1-1-2006

Investigation of the effect of magnetic field on the chemical oxygen demand removal of wastewater

Anup Jagadeesh
Ryerson University

INVESTIGATION OF THE EFFECT OF MAGNETIC FIELD ON THE CHEMICAL OXYGEN DEMAND REMOVAL OF WASTEWATER

By

Anup Jagadeesh, BE.
Siddaganga Inst. of Technology, India, 2003

A Project Report
presented to Ryerson University
in partial fulfillment of the requirements
for the degree of Master of Engineering
in
Chemical Engineering

Toronto, Ontario, Canada, 2006

Author's Declaration

I hereby declare that I am the sole author of this report. I authorize Ryerson University to lend this report to other institutions or individuals for the purpose of scholarly research.

ANUP JAGADEESH

I further authorize Ryerson University to reproduce this report by photocopying or by other means, in total or parts, at the request of other institutions or individuals for the scholarly research.

ANUP JAGADEESH

Acknowledgement

The work described in project was mainly performed at the Laboratory of Water and Wastewater Treatment Technologies of the Department of Chemical Engineering, Ryerson University. I am very grateful to everyone who supported me in conducting this Project.

First of all, I would like to express my sincere gratitude to my advisor, Prof. Dr. Huu Doan, who managed to supervise my work in a spirit of friendship, freedom and openness. Without his motivating guidance, helpful comments and support at various stages throughout this research project, this Project would never have been completed. I would also like to thank all other faculty members who helped me to successfully complete this project. They have played a significant part in my career development at Ryerson University.

I would also like to take this opportunity to thank my friends at Ryerson University especially Amar Weli, Gunaraja Thuraisingham, Chandra Adimolam, Anthony Biang, Randha El-Haj, Rakesh-Desai and Li-Wan.

All my life I will be deeply indebted to my parents and sibling for their love, care, emotional support, and guidance.

ABSTRACT

This study investigated the effect of magnetic field on the biological treatment of wastewater at varied liquid volumetric flow rates. Wastewater quality is measured by Chemical Oxygen Demand (COD) which quantifies the amount of oxygen required to chemically oxidize organic compounds present in the water. The results obtained from the present study show that at the flow rate of 6.7×10^{-5} m^3s^{-1} there was a significant effect on the COD removal. At lower flow rates the magnetic field had more time to act on the microorganisms which in-turn increased the COD removal rate. However at flow rates 3.3×10^{-4} to 1.2×10^{-4} m^3s^{-1} the effect of the applied magnetic field on the COD removal decreased slightly.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

COD	Chemical oxygen demand	mg/L
K	Rate constant	hr^{-1}
L	Concentration	mg/L
L_o	Ultimate Chemical oxygen demand	mg/L
mT	militesla	mT
BOD_5	5-day Biochemical oxygen demand	mg/L

CHAPTER 1. INTRODUCTION

Water is one of the most important resources used by mankind. Competition for increasingly precious water resources has intensified dramatically over the past decades, reaching a point where water quality degradation and aquatic ecosystem destruction are seriously affecting prospects for economic and social development as well as ecosystem integrity. In the industrial sector, application of cleaner production is being promoted by the government through regulations and incentives. The ISO standard also helps by pushing for wider application of clean industries so that they can be competitive in the world market.

Water, which has been utilized and discharged from domestic dwellings, institutions and commercial establishments (known as domestic wastewater) together with water discharged from manufacturing industries (known as industrial wastewater), contains a large number of potentially harmful compounds [1]. A significant event in the field of wastewater management was the passing of the US Federal Water Pollution Control Act Amendments of 1972 often referred to as the Clean Water Act (CWA). The CWA not only established national goals and objectives, but also marked a change in water pollution control philosophy [2].

Biological treatment is used primarily to remove the biodegradable organic substances in wastewater. Microorganisms are used for the degradation of the organic matter and the stabilization of organic wastes. Most of the microorganisms present in wastewater treatment systems use the organics in the wastewater as an energy source to grow, and are thus classified as heterotrophs from a nutritional point of view. Basically, these substances are converted into gases that can escape into the atmosphere [3].

There has been a steady evolution and development in the methods used for wastewater treatment. One such new method is the magnetic field effect. The use of a magnetic field on wastewater treatment has been attempted and the result shows an increased removal of chemical oxygen demand (COD). There are only a few studies that use the magnetic field for wastewater treatment processes, and in most cases, the magnetic field is only used for separation of solids or attached microorganisms from effluents[3]. However, there is an important observation here, the biological activity increased with the application of magnetic field. Therefore the main objective of this project is to determine the removal of the chemical oxygen demand under the influence of the magnetic field.

CHAPTER 2. THEORETICAL BACKGROUND

2.1 Role of Microorganisms in Wastewater

Microorganisms are used to oxidize dissolved and particulate organic matter in wastewater into simple end products and additional biomass. Microorganisms use polluting materials in wastewater as a source of food for growth. The sludge can then be removed from the wastewater by settling and the liquid effluent is discharged from the treatment plant to the receiving body.

Wastewater provides an ideal growth medium for a large number of different microorganisms. These microorganisms play a key role in all stages of biological wastewater treatment. Biological processes use microorganisms, which are mostly bacteria, to separate, concentrate, or detoxify the waste. Microorganisms play a major role in decomposing waste organic matter, removing carbonaceous Biological Oxygen Demand (BOD), coagulating non-settable colloidal solids, and stabilizing organic matter [3].

The type of bacteria found in wastewater can be aerobic and anaerobic. Aerobic bacteria use oxygen to breakdown complex organic substances into water (H_2O), carbon dioxide (CO_2), and release energy. For example, aerobic respiration involves the use of aerobic bacteria in the breakdown of organic matter in wastewater. Therefore anaerobic bacteria can't live in the presence of oxygen. They get energy through oxidation and reduction of food. Facultative bacteria have enzymes that use oxygen or other oxygen containing materials as the oxidizing agent to oxidize the food to get energy [4]. There are some specific bacteria, which are capable of oxidizing ammonia (nitrification) to nitrate and nitrite, while other bacteria can reduce the oxidized nitrogen to gaseous nitrogen. In phosphorus removal, biological processes are configured to encourage the growth of bacteria with the ability to take up and store large amounts of inorganic phosphorus.

There are different means of microbial classifications including nutritional type, oxygen requirements and temperature. To sustain reproduction and proper function, microorganisms require an energy source, a carbon source for synthesis of new cellular materials and inorganic nutrients such as nitrogen, phosphorus, sulfur, potassium, calcium, and magnesium. Autotrophs can make their own organic compounds by using an inorganic carbon source. Unlike autotrophs, heterotophs cannot make their own organic compounds [3].

Microorganisms are classified into three groups according to the temperature range in which they function best as they display a wide variety of responses to temperature. In general, bacteria that grow best at lower than 20°C are identified as psychrophiles. Bacteria that grow well at a temperature greater than 45°C are called thermopiles. Microorganisms growing best between 20°C and 45°C are referred to as mesophiles [5]. The optimum temperature for most microorganisms involved in wastewater treatment is 35°C and it is generally recognized that the rate of growth doubles with every 10°C increase in temperature up to some limiting temperature [6].

2.2 Chemical Oxygen Demand (COD)

Different tests can be conducted to determine the amount of organic content that is present in the wastewater. Gas chromatography and mass spectroscopy are used when dealing with small concentrations of organic matter in the range of 5 to 10 g/L. Biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC) methods are used when dealing with organic matter that has concentrations greater than 1 mg/L [7]. The simulated wastewater used in this project contained organic matter with a concentration greater than 1 mg/L and so the COD method was used in this project.

From an operational standpoint, one of the main advantages of the COD test is that it can be completed in about 2.5 hours compared to 5 or more days for the BOD test. To reduce the time further, a rapid COD test that takes only about 15 minutes has been developed [7].

The COD test is used to measure the oxygen equivalent of the organic matter that can be oxidized chemically using dichromate in an acid solution, illustrated in the following equation.

$$\text{Organic matter } (C_aH_bO_c) + (Cr_2O_7^{-2}) + H^+ \xrightarrow[heat]{catalyst} Cr^{+3} + CO_2 + H_2O$$

There are two methods to determine the COD.

- **The open reflux method:** Suitable for a wide range of wastes where a large sample size is preferred.
- **The closed reflux method:** More economical in the use of metallic salt reagents. It generates smaller quantities of hazardous waste, but requires homogenization of samples containing suspended solids to obtain reproducible results.

2.3 Seeding

Seeding material is often added to wastewater to allow a large population of aerobic bacteria to be present in the wastewater. A sample from a lake, stream, or sewage treatment plant does not need a seed since the water contains a large population of aerobic bacteria. However, industrial wastes need to be seeded. Seeding is done to ensure enough bacteria are present in the sample in order to oxidize the organic material. The seed consists of a mixed culture of microorganisms that can oxidize organics [8]. Non-chlorinated treatment plant's secondary effluent or raw sewage can be used for seeding, however, the most effective seeding are commercially prepared lyophilized bacteria called Polyseed® [9]. The use of Polyseed® will give the most reliable results and was used as seeding for this project.

2.4 Biological Treatment

A number of physical, chemical, and biochemical processes are used in the environmental engineering field. Physical unit processes require methods involving the use of physical forces. Chemical processes involve the additions of chemicals to remove or convert contaminants from wastewater. Some examples of chemical processes are precipitation, absorption and disinfection. Biological processes involve using biological treatment to remove biodegradable organic substances in wastewater [10]. The three stages involved in the biological treatment of wastewater are primary, secondary and tertiary (advanced) treatments.

2.4.1 Primary Treatment

A physical operation is used to remove the floating and settable material in wastewater. This process is the first step to treat wastewater. Untreated wastewater initially enters a primary treatment process. In the primary treatment, a bar screening is usually used to remove large objects and insoluble particles that can damage the treatment plant. Wastewater then enters a large settling basin. Due to gravity, sedimentation occurs during which the solids settle at the bottom to form sludge, while oil and grease remain on the top and are removed by a skimmer. Primary treatment only removes $1/5^{th}$ of biological treatment demand and hardly any dissolved mineral. This is the least effective method of treatment [10].

