

Process Design for Fat Removal from Dairy Effluent by Cyclone Baffled Reactor and Potash Alum

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ABSTRACT: Dairy plants are categorized under wet industry because large volume of water is used for its product processing stages. Current statistics shows India is ranked one in the global milk producers. The waste which is generated from the dairy plant is there for a hot topic for engineering discussions. The dairy industry, like most other agro-industries, generates wastewater characterized by high chemical oxygen demand (COD) and Biological oxygen demand (BOD) due to their high organic content. The dairy-industry wastewater is primarily generated from the cleaning and washing operations in milk processing plants, milk transportation vehicles, fault product discharge etc. Even though the biological treatment processes offer a cost effective method to remove organic compounds and nitrogen from the wastewater, the fat content in dairy effluent after aerobic treatment system is still a problem to be managed. Oil containing sludge produced after aerobic treatment is discarded from dairy treatment plants for land filling, which cause severe Environmental imbalances. More over in most cases product ideas from the waste dairy effluent fat is beyond the scopes of the current treatment processes. The aim of this work is to design a process mediated by Cyclone baffled Reactor and Potash Alum, which have the capability to enhance current dairy treatment process by separating fat content of dairy effluent at the initial stages itself prior to biological treatment steps. Results shows COD reduction of 70.73% and BOD reduction of 70.58% was achieved in CBR with a retention period of 20 minutes. Reduction in effluent treatment retention time and effective fat separation from the dairy effluent, thereby reducing the BOD and COD loads are the final outcome of this work.

KEYWORD: Cyclone baffled Reactor, COD, Dairy effluent, fat separation, Potash Alum

I. INTRODUCTION

Dairy and dairy based products are the unavoidable diet routine of mankind. All steps in the dairy chain, including production, processing, packaging, transportation, storage, distribution, and marketing, impact the environment [15]. The problem for most dairy plants is that waste treatment is perceived to be a necessary evil [14]; it ties up valuable capital, which could be better utilized for core business activity. Dairy wastewater disposal usually results in the problems like high treatment charges; pollution issues regarding untreated wastewater discharging into the environment, sludge disposal problem in aerobic biological system, land requirement for sludge drying, labor cost etc. To enable the dairy industry to contribute to water conservation, an efficient and cost-effective wastewater treatment technology is critical. Solids in waste water can be separated by addition of flocculants. Flocculation is the polymeric action in which bridges are formed between the flocs, and destabilized particles are bind into large clumps. Flocculent should be added slowly and mixed gently to ensure proper contact between the small flocs and their agglomeration into bigger particles. This property of flocculating agent Potash alum ($KAl(SO_4)_2 \cdot 12H_2O$) is explored for the design and treatment system for dairy effluent. Cyclone Baffled Reactor is designed in such a way as to provide proper mixing of

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dairy effluent and flocculating agent fed into it. The flocs, which formed as a result of reaction with effluent, may then float to the top of the liquid (creaming) phase. It can be effectively separated from the reactor top by designing a proper piping facility. The spend liquid after fat removal can be discharged to the secondary treatment procedures. Fat/oil content in the dairy effluent is the core source of COD and BOD. The phase separation of fat and liquid followed by the removal of fat from the dairy effluent will reduce the working load of the current secondary treatment procedures practiced in the dairy industry. There by reducing the treatment retention time requirement and improve the efficiency of treatment.

