PERFORMANCE STUDY ON DISSOLVED AIR FLOTATION (DAF) UNIT AND PROCESS PERFORMANCE IMPROVEMENT STUDY IN THE PHYSICO-CHEMICAL TREATMENT OF WASTEWATER

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To my beloved parents and family

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ABSTRACT

From the time of the early 20th century, Dissolved Air Flotation (DAF) had been used in the separation process. In the DAF system, air is dissolved in the wastewater under a pressure of several atmospheres, followed by release of the pressure to the atmospheric level. In this case, the recycle flow system has been studied. For this kind of system, a portion of the DAF effluent is being recycled, pressurized and semi-saturated with air. The main study object is the DAF System in HACO Asia Pacific Sdn. Bhd. In the first stage, process performance improvement study was carried out to determine the most effective operating parameters and conditions of the DAF. Then, a performance monitoring study was continued by operating the DAF in the most effective and optimum condition. Samples were being taken before and after the DAF treatment to determine its pollutant removal efficiency. Results from the performance monitoring study showed that the DAF is able to meet its original design specification of Total Suspended Solids (TSS) removal efficiency up 85%-95%. At a later stage, an emerging design system known as Band-pass Filter (BF) was brought in for a comparative performance study with the DAF system. The BF is intended for mechanical filtering of wastewater in situations where rejections of waste products in connection with processing plants are required. To obtain optimum cleansing, the BF is tuned for the imminent cleansing process. Results from the comparative performance study showed that the BF can achieve a slightly higher average TSS and Chemical Oxygen Demand (COD) removal efficiency, with 93.9% and 49.6% respectively. On the other hand, DAF can achieve a slightly higher average Oil and Grease (O&G) removal efficiency up to 91.9%.

ABSTRAK

Daripada abad kedua-puluhan, "Dissolved Air Flotation (DAF)" telah digunakan dalam proses pengasingan. Di dalam sistem DAF, udara akan dilarutkan dalam air sisa pada tekanan yang tertentu, diikuti dengan pembebasan tekanan udara mengikuti tahap tekanan udara biasa. Di sini, sistem pengedaran pengaliran semula akan dikaji. Bagi sistem ini, sebahagian air daripada rawatan DAF akan diedarkan semula ke dalam sistem, ditambahkan tekanan angin dan dilarutkan separa dengan angin. Bahan kajian utama ialah sistem DAF di HACO Asia Pacific Sdn. Bhd.. Pada peringkat pertama, proses peningkatan prestasi DAF telah dikaji untuk mendapatkan parameter dan keadaan operasi yang paling berkesan. Seterusnya, kajian prestasi DAF telah dilanjutkan pada keadaan operasi yang paling baik dan berkesan. Sampel air sisa sebelum dan selepas rawatan DAF telah diambil dan dianalisis untuk mengenalpastikan keberkesanan pengasingan bahan-bahan pencemar oleh DAF. Keputusan daripada kajian prestasi DAF menunjukkan bahawa DAF berupaya untuk mencapai spesifikasi reka bentuk asalnya yang dapat mengurang "Total Suspended Solids (TSS)" sebanyak 85% - 95%. Pada peringkat akhir, satu reka bentuk terbaru yang dikenali sebagai "Band-pass Filter (BF)" telah dibawa masuk untuk membandingkan prestasinya dengan DAF sistem. BF ini adalah digunakan untuk penapisan air sisa secara mekanikal dalam keadaan di mana penyinggiran bahan-bahan sisa berhubungan dengan kilang pemprosesan adalah ddiperlukan. Untuk mencapai pencucian optima, BF ini telah diubahsuai untuk proses pencucian yang cepat. Keputusan daripada kajian pembandingan prestasi ini telah menunjukkan bahawa BF dapat mencapai purata keberkesanan penyinggiran TSS dan "Chemical

Oxygen Demand (COD)” yang lebih tinggi , iaitu 93.9% dan 49.6%. Manakala, DAF dapat mencapai purata keberkesanan penyinggiran minyak dan gris yang lebih tinggi, dengan bacaan sebanyak 91.9%.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BF	-	Band-pass Filter
BOD_5	-	5-days Biochemical Oxygen Demand
C&F	-	Coagulation and Flocculation
COD	-	Chemical Oxygen Demand
DOE	-	Department of Environment
DAF	-	Dissolved Air Flotation
IESWTR	-	Interim Enhanced Surface Water Treatment Rule
LT1ESWTR	-	Long Term 1 Enhanced Surface Water Treatment Rule
O&G	-	Oil and Grease
P&ID	-	Process and Instrumentation Diagram
SI	-	System International
SBR	-	Sequencing Batch Reactor
SWTR	-	Surface Water Treatment Rule
TSS	-	Total Suspended Solids
US	-	United States
USEPA	-	United States Environmental Protection Agency
WWTP	-	Wastewater Treatment Plant

LIST OF SYMBOLS

%	-	Percent
g/d	-	Gram per day
g/m^3	-	Gram per cubic meter
gpd	-	Gallons per day
kg/d	-	Kilogram per day
lit.	-	Liter
lit./min	-	Liter per minute
$lit./m^2/min$	-	Liter per meter square per minute
lit./hr	-	Liter per hour
lit./d	-	Liter per day
mm	-	Millimeter
m	-	Meter
m^2	-	Meter square
m^3	-	Cubic meter
m^3/hr	-	Cubic meter per hour
m^3/d	-	Cubic meter per day
mg/l	-	Milligram per liter
mL/mg	-	Milliliter per Milligram
^oC	-	Degree of Celsius
sec	-	Seconds