2.4.2 Secondary Treatment

Secondary treatment involves removing the remaining organic molecules that are leftover from the primary treatment process. A biological process is commonly used to remove organic matters. The effluent is brought into contact with oxygen, and aerobic microorganisms break down the organic matter. The combination of primary and secondary treatment can remove 90% of the biodegradable organic substance in wastewater.

The two main methods used for the secondary treatment are a suspended growth process and a fixed film process [5].

2.4.2.A. Suspended Growth Method - Activated Sludge

The activated sludge process is a continuous or semi-continuous (fill and draw) aerobic method for the biological wastewater treatment including carbonaceous oxidation and nitrification. This process was developed in England in 1914 by Ardern and Lockett. The process is based on the aeration of wastewater with flocculating biological growth followed by separation of treated wastewater from this growth [11].

The clarified wastewater discharged from the primary clarifier is delivered into the aeration basin where it is mixed with an active mass of microorganisms and oxygen.

The oxygen is provided by using either aerators or diffusers. The aerobic environment in the reactor was achieved by the use of diffusional or mechanical aeration, which also serves to maintain the mixed liquor in a completely mixed regime. After a specified period of time, the mixture of new cells and old cells was passed into a settling tank where the cells are then separated from the treated wastewater. A portion of the settled cells is recycled to maintain a desired concentration of organisms in the aeration tank [12]. The activated sludge process is demonstrated below in Figure 2-1: -

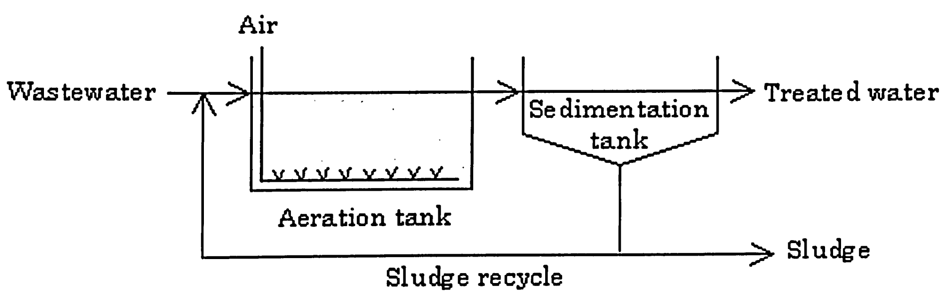

Figure 2-1 Schematic diagram of an activated sludge system [13]

Advantages of Activated Sludge Process:

1) Flexible - can adapt to minor pH, organic and temperature changes.
2) Small area required.

Disadvantages of Activated Sludge Process:

1) Generates solids requiring sludge disposal.

2) High operation costs (skilled labour, electricity, etc)

2.4.2.B. Suspended Growth Method - Lagoon

Aerated lagoon is a shallow basin, between 2 m and 5 m deep with a large surface area, which receives a continuous flow of wastewater. Oxygen is usually supplied by means of surface aerators or diffused air units. Suspended growth aerated lagoons are operated on either a flow-through basis or with solids recycled. Lagoons are fitted with a liner to prevent seepage, and have aerators to supply air at all depths.

The classification of a lagoon depends on the oxygen availability in the lagoon. For example, aerobic lagoons are 0.3048 m to 1.524 m in depth and are kept aerobic by mechanical mixing while facultative lagoons are 0.9144 to 2.7432 m in depth and have no forced aeration, which results in an upper, middle, and lower layer. The upper layer operates aerobically; the lower level operates anaerobically, while the middle layer contains facultative bacteria [10].

Advantages of Lagoons:

1) They use less energy than most of the wastewater treatment methods.

2) They are simple to operate and maintain.

3) They are very effective at removing disease-causing organisms (pathogens) from wastewater.

Disadvantages of Lagoons:

1) The system requires more land than any other system.

2) They are less efficient in cold climates and may require additional land.

3) They are not effective in removing heavy metals from wastewater.

2.4.3 Fixed Film Method - Trickling Filter

The trickling filter has been used to provide biological wastewater treatment for nearly 100 years. The trickling filter is an attached-growth biological process that uses an inert medium to attract microorganisms, which forms a film on the surface medium. The wastewater is distributed over the filter, trickles down the filter and is collected at the bottom of the filter bed. Figure 2-2 provides a schematic diagram of the trickling filter process: -

When the film thickness increases, the region of the film near the medium surface can be deprived of organic matter, reducing the adhesive ability of the microorganisms. Therefore, a thick film is more susceptible to the sloughing effect caused by wastewater flow

Many conventional trickling filters using rock as packing material have been converted to plastic packing to increase treatment capacity. Virtually all new trickling filters are now filled with plastic packing.

Two or more trickling filters may be connected in series, and the sewage can be

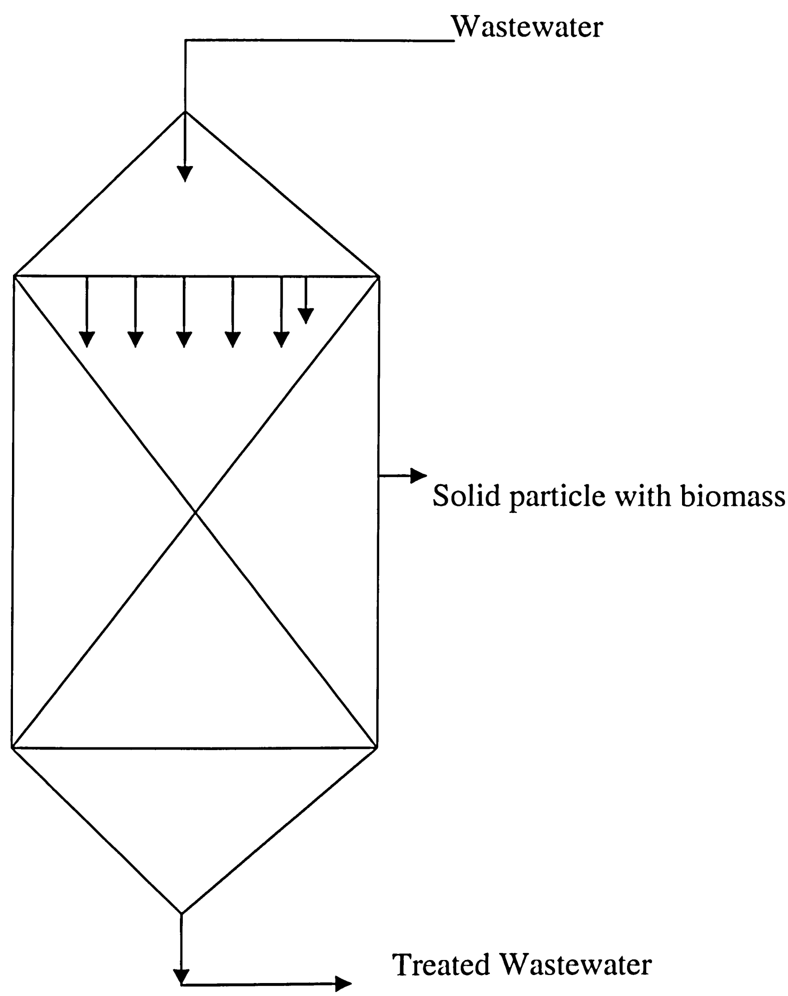

Figure 2-2 Schematic diagram of a trickling filter

re-circulated in order to increase treatment efficiency. In predicting the performance of a trickling filter, organic and hydraulic loading, and the degree of treatment required are among the important factors that must be considered. This technology is not very effective in treating wastewater with a high concentration of soluble organic compounds [10].

2.5 Tertiary Treatment Process

Primary and secondary treatment processes remove the majority of the BOD and solids in the wastewater. The tertiary process removes any remaining nitrates, phosphates and heavy metals that are leftover from the primary and secondary treatment processes. These inorganic compounds can cause eutrophication of the surface water receiving the effluent, due to algae growth. Unlike the primary treatment process, tertiary treatments are usually chemical processes [5].

CHAPTER 3. LITERATURE REVIEW

3.1 Effect of pH on the COD Removal

Celebi and Yavuz [14] studied the effect of magnetic field on the activity of activated sludge in wastewater treatment. The medium pH and the direct current (DC) magnetic field strength were changed in the ranges of 6.0 to 8.5 and 8.9 to 46.6 mT, respectively. There was maximum substrate removal rate at magnetic field strength 17.8 mT and any further increase in magnetic field decreased the substrate removal rate. The highest substrate removal and microorganism growth rates were noted in the system at pH 7.5. Also at pH 7.5 it was noticed that the substrate removal rate difference was at its maximum when experiments were conducted with or without magnet fields.

3.2 Magnetic Field Effect

The use of the magnetic field is one of the new methods involved in the purification of wastewater methods. The application of magnetic fields for different purposes has become very popular due to its considerable advantages such as protein recovery, cell filtration, enzyme immobilization, fermentation, affinity chromatography, microbial and plant cell culture processing, and biological wastewater treatment processes [15]. These are promising examples of magnetic field applications. Though the general purpose of magnetic field application in biological treatment systems is the separation of immobilized microorganisms from the liquid phase, it has also been shown that magnetic field application has considerable effects on microbial activity and system performance directly [14].

Numerous studies have been carried out "on the effect of magnetic field on living organisms, but the results are usually conflicting. Although some of them shows a negative effect most of them show an enhancement in growth because the effect depends on the strength of the magnetic field [15.a and 15.b]. Although the reason for this effect has not yet been understood in detail yet, it is obvious that by applying a magnetic field, there is an increase or decrease in the growth rate of microorganisms... [16]". One such method was carried out by using a magnetic field on activated sludge in wastewater treatment in a batch reactor system.

The effect of a magnetic field on wastewater treatment with a fluidized bed biofilm reactor was investigated by Celebi and Yavuz [14]. The activated sludge was obtained as a seed from a real wastewater treatment plant. Using the fluidized bed biofilm, magnetic field application allowed the operation of the column at high liquid flow rates, thus by lowering the external diffusion limitations on the biofilm surface the efficiency of biodegradation was increased. Denser, thinner, and more active biofilm was obtained with magnetic field application, especially in pulsed form. The system performance changed with operational parameters, and the increase in substrate removal reached up to 26% with pulsed application of a 17.8mT DC-magnetic field under optimum conditions where incubation was performed at 30 ^{0}C for 24 hours under aseptic condition with 10 % inoculums [14].