II. LITERATURE REVIEW

The dairy industry is generally considered to be the largest source of food processing wastewater. Although the dairy industry is not commonly associated with severe environmental problems, it must continually consider its environmental impact—particularly as dairy pollutants are mainly of organic origin or dairy companies with good effluent management systems in place [13], treatment is not a major problem, but when accidents happen, the resulting publicity can be embarrassing and very costly. All steps in the dairy chain, including production, processing, packaging, transportation, storage, distribution, and marketing, impact the environment [15]. Owing to the highly diversified nature of this industry, various product processing, handling, and packaging operations create wastes of different quality and quantity, which, if not treated, could lead to increased disposal and severe pollution problems. In general, wastes from the dairy processing industry contain high concentrations of organic material such as proteins, carbohydrates, and lipids, high concentrations of suspended solids, high biological oxygen demand (BOD), chemical oxygen demand (COD), high nitrogen concentrations, high suspended oil and grease contents, and large variations in pH. The dairy waste streams are also characterized by wide fluctuations in flow rates, which are related to discontinuity in the production cycles of the different products. All these aspects work to increase the complexity of wastewater treatment. The waste auditing of various industries is studied by many researchers. [8] carried out a case study on waste auditing of ice cream factory at Thailand and they observed that the generation of ice cream waste is attributed to the high consumption of water in the plant for washing and cleaning operations [12]. As a result of waste auditing, methods like change in existing equipments, waste segregation were proposed to save water and to modify the existing wastewater treatment system of the ice cream plant for better treatment efficiency [12]. To enable the dairy industry to contribute to water conservation, cost-effective and efficient wastewater treatment technology is critically important. The biggest problem in the chemical treatment of wastewater is the selection of the chemicals, which must be added to the wastewater in order to separate the dispersed pollutants [9]. The problem nearly always cumulates in finding a suitable coagulant as this must be easy to handle, store and prepare. Most widely used coagulant in wastewater treatment is based on aluminium, called aluminium sulphate ($Al_2(SO_4)_3$) or alum, filter alum or alumina sulphate. Coagulants react with available alkalinity such as carbonate, bicarbonate and hydroxide or phosphate to form insoluble aluminum salts [9]. As metal salts, alum will react with alkalinity in the water to produce an insoluble metal hydroxide floc which incorporates the colloidal particles. When alum is added to solution, it will begin to form hydrated reaction products, which means that one or more hydrogen ions are released when electron densities are drawn in the direction of central metal atom and oxygen-hydrogen bond becomes disturbed [9]. In the present study Aluminium Pottasium Sulfate (Potash Alum) is investigated for the coagulation and floatation study of dairy industry waste water.

III. MATERIALS AND METHODS

Experimental Setup

Cyclone baffled reactor is similar to UASB reactor but the internal baffle scheme and flow velocity and directions are different. Cyclone action redirects the mixing of flocculating agents and effluent effectively, the baffles of CBR play an important role at this phase

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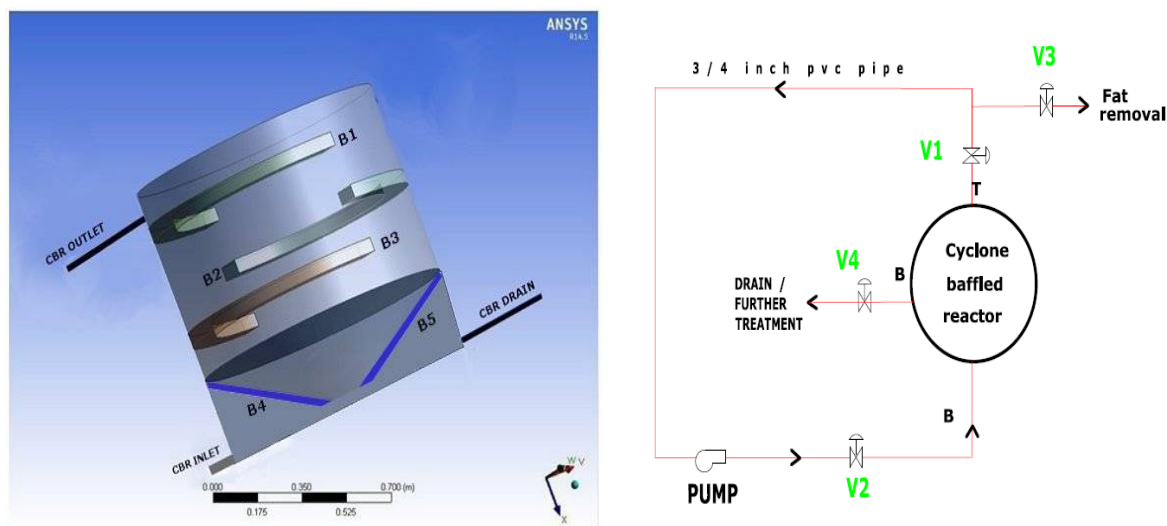


Fig 1: Cyclone Baffled Reactor, 3-Dimensional (ANSYS) and Piping diagram (AUTOCAD Drawing) (B1, B2, B3, B4, B5 are baffles and V1, V2, V3, V4 are valves)

Design Protocol and formula: When designing a treatment facility using a CBR, the following design considerations must be followed.

