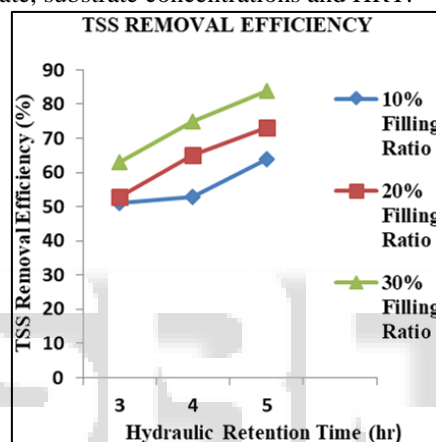


Fig. 10: Effect of Total Nitrogen removal efficiency by Kaldnes K1

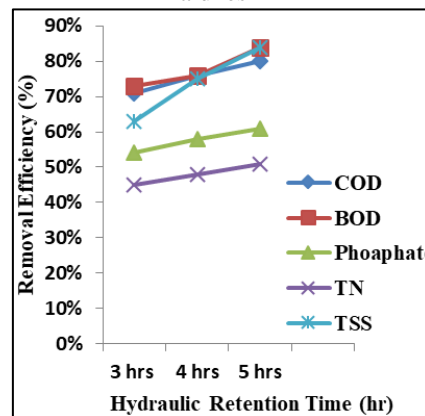


Fig. 11: Overall removal efficiency by 30% of Kaldnes K1  
The optimization result showed a high rate of overall removal efficiency in 30% carrier filling of Kaldnes K1 at 5hrs HRT. The obtained experimental values of BOD, COD, TSS, Total Phosphate and Total Nitrogen are tabulated in Table 6 AND Table 7.

HRT (hrs)	Phosphate			Total nitrogen		
	Influent (NTU)	Effluent (NTU)	Removal (%)	Influent (mg/L)	Effluent (mg/L)	Removal (%)
3	6.6	3.1	54	34	18.9	45
4	6.6	2.8	58	34	18.2	48
5	6.6	2.6	61	34	16.9	51

Table 8: Experimental Values

HRT (hrs)	BOD			COD		
	Influent (NTU)	Effluent (NTU)	Removal (%)	Influent (mg/L)	Effluent (mg/L)	Removal (%)
3	207	54	73	523	156	71
4	207	47	77	523	120	76
5	207	32	84	523	103	80

Table 9: Experimental Values

## VII. CONCLUSION

The experimental results proved that the filling of carrier elements is important for organic and nutrient removal and for specific biofilm growth. The optimum percent filling of biocarriers achieved best performance and beyond the optimum percent filling the removal efficiency started to decrease.

In 30% filling, the movements of Kaldnes K1 were able to move uniformly and give favorable surface area for microbial growth. As a result, higher organics and nutrients removal efficiency were achieved compared to that of 10% and 20% carrier filling rates. Similarly the retention time of bioreactor influences the hydrolysis of particulate and organic matter such that the removal efficiency also becomes high.

The important conclusions of this study are as follows

- 1) The performance of Kaldnes K1 was efficient in 30% filling ratio at 5hours HRT with high removal efficiency of 80% of COD, 87% of BOD, 61% of Total Phosphate, 51% of Total nitrogen and 84% of TSS.
- 2) Kaldnes K1 media seems to be more efficient in nutrients and organics removal.
- 3) Higher the suspended biomass concentration, enzymatic hydrolysis and bioflocculation, higher the pollutant removal, the experimental works proved that the optimum filling ratio was 30% which helped for effective treatment of domestic wastewater in removing organics and nutrients at HRT of 5hours.
- 4) Kaldnes K1 media are required in less numbers for efficient treatment of domestic wastewater.
- 5) Cost of buying and handling the biocarriers is also low and easy for Kaldnes K1 media.
- 6) High accumulation of biomass in the biofilm when coupled with good oxygen transfer capability of the system ensures the high treatment capacity and operational stability. This can make the FBBR process attractive and promising to apply organic matter removal from wastewater. Thus Kaldnes K1 media is far efficient and seems to be a media which is practical and cost effective for pollutants removal in domestic wastewater.

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