Bio-particles tend to agglomerate along the magnetic field lines at intensities higher than 35.5mT and cause a short passing through the bed and finally the fluidization is hindered. The main difficulty lies in maintaining uniform fluidization throughout the bed especially at high liquid flow rates. This can be overcome by using magnetically loaded polymeric particles as support material for a biofilm and operating the column under a magnetic field.

CHAPTER 4. EXPERIMENTAL METHOD

4.1 Materials

The characteristics of microorganisms seeds used in the present study are shown in table 4.1 the microorganisms were packed in capsules, from INTER LAB, Texas.

Table 4-1 Characteristics of microorganisms used [9]

Specific Gravity	4.1. – 5.8
Particle Size	1.588 mm
Moisture (%Wet Wt.)	6% - 12%

Magnet used - Eclipse Magnetic, England

Table 4-2 Specification of magnetic field

Power Magnet 813 – RB	90 mT (11.8 Kg pull)
Dimensions	30mm W. 30mm H. 45mm L.

4.2 Preparation of simulated wastewater

The simulated wastewater used in this experimental study was prepared with sugar, polyseed® and distilled water. The composition of the wastewater is shown in table 4.3 below.

Table 4-3 Composition of the wastewater

Ingredients	Amount used
Microorganisms	3 Capsules
Water	24 and 30 liters
Sugar	5 and 30 grams

4.3 Experimental setup

Simulated wastewater was circulated through an apparatus as shown in Figure 4.1. A pump was used to pump the simulated wastewater from the liquid reservoir through the magnetic field and back to the liquid reservoir. A rotameter was used to measure the flow rate through the system (Dwyer Instrumentation Inc Michigan USA.). Air was supplied to the bottom of the liquid holding tank. PVC pipe of 3.1725 cm inside diameter was used for the main stream and for the by-pass. The only exception was the part between the two sampling outlets, which was made of copper. A magnetic field was applied between the two sampling outlets i.e. on the copper pipe of 40 cm. For different experimental runs at varied liquid volumetric flow rates, 90mT of magnetic field was applied just below outlet 2. A picture of the actual experimental setup is displayed in Figures 4.2.

4.4 Experimental Procedure

Prior to any experimental run, the apparatus was cleaned with distilled water. Distilled water was flushed through the system for at least one hour and then drained.

In order to evaluate the effect of magnetic field and liquid flow rate, the experiments were carried out at varied liquid volumetric flow rates with and without the application of magnetic field. A total of 10 runs were conducted in this study. The experiments were carried out for different liquid volumetric flow rates such as 6.7×10^{-5}, 1.2×10^{-4}, 2.0×10^{-4}, 2.6×10^{-4}, and $3.3 \times 10^{-4}\ m^3s^{-1}$.

A seeding material called Polyseed® was introduced into the wastewater. The quantity of sugar and stimulated wastewater used are given below. The experiment was conducted with no seeding and in some runs the seeding material was added after five minutes of the experimental run. Five (5) grams and thirty (30) grams of sugar were used. Two quantities of simulated wastewater were used - 24 liters and 30 liters respectively.

Three capsules of Polyseed® were added to the wastewater for each run. Aeration was applied to the bottom of the tank. As the wastewater was continuously flowing throughout the experimental setup for 54h duration, samples of the wastewater were taken at the beginning of the experiment and at 1, 6, 24, 30, 48 and 54 hours. The collected samples were then vacuum filtered, and then subjected to COD testing.

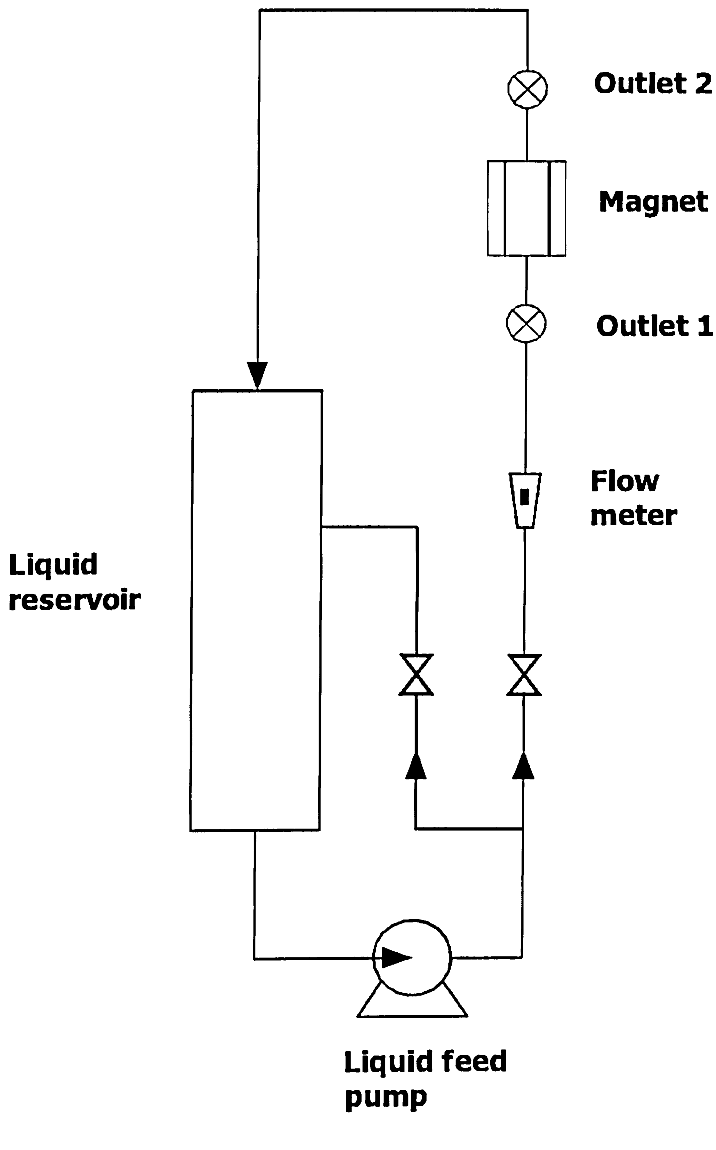

Figure 4-1 Diagram of the experimental setup

Figure 4-2 Front view of the experimental setup

4.5 Chemical Oxygen Demand (COD) Analysis

The COD analysis of wastewater involves a series of steps to be followed. The COD determination was done by closed reflux colorimetric method. The procedure for this method was done according to the manufacturer's (Orbeco-Hellige, Farmingdale, New York) instructions. The method specified was for mid-range COD concentrations in the range of 20 to 900 mg/l.

At least 30 minutes prior to COD measurement, the COD digester (Bioscience, Inc.) is turned on to achieve a temperature of $150 \pm 2^0 C$. The wastewater sample is filtered to remove any bio-film or other suspended organic matter present that would result in a positive bias of the COD results. Vacuum filtration with a Buchner funnel and low ash 32 Whatman filter paper were used. 2.5 ml of the filtered sample was then added to the COD vial (Bioscience, Inc.) and heated at $150 \pm 2^0 C$ for 2 hours. Upon cooling to room temperature, the COD concentration was determined. Since the COD readings appeared to fluctuate, it was difficult to obtain an accurate reading. As a result, multiple readings were obtained [7].

CHAPTER 5. RESULTS AND DISCUSSION

5.1 Effect of Liquid Flow Rate on COD Removal

First the baseline experiment is defined and after that the variations of each parameter is described and the impact of these variations on the COD removal is highlighted. All the experiments were run for a duration of 54 hours with samplings at 6 hour intervals. The COD removal rate decreased with increasing run time; however, after run time (54h), there was not much decrease in COD removal. Therefore 54 hours was chosen as the maximum run time for all the experiments. The experiments were conducted to determine the effect of the magnetic field on the removal of COD for different liquid volumetric flow rates. Table 5.1 shows different runs conducted under varied conditions.

During the baseline experiment without the application of the magnetic field or seeding the volumetric flow rate was 3.3×10^{-4} m^3s^{-1} and the duration of the experiment as explained above was 54 hours. The results showed a negligible COD removal of only 6 mg/L over 54 hours. The magnetic field was then applied with all the other parameters identical to the baseline experiment. The COD rate increased to sixteen. Further, a new parameter was added, that is, the introduction of seeding. Seeding increased the COD removal rate by more then 225% with respect to the baseline experiment and showed a positive influence on the COD removal. This resulted in the use of seeding for all further experiments. In the next trial two parameters were varied viz. the sugar was replaced with glucose and the magnetic field was also applied. However the experiment results showed a negligible increase in the COD removal rate when glucose was used. Hence for further experiments glucose was replaced with sugar.

Table 5-1 COD removal after 54 hours of treatment at different volumetric flow rates.

Run	Amount of Seeding	Sugar grams	Magnetic Field 90mT (11. 8 Kg pull)	Volumetric flow rate m^3s^{-1}	COD Removal mg/L
1	No Seeding	5	Not Applied	3.3×10^{-4}	6
2	No Seeding	5	Applied	3.3×10^{-4}	16
3	Seeding at 0 hour	5	Not Applied	3.3×10^{-4}	20
4	Seeding at 0 hour	12*	Applied	3.3×10^{-4}	21
5	Seeding at 0 hour	30	Not Applied	3.3×10^{-4}	22
6	Seeding at 0 hour	30	Applied	3.3×10^{-4}	29
7	Seeding at 0 hour	30	Applied	2.6×10^{-4}	33
8	Seeding at 0 hour	30	Applied	2.0×10^{-4}	35
9	Seeding at 0 hour	30	Applied	1.2×10^{-4}	38
10	Seeding at 0 hour	30	Applied	6.7×10^{-5}	40

* Glucose was used for this run

Further experiments were conducted with the variation of the flow rate. The flow rate was roughly reduced to 0.6×10^{-4} m^3s^{-1}. With every step in reduction in the flow rate the COD removal increased by a few percentages this can be seen in Figure 5.1 and 5.2.

Considering all the tests conducted in this project, it is seen that a magnetic field will have more effect compared to other flow rates on microorganisms when the flow rate is 6.7×10^{-5} m^3s^{-1}. Thus by providing enough time, per pass for a magnetic field to act on microorganisms there-by increases the COD removal rate [7].

Table 5.2 shows the legends that are used in Figures 5.1, 5.2, 5.5 and 5.6. As explained before, the COD removal rate for different conditions is depicted in the bar graph of Figure 5.3 and 5.4.