Flow rate (Q): The flow of dairy effluent in the proposed model is achieved using a 0.5 HP centrifugal pump with a fluid flow rate of 3300 liter/hour in a closed loop.

Hydraulic Retention Time (HRT): In typical suspended solids reactors without recycle, the SRT has to be equal to the HRT. HRT can be calculated as shown below.

$$HRT = V/Q$$

Volume of Reactor (V): The volume of the reactor can be determined based on the flow rate and a set HRT or the HRT can be determined based on a set reactor volume, depending on the application.

$$V = Q * HRT$$

This volume calculation describes the minimum volume needed in order for the tank to handle the incoming flow of wastewater. A factor of safety should be applied when designing a wastewater treatment plant to avoid flooding of the system. This safety factor will take into account population growth and any increased usage of water resources.

Cylindrical shells Thickness (T): The following formulae shall apply in the case of cylindrical shells [2].

$$T = pD_o / 400fJ + p$$

Where, V: Volume of reactor, Q: Volumetric Flow rate, HRT: Hydraulic retention time, D_o : outside diameter of the shell in mm, f: allowable stress value in kgf/mm^2 , J: well joint factor, P: Design Pressure in kgf/mm^2 , E: modulus of elasticity kgf/mm^2 .

IV. PROCESS DESIGN AND EXPERIMENTAL SETUP

170 liter capacity Cyclone Baffled Reactor with total of 5 baffles includes 3 semi circular baffles and 2 horizontal baffles were fabricated and used for the study. Circular baffles are provided with 20mm diameter holes on its surface to provide high efficiency in mixing. Mild steel with 3 mm thick is selected as the material of construction for the CBR and is coated inside and outside with double coats of corrosion resistant paint and all piping are of PVC make. A 0.50

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HP centrifugal pump were used for the circulation of effluent in a cyclic manner from bottom to top direction with a flow rate of 3300liter/hour. Control valves were provided for flow control. During operation $KAl(SO_4)_2 \cdot 12H_2O$ is sparged to CBR for flocculation to occur and the mixing were done using 0.50 HP centrifugal pump and the whole operation is employed in batch wise. During pumping time, only the valve V1 and V2 are in open condition. After providing rapid circulation of fluid in close loop, the pumping is stopped for the flocculation of the effluent to occur. The fat floated at the top of CBR is removed effectively by opening valve V3, here the valve V2 should be kept closed to avoid recirculation of fat into CBR inlet. The clear liquid after fat separation is discharged through V4 for further treatment prior to discharge.



Fig 2: Fabricated Experimental Setup

Sample Collection

Dairy sample required for the study is collected from MILMA dairy Naduvattom, Kozhikode and is transported to project study site at Government Engineering college, Kozhikode. Ghee and fat based products are the daily production scope of this dairy plant. Due to this reason, the fat content in the generated effluent is comparatively high in this plant.

Analytical Methods

All water quality parameters were determined according to Standard Methods APHA. Table 1 gives the methods and instruments used for the analysis.

Table: 1 Parameter Analysing technique

Parameter	Method	Instrument
pH	Electrometric method	Water quality Analyser
COD	Potassium dichromate reflux method	Reflux Apparatus
BOD	Five day test	Incubator
TSS, TDS	Filtration and drying in oven method	Hot air Oven
Conductivity	Electrometric method	Conductivity probe
Functional Group	Quantitative analysis	FTIR

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V. EXPERIMENTAL RESULTS

V.A.1. FTIR STUDY OF DAIRY EFFLUENT

IR spectroscopy is an excellent method for biological analysis. It enables the nonperturbative, label-free extraction of biochemical information and images toward diagnosis and the assessment of cell functionality [10]. The functional group present in the dairy effluent are Alcohol (at 3340.35 cm^{-1} , $52.22\%T$) and Amides (at 1634.21 cm^{-1} , $72.20\%T$). Alcohol is formed due to fermentation results from microbial activity of air with exposed dairy effluent. Amide is one of the functional group present in the natural oil FTIR result confirms the presence of the oil in dairy effluent.