Table 5-2 Experimental conditions for different runs

Run	Conditions
2	With aeration, sugar, magnetic field, No polyseed, Flow rate = 3.3×10^{-4} m^3s^{-1}
3	With aeration, sugar, no magnetic field, polyseed, Flow rate = 3.3×10^{-4} m^3s^{-1}
4	With aeration, glucose, magnetic field, polyseed, Flow rate = 3.3×10^{-4} m^3s^{-1}
5	With aeration, sugar, no magnetic field, polyseed, Flow rate = 3.3×10^{-4} m^3s^{-1}
6	With aeration, sugar, magnetic field, polyseed, Flow rate = 3.3×10^{-4} m^3s^{-1}
7	With aeration, sugar, magnetic field, polyseed, Flow rate = 2.6×10^{-4} m^3s^{-1}
8	With aeration, sugar, magnetic field, polyseed, Flow rate = 2.0×10^{-4} m^3s^{-1}
9	With aeration, sugar, magnetic field, polyseed, Flow rate = 1.2×10^{-4} m^3s^{-1}
10	With aeration, sugar, magnetic field, polyseed, Flow rate = 6.7×10^{-4} m^3s^{-1}

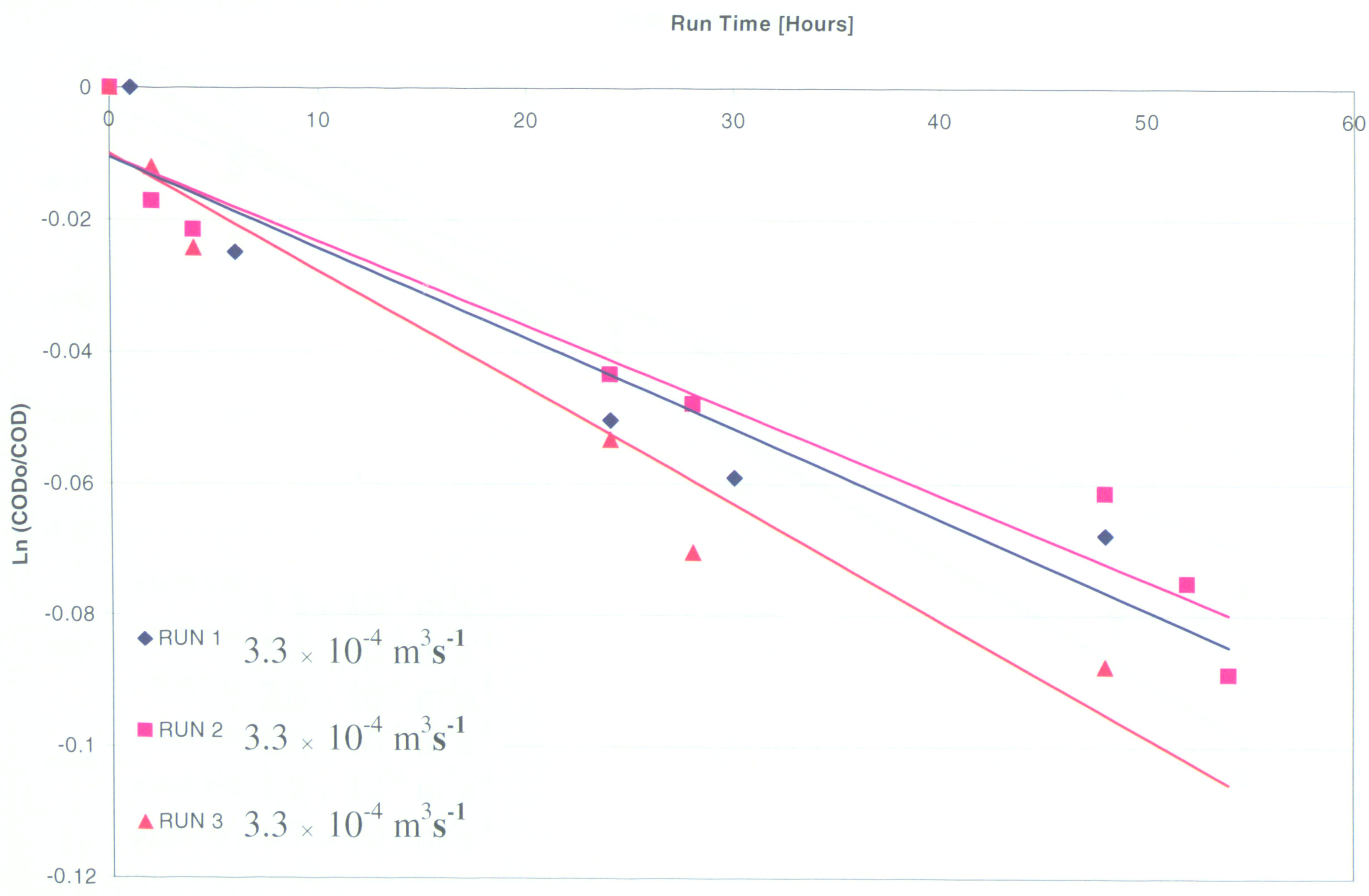

Figure 5-1 COD remaining vs. Run time for different flow rates

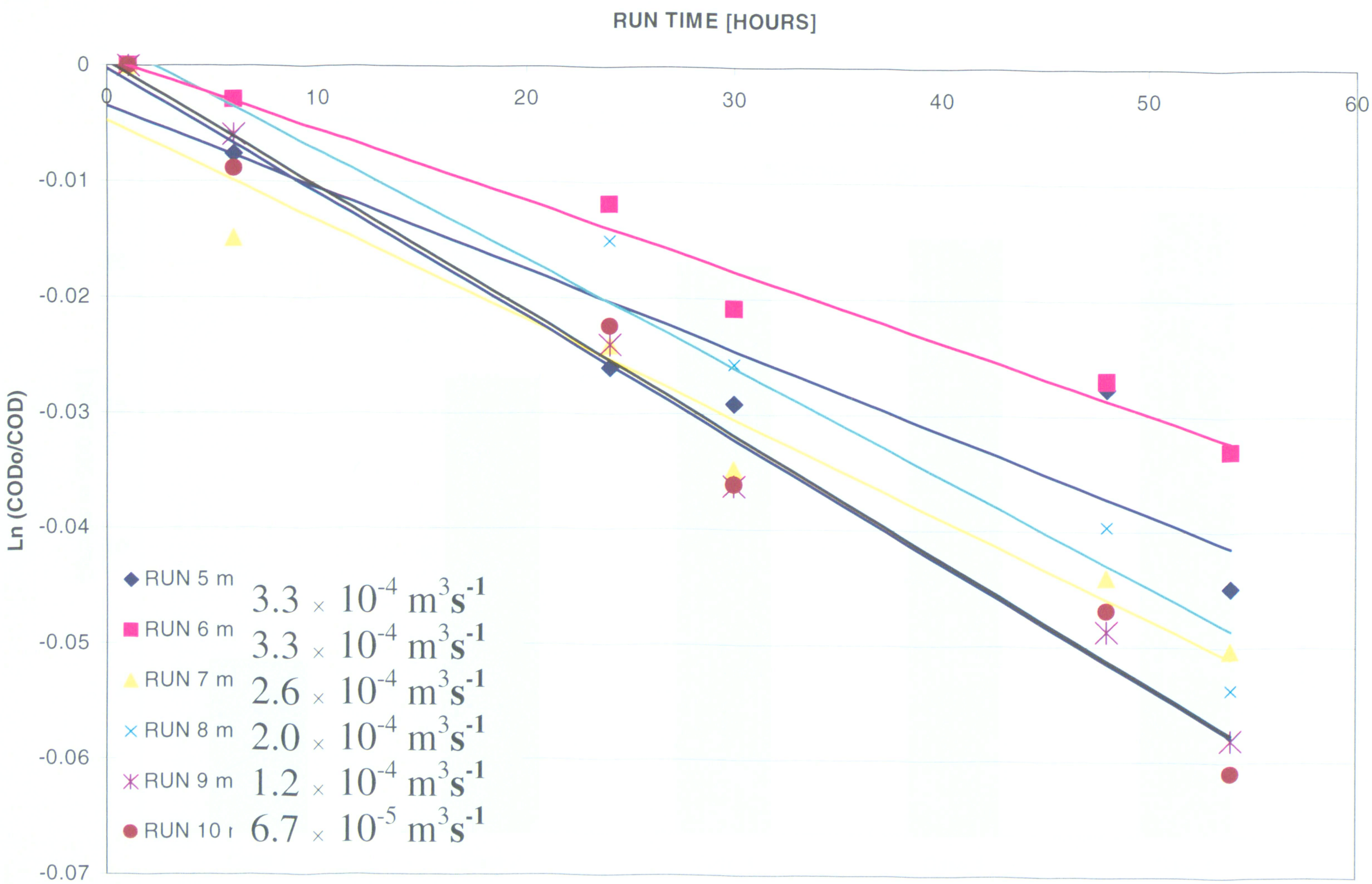

Figure 5-2 COD remaining vs. Run time for different flow rates

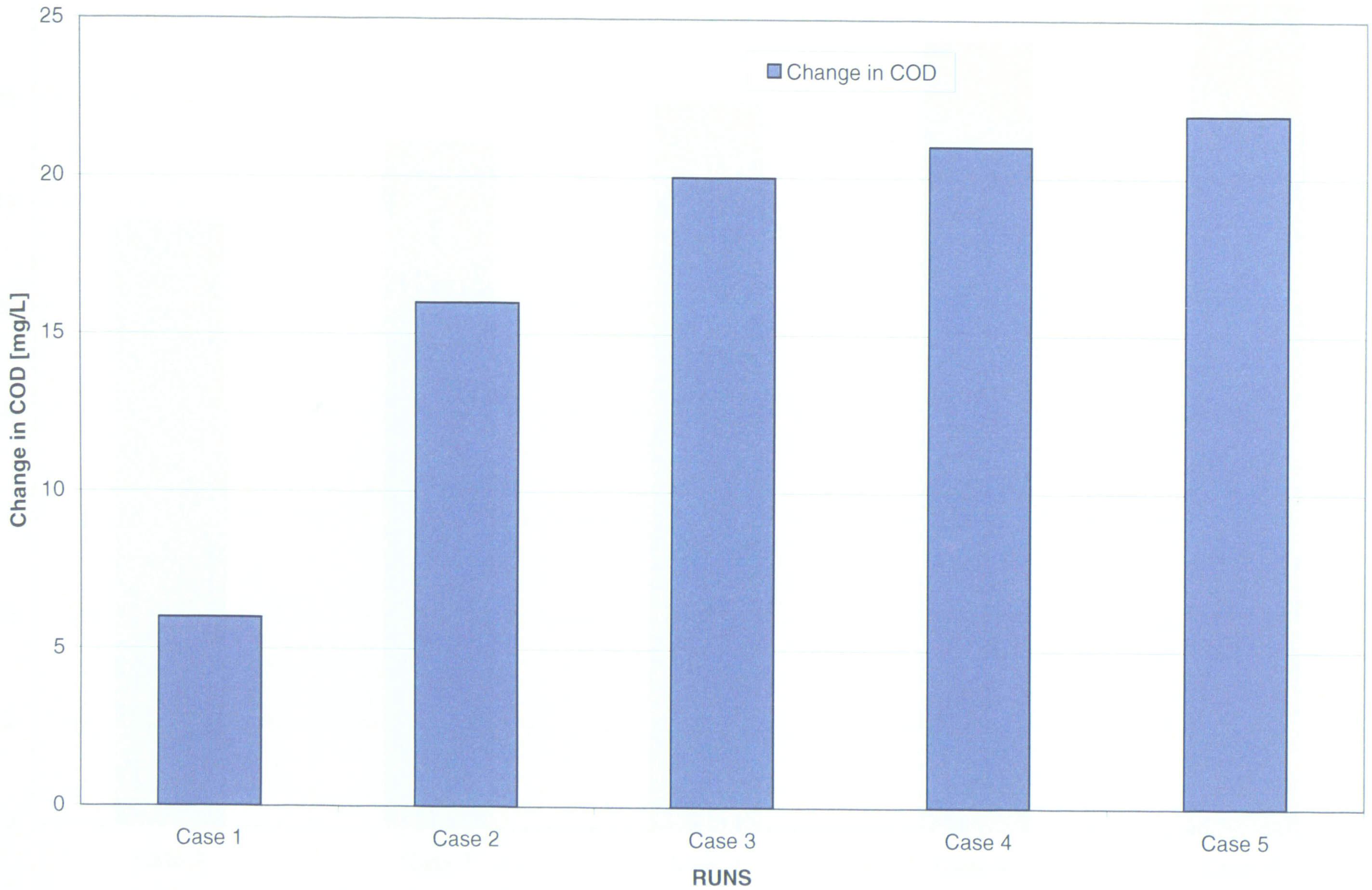

Figure 5-3 COD removal for different conditions as shown in table 5.1

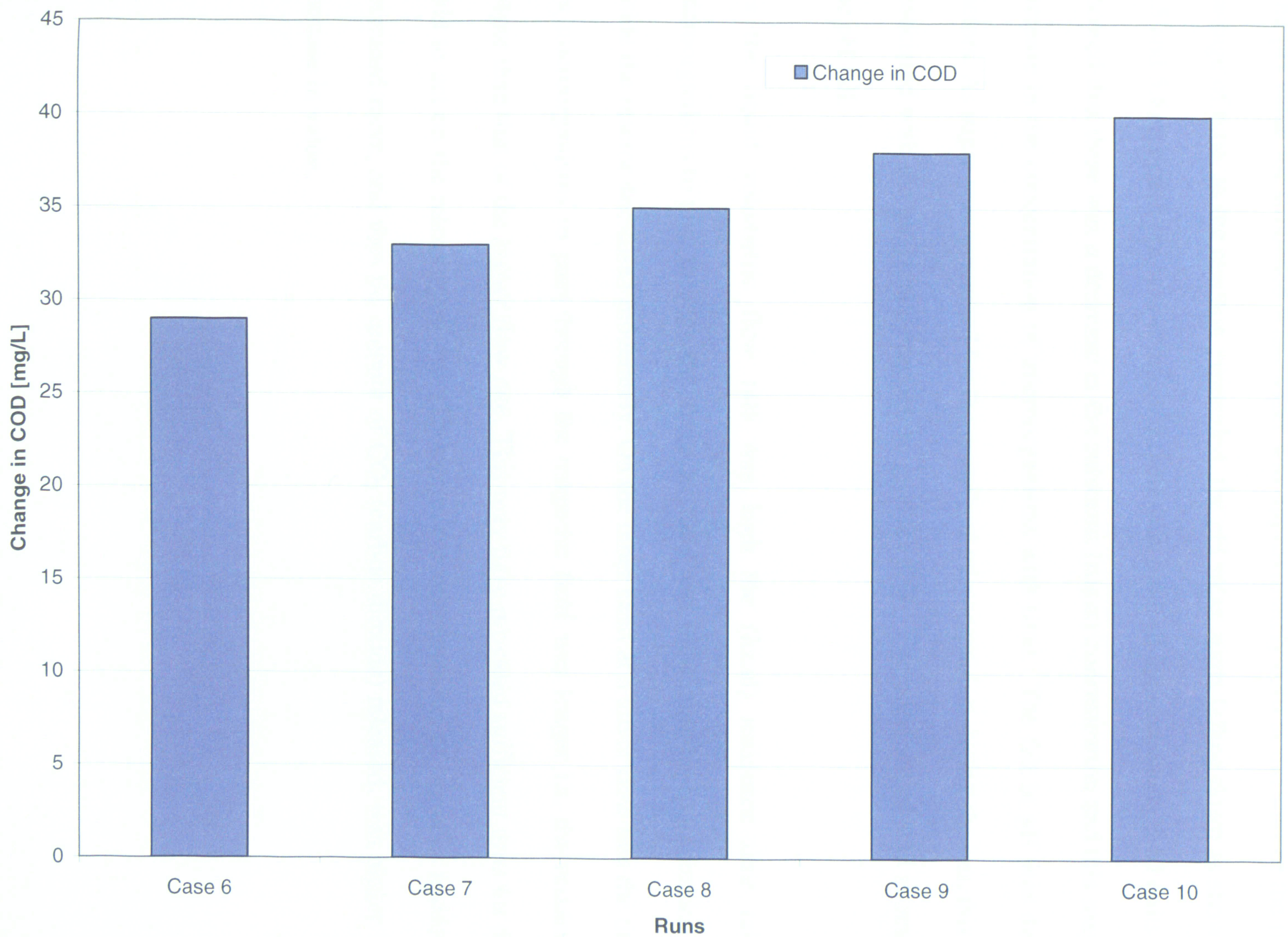

Figure 5-4 COD removal for different conditions as shown in table 5.1

5.2 Variation of pH with treatment time

The pH value for simulated wastewater was approximately 6.40 at the start of the run. With the passage of time, as the reaction proceeded, the pH value starts falling down as shown in Figures 5.5 and 5.6. As each run was completed there was a fall of approximately 0.60 units. The results showed that there was a decrease in the substrate (sugar) concentration and this may lead to the increase in the concentration of microorganisms with time. The fall in pH was due to several factors. As sugar was consumed for the growth of microorganism during the run, this growth was associated with the enzymatic reaction to produce CO_2. The presence of acid is responsible for the pH fall.

As the liquid volumetric flow rate was high the (local) residence time taken by the microorganisms to pass through the magnetic field was short, and the concentration of organics inside the reactor decreased moderately. On the other hand at a lower flow rate the time taken by the microorganisms to pass through the magnetic field was longer i.e. the resident time was longer than that of the higher flow rate. This may have provided sufficient time for the magnetic field to act on the microorganisms. Therefore, the concentration of organics inside the reactor decreased more, and thus the amount of CO_2 (carbon dioxide) released, was higher leading to a decrease in value.

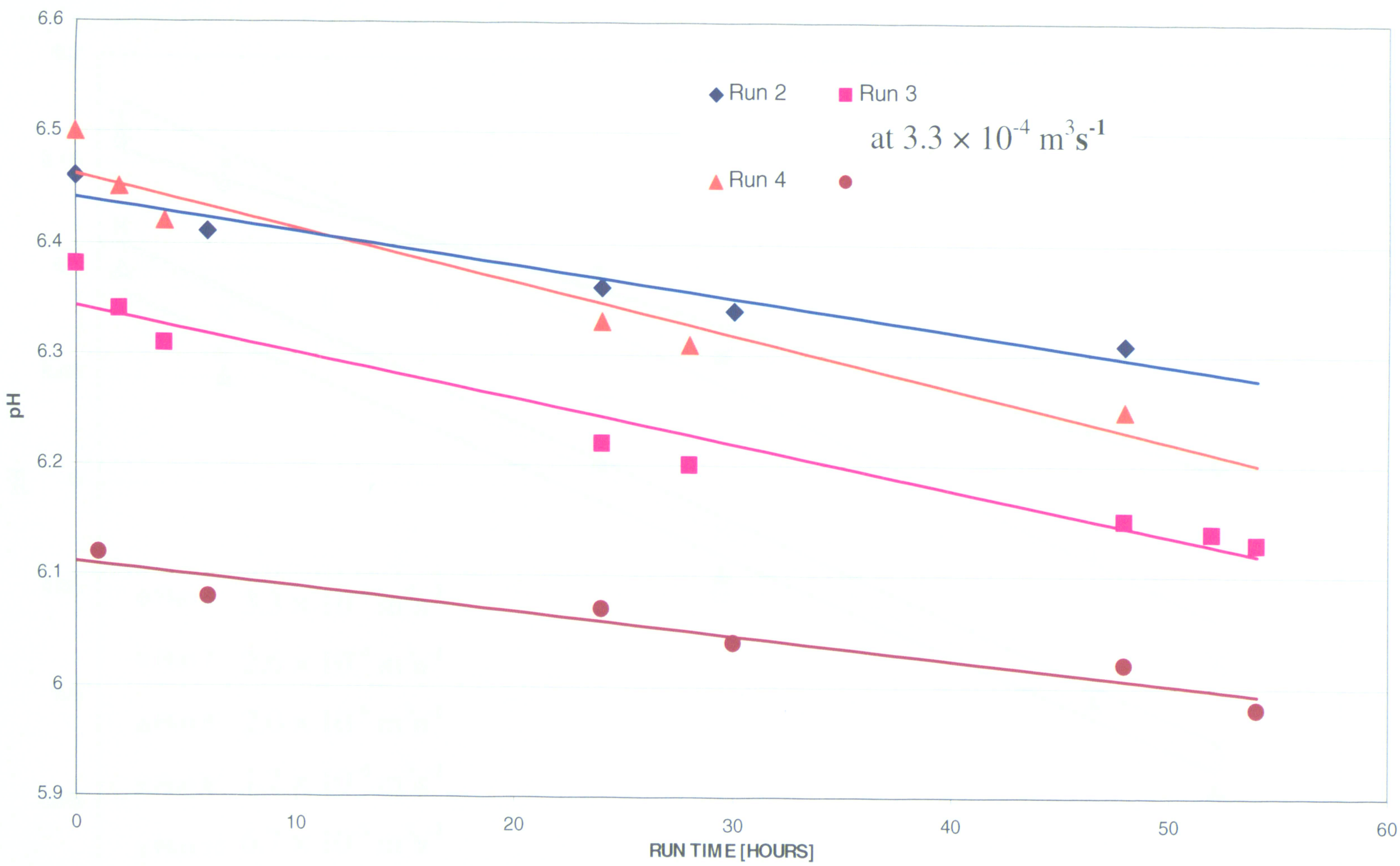

Figure 5-5 Effect of flow rate on pH of simulated wastewater

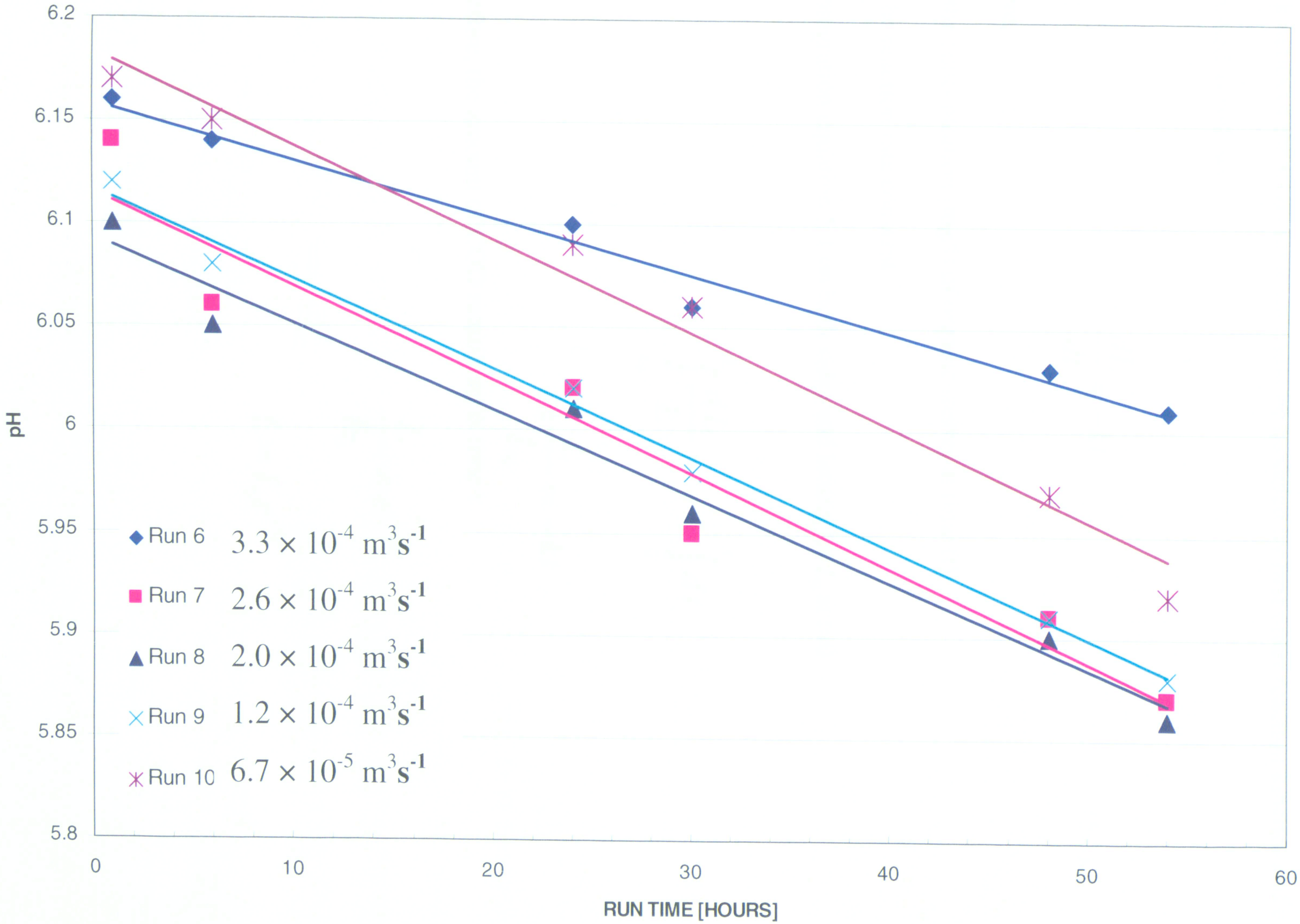

Figure 5-6 Effect of flow rate on pH of simulated wastewater

5.3 Kinetic Model for COD

The kinetics of the COD removal could be modeled by first order reaction kinetics and can be expressed as follows:

$$\frac{dL}{dt} = -kt \qquad (5.1)$$

Where,

L is the concentration (mg/l) of organic matter at time (t)

k is the reaction rate constant

By integration equation 5.1 on both sides and letting L= L_0 at t=0

$$\int_{L_0}^{L} \frac{dL}{L} = -k \int_{0}^{t} dt$$

$$\ln \frac{L}{L_0} = -kt$$

Therefore, the amount of COD remaining at time t:

$$\frac{L}{L_0} = e^{-kt}$$

$$L = L_0 e^{-kt}$$

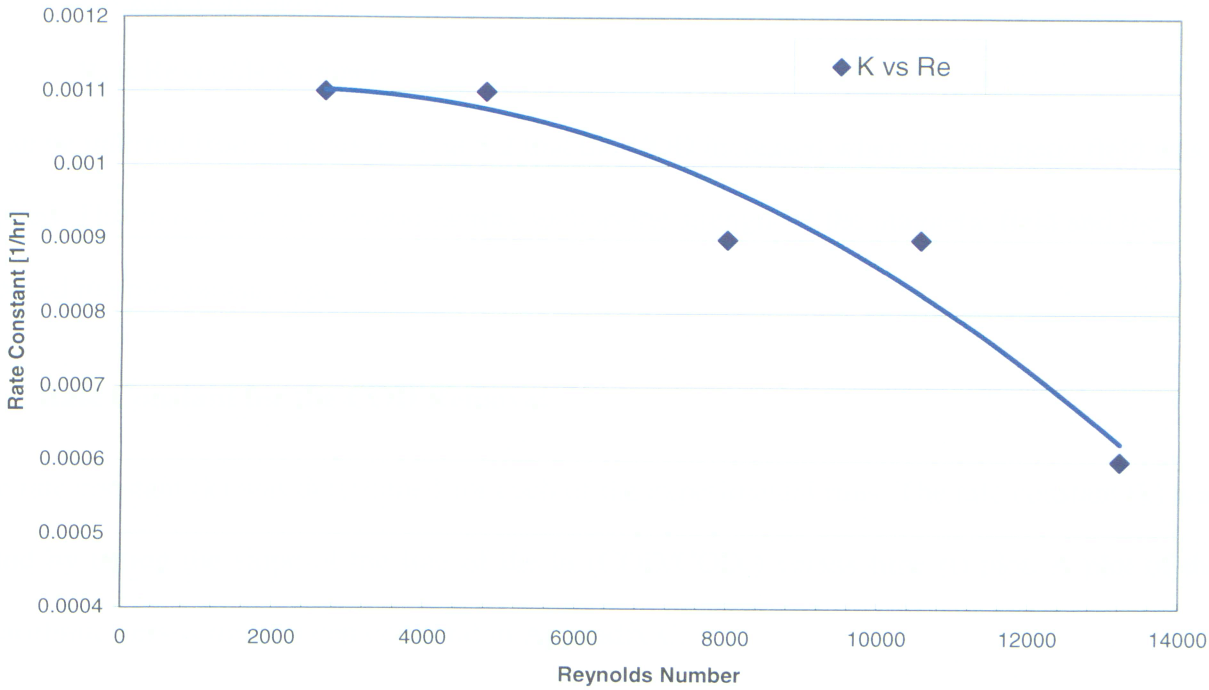

Figure 5-7 Variation of rate constant with Reynolds number

Figure 5.7 shows that as the flow rate (i.e. the Reynolds number) increases the overall rate constant decreases. The overall rate constant depends on two factors, one is due to suspended biomass in the tank and the other is the magnetic field. Air is supplied at the bottom of the reactor causing circulatory motion of the gas-liquid-solid mixture in the reactor. The circulation velocity was a strong function of the supplied gas flow rate. As a result, the content of the reactor was intensely mixed.

The above figure shows that the polynomial correlation fits the experimental data significantly with $R^2 = 0.9373$. This polynomial correlation between K and R_e can be written as

$$K = -4\times10^{-12}\,R_e^{\,2} + 2\times10^{-8}\,R_e + 0.0011$$

Where,

K= Rate constant [hr^{-1}]

R_e = Reynolds Number

It can be inferred from Figures 5.1 and 5.2 that the COD increased when the magnetic field was applied. This may be due to several factors such as the strength of the magnetic field and the exposed microorganism type.

5.4 Rate Constant for the COD Removal

The rate constant (k) was determined for each of the experimental runs. The rate constant (k) was found by taking the slope of the line of the ln (COD/COD_0) versus time (t) plot. A plot of the logarithmic versus time (t) can be found in Appendix C.