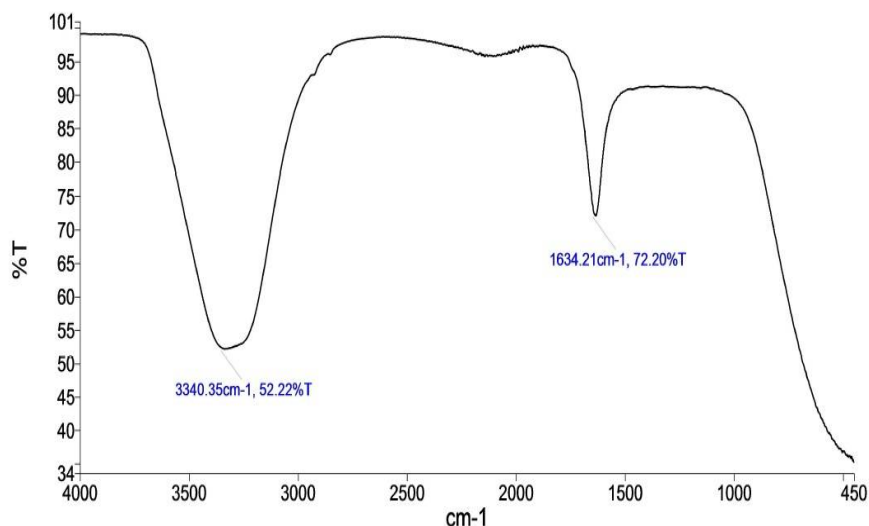


Fig: 3 FTIR result of Dairy effluent

V.A.2. CHEMICAL OXYGEN DEMAND AND BIOLOGICAL OXYGEN DEMAND STUDY IN CBR

Chemical Oxygen Demand (COD) of dairy effluent collected is analysed. In the proposed process of separation of fat and liquid phase by adding Potash Alum in the CBR and a 0.5 Hp centrifugal pump is provided for thorough mixing. At regular intervals of 250 g addition of Potash Alum allowing a retention time of 20 minutes, samples were taken from CBR top and bottom. The COD of effluent is high at CBR top compared to the CBR bottom. The Figure 3b indicates the COD profile inside the reactor. COD of the dairy effluent direct sample collected is observed as 820 mg/l. As the Potash Alum added to the system, phase separation starts inside the CBR, results in the distribution of COD in non uniform manner. COD value at CBR top increases linearly from 480 mg/l at 250 g addition of Potash Alum to 660 mg/l at 1750g Potash alum addition respectively. COD value of CBR bottom side decreases linearly from 434 mg/l to 245 mg/l at the end of the process in contradiction to CBR top side. COD removal of the dairy effluent at a rate of 70.73% is obtained at bottom of Cyclone Baffled Reactor. The Figure 3a indicates the Biological oxygen demand (BOD) profile which is a maximum at CBR top. The BOD value at CBR top increases linearly from 680 mg/l at 250g addition of Potash Alum to 754 mg/l at 1750g Potash alum addition respectively. BOD value of CBR bottom side decreases linearly from 680 mg/l to 222 mg/l at the end of the process with a percentage BOD removal of 70.58 % .

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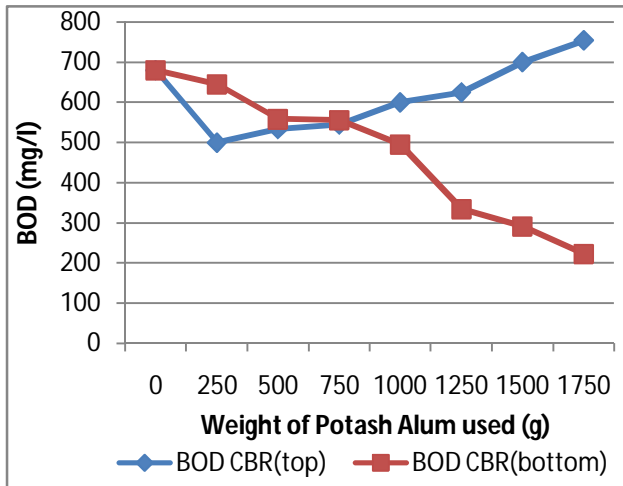