Table 5-3 Rate constant (k) for the COD removal at different operational conditions

Run	Reynolds Number	Rate Constant k (hr^{-1})
6	15095	0.0006
7	12451	0.0009
8	9889	0.0009
9	6686	0.0011
10	3879	0.0011

From table 5.3 the rate constant depends on the flow rate

Table 5-4 Comparison of substrate removal

Experimental Results of the present study		Yavuz et. al. (1999)	
Runs	Substrate Remaining (mg/L/h)	Runs	Substrate Remaining (mg/L/h)
Magnetic field	0.4167	Magnetic field	6.1
No magnetic field	0.708	No magnetic field	5.8
Percentage increase*	70 %	Percentage increase*	5.17 %

* Percentage increase in the substrate removal when the magnetic field was applied.

In the present study the substrate concentration was maintained at 1000 mg/ L. Yavuz et al [14] conducted an experiment to study the effects of the magnetic field on the activity of activated sludge in wastewater treatment using synthetic wastewater. The experiments were conducted for two cases (i) with magnetic field and (ii) without magnetic field. Sugar was used as the substrate at a concentration of 10000 mg/L. Yavuz et al reported that the substrate removal rate increased about 5.17 % after approximately 8 hours of treatment while in the present study 70 % increase in the COD removal was observed after 52 hours of treatment.

5.5 Biochemical Oxygen Demand (BOD_5)

To complement the above experiments a Biochemical oxygen demand (BOD_5) experiment was also done in the course of this project. This experiment was conducted on wastewater sample identical to the Run 9 COD experiment sample. The BOD_5 tests were performed according to Standard Methods for the Examination of Water and Wastewater [16]. A complete set of data is provided in tables along with sample calculation in Appendix E.

Theoretically BOD would be zero for non-biodegradable compounds. For biodegradable compounds, the value of BOD will tend to approach COD as the test period increases. Other factors which affect the BOD are concentration and nature of organic matter, concentration and type of bacteria in the waste water.

Various factors affect the oxygen requirement (BOD_5 measurement) of organic substances in wastewater for a period of time, such as temperature, concentration of organic matter, nature of organic matter, concentration and type of bacteria in the wastewater. The amount of BOD_5 is measured in the unit of mg/L.

In the process of 3 day experiment of COD, wastewater sample was taken from holding tank for every 24 h interval. The same sample of wastewater was used to run BOD_5 and results were tabulated in Appendix E. From the results obtained, the percentage BOD_5 versus treatment time[h] graph is presented in Figure 5-8. BOD_5 removal was increased to about 62.16% after 5 days.

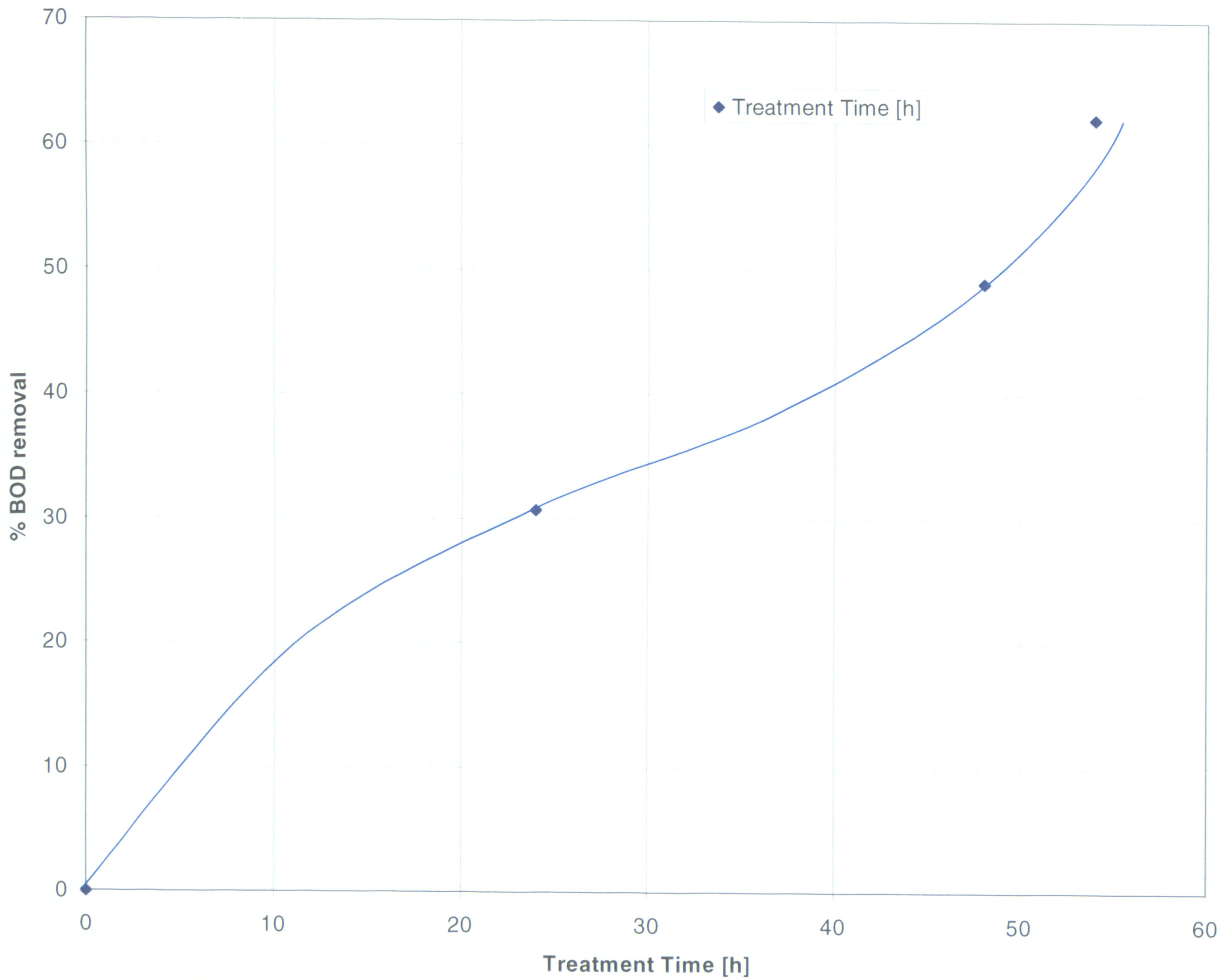

Figure 5-8 Effect of BOD removal of the Wastewater at a fixed volumetric flow rate of 0.000067 m3 s-1.

CHAPTER 6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

An experimental investigation was done to study the effect of magnetic field on the COD removal during wastewater treatment. A total of 10 runs were conducted by varying the volumetric flow rates from $3.3\text{x}10^{-4}$ to $6.7\text{x}10^{-5}$ m^3s^{-1}. Results showed that the magnetic field had a positive influence on the COD removal. The maximum amount of COD removal occurred when the liquid volumetric flow rate was 6.7×10^{-5} m^3s^{-1}. However the effectiveness of this technique was reduced when the volumetric flow rates were increased.

6.2 Recommendations

The following recommendations are proposed following this study: -

1) Place the individual magnets at different locations.
2) Replace the copper pipe used in the above experiments with a spiral pipe.

REFERENCES

1. Liu, H.F. D, Liptak, G.B (2000) Wastewater Treatment: Second Edition, McGraw- Hill, New York, pp.125- 128.
2. Verschueren, K., (1983) Handbook of Environmental Data on Organic Chemicals: Fourth Edition, Wiley Interscience, New York. pp 647-649.
3. Tchobanoglous, G., (1991) Wastewater Engineering Treatment, Disposal, and Reuse: Third Edition, McGraw- Hill, Boston, pp139-145, 403-429.
4. Guyer, H.H, (1998) Industrial Processes and Waste Stream Management: First Edition., John Wiley & Sons, New York, pp. 87-94.
5. Techobanoglous, George (2003) Wastewater Engineering Treatment, Disposal and Reuse: Fourth Edition, McGraw-Hill, Bostan, pp 10-12, 890-930, 930-940, 1608-1621.
6. Stanley Associates Engineering Ltd. (1979) Biological Treatment of Food Processing Wastewater Design and Operations Manual, Water Pollution Control Directorate, Environmental Protection Service, Environment Canada, pp. 29-31
7. American Water Works Association (AWWA) (1998) Standard Methods for Examination of Water and Wastewater: 20th Edition, water pollution control federation. American Public Health Association, New York.
8. Droste, L.R, (1997) Theory and Practice of Water and Wastewater Treatment: First Edition., J.Wiley, New York, pp.145-156.
9. Polyseed®, website (Frequently asked questions);

   http://www.polyseed.com/html/faq/JM-polyseedfaq.htm#c1

10. Horan, N. J, (1990) Biological wastewater treatment systems theory and operation: First Edition, John Wiley and Sons, New York, pp. 310-316.

11. Drinan, E., (2001) Water & Wastewater Treatment, a Guide for the non-Engineering Professional: Technology Publishing company, Inc, Pennsylvania, pp 133-137.

12. Arden, E., Lockett, W.T. (1914) Experiments on the Oxidation of Sewage without the Aid of Filters: Journal of science, Chemical Industries., pp. 33, 523.

13. http://www.chiyoda-corp.com/ activated sludge.

14. Yavuz, H, Celebi, S.S, (2000) "Effect of magnetic field on activity of activated sludge in wastewater treatment. Enzyme and Technology," Enzyme and Microbial Technology, Vol. 26, pp. 22-27.

15. Yavuz, H, Celebi, S.S, (2003) "A typical application of magnetic field in wastewater treatment with fluidized bed biofilm reactor," Chemical Engineering Communications, Vol. 190, pp. 599-609.

15.A. Moore RL. (1979) Biological Effects of Magnetic Field: Studies with Microorganisms. Canadian Journal Microbiol, Vol.25: pp.1145-51.

15.B Ramon C, Martin JT, Powel MR. (1987) "Low-level, Magnetic-field induced growth modification of Bacillus subtilis," Bioelectromagnetics.Vol. 8, pp.275- 82.

16. Renzo, D.J. (1981) Pollution Control Technology for Industrial Wastewater: Noyes Data Corporation, USA. pp. 356-403.

17. H. D. Doan and M.E. Fayed (2006) Process measurements lab manual: Ryerson University, department of chemical engineering.

APPENDIX A

Experimental Results

Run 1 – Liquid flow rate at 0.00033 m^3s^{-1}, without using sugar, magnetic field, aeration and Polyseed®.

RUN TIME (HOUR)	COD mg/L
1	677
4	676
24	674
28	672
48	671

Run 2 – Liquid flow rate at 0.00033 m^3s^{-1}, using sugar, magnetic field, aeration without Polyseed®.