Fig 3a: Biological Oxygen Demand analysis in CBR

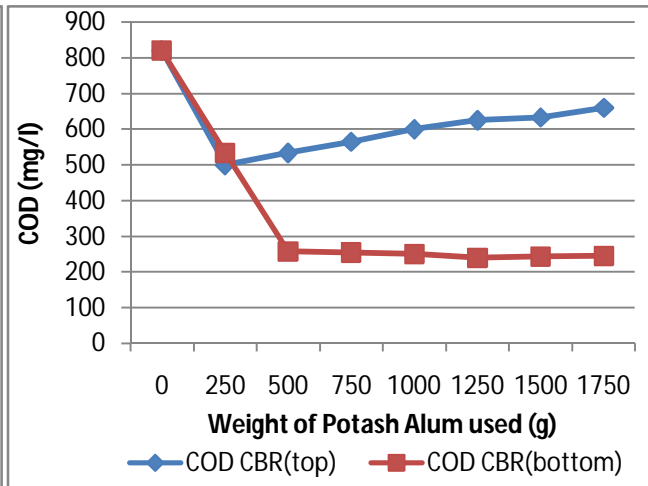


Fig 3b: Chemical Oxygen Demand analysis in CBR

V.A.3. TOTAL SUSPENDED SOLIDS AND TOTAL DISSOLVED SOLIDS PARTICLE STUDY IN CBR

Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) concentration in mg/l in every 250 g addition of Potash Alum to the effluent in CBR is given in Figure 4a and 4b. Analysis result shows that TSS concentration is decreased gradually at CBR bottom. Whereas TSS value increases progressively at CBR top portion due to the accumulation of fat matter. Provided baffles in CBR enhance the biomass mixing during pumping time and enhance the fat floatation from the effluent. Total dissolved solid particle results represent the gradual accumulation of total dissolved solids at the CBR bottom compared to the CBR top. Accumulation of ions at CBR bottom due to the addition of Potash Alum is the reason for high TDS value in this area.

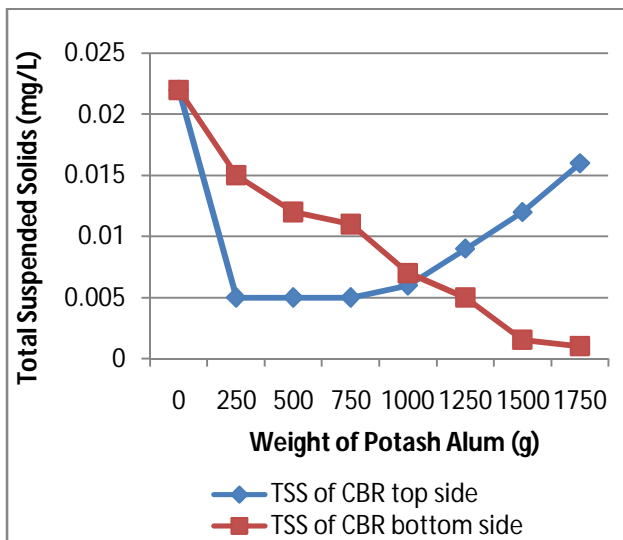


Fig 4a: Total Suspended Solids analysis in CBR

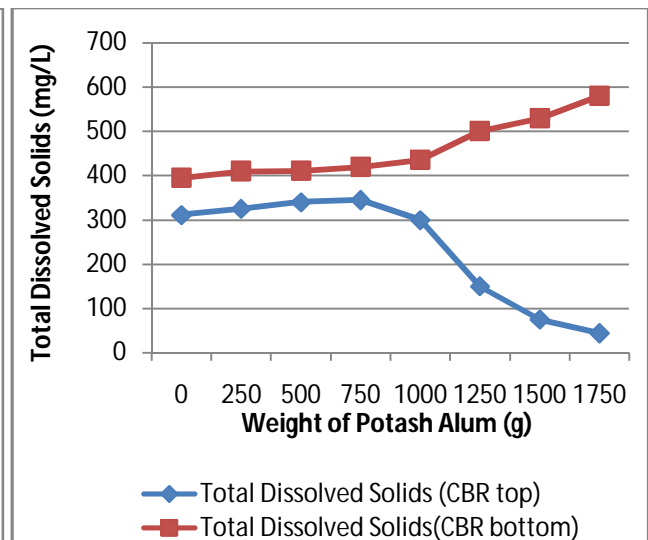


Fig 4b: Total Dissolved Solids analysis in CBR

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V.A.4. CONDUCTIVITY AND pH STUDY IN CBR