RUN TIME (HOUR)	COD mg/L
1	244
6	238
24	232
30	230
48	228

Run 3 – Liquid flow rate at 0.00033 m^3s^{-1}, using polyseed®, sugar, aeration, without magnetic field.

RUN TIME (HOUR)	COD mg/L
0	235
2	231
4	230
24	225
28	224
48	221
52	218
54	215

Run 4 – Liquid flow rate at 0.00033 m^3s^{-1}, using Polyseed®, glucose, aeration, and magnetic field

RUN TIME (HOUR)	COD mg/L
0	250
2	247
4	244
24	237
28	233
48	229

Run 5 – Liquid flow rate at 0.00033 m^3s^{-1} using sugar, aeration, without magnetic field, but no Polyseed®.

RUN TIME (HOUR)	COD mg/L
1	661
6	656
24	644
30	642
48	643
54	632

Run 6 – Liquid flow rate at 0.00033 m^3s^{-1} using polyseed®, sugar, aeration, magnetic field.

RUN TIME (HOUR)	COD mg/L
1	677
6	675
24	669
30	663
48	659
54	655

Run 7 – Liquid flow rate at 0.00026 m^3s^{-1}, using Polyseed®, sugar, aeration, and magnetic field

RUN TIME (HOUR)	COD mg/L
1	673
6	663
24	657
30	650
48	644
54	640

Run 8 – Liquid flow rate at 0.00020 m^3s^{-1}, using Polyseed®, sugar, aeration, and magnetic field

RUN TIME (HOUR)	COD mg/L
1	670
6	666
24	660
30	653
48	644
54	635

Run 9 – Liquid flow rate at 0.00012 m^3s^{-1}, using seeding, sugar, aeration, and magnetic field

RUN TIME (HOUR)	COD mg/L
1	674
6	670
24	658
30	650
48	642
54	636

Run 10 – Liquid flow rate at 0.000067 m^3s^{-1}, using seeding, sugar, aeration, and magnetic field

RUN TIME (HOUR)	COD mg/L
1	677
6	671
24	662
30	653
48	646
54	637

APPENDIX B

Run 2 – pH vs. Run time at a liquid flow rate of 0.00033 m^3s^{-1}, using sugar, magnetic field, aeration without Polyseed®.

RUN TIME [Hr]	pH
0	6.46
6	6.41
24	6.36
30	6.34
48	6.31

Run 3 – pH vs. Run time at a liquid flow rate of 0.00033 m^3s^{-1}' using sugar, aeration Polyseed® without magnetic field

RUN TIME [Hr]	pH
0	6.38
2	6.34
4	6.31
24	6.22
28	6.2
48	6.15
52	6.14
56	6.13

Run 4 – pH vs. Run time at a liquid flow rate of 0.00033 m^3s^{-1}, using Glucose, magnetic field, aeration and Polyseed®

RUN TIME [Hr]	pH
0	6.5
2	6.45
4	6.42
24	6.33
28	6.31
48	6.25

Run 5 – pH vs. Run time at a liquid flow rate of 0.00033 m^3s^{-1}, was used using sugar, magnetic field, aeration and Polyseed®.

RUN TIME [Hr]	pH
1	6.12
6	6.08
24	6.07
30	6.04
48	6.02
54	5.98

Run 6 – pH vs. Run time at a liquid flow rate of 0.00033 m^3s^{-1}, using sugar, aeration Polyseed® without magnetic field.

RUN TIME [Hr]	pH
1	6.16
6	6.14
24	6.10
30	6.06
48	6.03
54	6.01

Run 7 – pH vs. Run time at a liquid flow rate of 0.00026 m^3s^{-1}, using sugar, magnetic field, aeration and Polyseed®.

RUN TIME [Hr]	pH
1	6.14
6	6.06
24	6.02
30	5.95
48	5.91
54	5.87

Run 8 – pH vs. Run time at a liquid flow rate of 0.00020 m^3s^{-1}, using sugar, magnetic field, aeration and Polyseed®.

RUN TIME [Hr]	pH
1	6.1
6	6.05
24	6.01
30	5.96
48	5.9
54	5.86

Run 9 – pH vs. Run time at a liquid flow rate of 0.00012 m^3s^{-1}, using sugar, magnetic field, aeration and Polyseed®.

RUN TIME [Hr]	pH
1	6.12
6	6.08
24	6.02
30	5.98
48	5.91
54	5.88

Run 10 – pH vs. Run time at a liquid flow rate of 0.000067 m^3s^{-1}, using sugar, magnetic field, aeration and Polyseed®.

RUN TIME [Hr]	pH
1	6.17
6	6.15
24	6.09
30	6.06
48	5.97
54	5.92

APPENDIX C

E-1 Calculation of Reynolds Number

Once the dynamics viscosity and density were calculated, the Reynolds numbers for different volumetric liquid fluxes were calculated from the equation below [17]. The density of the wastewater was found to be 999.83 kgm^{-3}.

$$R_e = \frac{\rho u D}{\mu}$$

Density = ρ =999.83 $kg.m^{-3}$

Viscosity = μ = 0.00089 $kg.m^{-1}.s^{-1}$

Diameter of the pipe = D= 3.2×10^{-2} m

$$Re = \frac{999.83x\ 0.4718\ x\ 3.2X10^{-2}}{0.001}$$

$$Re = 15095$$

K [hour^{-1}]	Re
0.0006	15095
0.0009	12451
0.0009	9889
0.0011	6686
0.0011	3879

In this experiment, a stormer rotating – cylinder viscometer, in which the inner cylinder rotates was used. The procedure is as follows:-

1. Fill the outer cylinder (a container) with a solution to the top of the baffle.
2. Raise the container, which is holding the solution all the way up.
3. Rewind the string holding a weight with the release knob in "open" position.
4. Turn the release knob to allow the weight to fall.
5. Measure the time- t- it takes the rotating cylinder to rotate n revolutions. Record the time t in seconds and n. The number of revolutions per second is N=n/t
6. Using the equation for viscosity (measured by the viscometer with the inner cylinder rotating) [17];

$$\mu = \frac{M.g.a.D}{8.\pi^2.r_1^3.L.N}$$

Where: μ = dynamic viscosity (kg/m.s)

M = mass of weight (kg)

g = gravitational acceleration (9.81 m/s^2)

a = radius of wound drum (m)

D = (r_2-r_1) that is the gap between the inner and outer cylinders (m).

L = length of the inner cylinder submerged in solution (m).

N = number of revolutions of the inner cylinder per second.

r_1 = the outside radius of the inner cylinder cylinder (m).

r_2 = the inside radius of the outer cylinder (m).

APPENDIX D

BIOCHEMICAL OXYGEN DEMAND (BOD5) CALCULATIONS

From the Equation:

$$BOD_5 = \frac{(D_1 - D_2) - (B_1 - B_2)f}{P}$$

Where,

D1 = Initial dissolved oxygen of diluted sample (immediately after preparation), mg/L

D2 = Final dissolved oxygen of diluted sample (after 5-day incubation at 20°C), mg/L

B1 = Initial dissolved oxygen of seed control (before incubation), mg/L

B2 = Final dissolved oxygen of seed control (after 5-day incubation), mg/L

f = fraction of the volume of the seed solution added to wastewater sample bottle to the volume of seed solution added to the seed control bottle.

P = fraction of wastewater sample volume to total combined volume

Flow rate: 0.000067 m^3s^{-1}

Amount used: 30 liters + 30 grams of sugar + 3 capsules of Polyseed® + Magnet

Table: Experimental data and BOD5 results, with 30L simulated wastewater, Liquid volumetric flow rates of 0.00012 m^3/s.

Treatment Time [day]	Treatment Time [h]	DO_1 [mg/L]	DO_2 [mg/L]	B_1 [mg/L]	B_2 [mg/L]	BOD_5 [mg/L]	BOD_5 [mg/L]	BOD_5 [mg/L]
0	0	8.97	5.45	9.57	9.41	252.063	260.69	0.00
		8.87	5.12	9.47	9.36	269.31		
1	24	9.33	5.98	9.49	9.42	246.06	180.60	30.72
		9.63	6.17	9.42	9.30	250.56		
2	48	9.32	7.97	9.45	9.38	129.78	133.16	48.93
		9.54	7.65	9.43	9.36	136.53		
3	54	9.52	8.03	9.46	9.37	105.02	98.64	62.16
		9.64	8.14	9.53	9.26	92.27		

Calculation Steps

Step1: The initial BOD5 of the stimulated water (AT 0 h treatment)

$$\text{BOD5,1} = \frac{(8.97-5.45)-(9.57-9.41)\times 1}{(4/300)} = 252.063 \text{ mg/L}$$

$$\text{BOD5,2} = \frac{(8.87-5.12)-(9.47-9.36)\times 1}{(4/300)} = 269.06 \text{ mg/L}$$

Therefore, the average BOD5(BOD5, avg) can then be calculated as follows

$$\text{BOD5, Avg} = \frac{(BOD_{5,1}+BOD_{5,2})}{2}$$

$$= (252.063+269.06)/2$$

$$= 260.69 \text{ mg/L}$$

BOD5 removal

After 24 h treatment, the percentage BOD5 removal was calculated using following equation

$$\%\ \text{BODremoval} = \frac{(BOD_{5,0hrs}-BOD_{5,24hrs})}{BOD_{5,0hrs}}\times 100\%$$

$$= \frac{(260.69 - 180.60)}{260.69} \times 100\%$$

$$= \quad 30.72\%$$

After 48 h treatment, the percentage BOD5 removal is calculated as follows

$$\%\ \text{BODremoval} \quad = \quad \frac{(BOD_{5,0hrs} - BOD_{5,48hrs})}{BOD_{5,0hrs}} \times 100\%$$

$$= \frac{(260.69 - 133.16)}{260.69} \times 100\%$$

$$= \quad 48.92\%$$

After 54 h treatment, the percentage BOD5 removal is calculated as follows

$$\%\ \text{BODremoval} \quad = \quad \frac{(BOD_{5,0hrs} - BOD_{5,54hrs})}{BOD_{5,0hrs}} \times 100\%$$

$$= \frac{(260.69 - 98.64)}{260.69} \times 100\%$$

$$= \quad 62.16\%$$