Conductivity is a parameter which is simple to measure and can easily be measured with continuous measurement device. This parameter is a general indicator of water quality, especially a function of the amount of dissolved salt, and can be used to monitor processes in the wastewater treatment. The processes that in many treatment plants cause changes in conductivity are mainly due to biological nitrogen removal [2]. The Figure 5a represents the conductivity profile in CBR. Results indicate the conductivity increases at CBR bottom and decreases at CBR top in linear manner. Due to high TDS accumulation, the Conductivity increases at CBR bottom. Conductivity value at CBR top decreases from 1500 mS to 925 mS. Whereas, the conductivity at CBR bottom increases from 1500mS to 1609 mS at the end of the process. The Figure 5b depicts the pH profile inside CBR, the pH value at CBR top is reduced from 8.89 to 7.69 and CBR top is reduced from 8.58 to 7.69 at the end of the process. The reported pH value is closer to neutral range and is good enough to be discharged after providing proper ion exchange and filtration process [16].

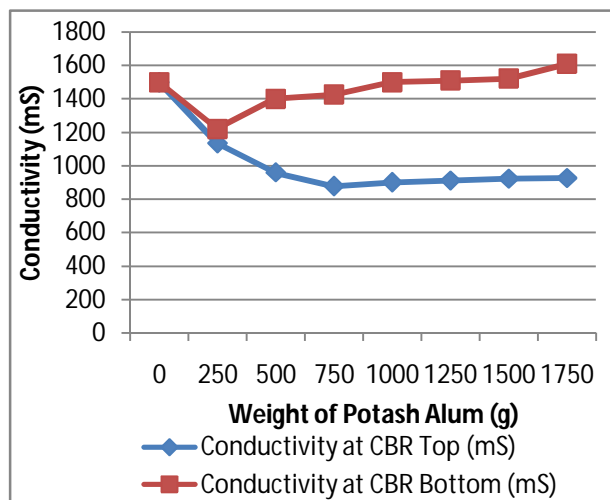


Fig 5a: Conductivity study in Cyclone Baffled Reactor

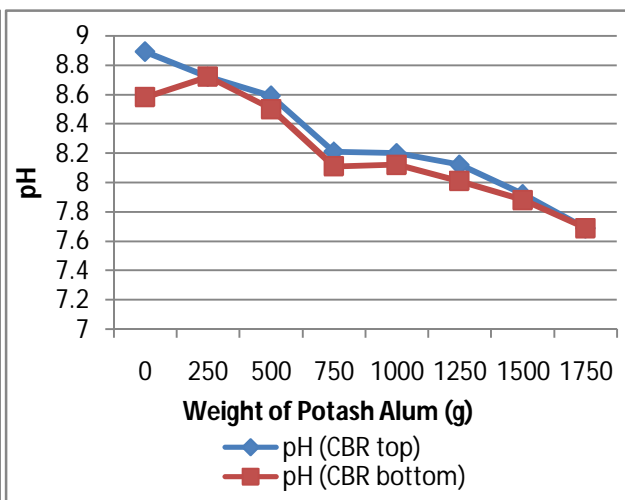


Fig 5b: pH study in Cyclone Baffled Reactor

V.A.5. Cyclone Baffled Reactor Conversion Profile

The Table 2 represents the conversion profile of the dairy effluent in Cyclone Baffled Reactor and the technical statistics are depicted below.

Table: 2 Parameter study in CBR

Parameters	Details
Total Capacity of Effluent in CBR	170 liter
KAl(SO ₄) ₂ .12H ₂ O used for complete floatation of fat	1750grams (10.29 g/liter)
Retention time requirement	20 minutes
Total mass of Fat separated	1.011 Kg
Total Volume of Fat separated	1.013 liter
Density of Fat	1.002 kg/m ³ ,
Density of spent water	1.011 kg/m ³
Fat separated in CBR from the collected dairy effluent	0.595 %

VI. CONCLUSION

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Process for Dairy effluent treatment system mediated with Cyclone Baffled Reactor (CBR) with 170 liter capacity was designed, fabricated and analysed. 0.595 % fat is present per liter of Dairy effluent and can be separated effectively using cyclone Baffled Reactor at 10.29 grams/l $KAl(SO_4)_2 \cdot 12H_2O$. Retention time requirement for the process is found to be 20 minutes. COD removal of effluent in CBR were found to be 70.73% and corresponding BOD removal is 70.58 %. The rapid reduction of COD and BOD observed at CBR bottom side. The result opens a wide scope of CBR implementation in dairy treatment plants. Fat separated by this method can have different value added product scope in future.

VII. ACKNOWLEDGEMENT

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