CHAPTER 1

INTRODUCTION

1.1 General Overview in the Environmental Control of Industrial Wastewater

All industrial operations produce some wastewater which must be returned to the environment. In Malaysia, these industries generally include the crude palm oil mills, raw natural rubber factories, rubber-based industry, food and beverage manufacturing industry, wood-based industry, textile industry and etc. Coffee production and manufacturing factory, which can be categorized under the food and beverage manufacturing industry, produce a lot of process wastewater during its production cycle. Unlike the domestic wastewater, this kind of process wastewater does not pose the potential for pathogenic microorganisms, but they do pose potential damage to the environment through either direct or indirect chemical reactions.

Coffee production and manufacturing factories have been long operated in Europe and United States before their production lines started to be shifted to

Malaysia. In the United States, the discharge of process wastewater from this kind of food and beverage industry has fully emphasized on the removal of constituents that may cause long-term health effects and environmental impacts since 1980. In here, the important US federal regulation that govern the control of wastewater issues, and have brought about the changes in the planning and design of wastewater treatment facilities in the US are as follows:

i. Clean Water Act (CWA)(Federal Water Pollution Control Act Amendments of 1972)

⇨ Establishes the National Pollution Discharge Elimination System (NPEDS), a permitting program based on uniform technological minimum standard for each discharger.

ii. Water Quality Act of 1987 (WQA) (Amendment of the CWA)

⇨ Strengthen federal water quality regulations by providing changes in permitting and adds substantial penalties for permit violations.

(U.S.EPA, 1997)

As one of the fast developing countries, Malaysia has also planned and implemented its environmental protection management policy and activities in the control of the industrial wastewater discharge by referring to the control strategies as presently adopted in the US. In Malaysia, the achievements and progress in the works of pollution abatement and control is mainly via the enforcement of pollution control and regulations under the Environmental Quality Act, 1974 carried out by the Department of Environment (DOE). The enforcement of the existing environmental laws and legislation is essential and has been stepped up so as to ensure the capability of the industrial sector, in particular to control the production of environmental pollutants and to practice effective storage and disposal systems. Some technological progress has been noted in treating and controlling pollution resulting from the agro-based industries. However, on the whole, performance records show that the status of compliance of these industries is still far from satisfactory. The problems are attributed to improper management of treatment systems, the use of under-sized system as well as increased milling capacity (Abu Bakar Jaafar, KMN, 1992).

More concerted efforts are needed to curb down pollution problems resulting from all these manufacturing industries. With stricter enforcement of the Environmental Quality (Sewage and Industrial Effluents) Regulations 1979, it is envisaged that the river pollution problems can be minimized. Strict revision on the issuance of contravention licenses made under the Section 22(1) and Section 25(1) of the Environmental Quality Act, 1974 will help to facilitate further the compliance to these regulations. In addition, factors that aggravate or increase non-compliance, such as the incompetence of some waste management consultants in designing effective treatment systems, have been recognized, and efforts initiated to address and resolve these problems. The implementation and enforcement of the mandatory environmental impact assessment (EIA) procedure and requirements under the Environmental Quality (Prescribed Activities)(Environmental Impact Assessment) Order 1987 have been stepped up in tandem with the country's increasing rate of development and inclination to industrialize (Laws of Malaysia, 2003)

1.2 Physico-chemical Treatment of Industrial Waste Water

Premises other than those prescribed (crude palm oil and raw natural rubber mills) i.e. largely manufacturing industries, are subjected to the Environmental Quality (Sewage and Industrial Effluents) Regulations 1979, the Environmental Quality (Clean Air) Regulations 1978 and the Environmental Quality (Scheduled Wastes) Regulations 1989 (Laws of Malaysia, 2003). As a coffee production and manufacturing factory that have a great production capacity, HACO Asia Pacific Sdn. Bhd. should be categorized under a general term known as “Food & Beverages” manufacturing industries.

This kind of industry does contribute significantly to water pollution in the country. Their non-compliance is largely due to the absence of a proper wastewater treatment system, under capacity of the existing treatment system to cater for the increased production capacity of the industry and lack of maintenance of the wastewater treatment system. For the year 1991, about 32 industries have applied for the contravention license under Section 25(1) of the Environmental Quality Act. This constitutes about 39.5 per cent of the total contravention licenses issued under Section 25(1) of the Environmental Quality Act for that year (Abu Bakar Jaafar, KMN, 1992).

In order to implement a proper wastewater treatment system and to avoid any ineffective treatment system design that was mentioned previously, physico-chemical treatment system has always be a wise choice to be adopted in the primary treatment stage. Common physico-chemical treatment systems normally adopted in the wastewater treatment plant design are Dissolved Air Flotation Systems and Sedimentation Tank Systems. Due to advances in the material developing technology, some kind of filtration system known as the Band-pass Filter can even breakthrough the cost constraints and is beginning to be adopted in the primary treatment stage for small WWTP. The main focus of this study is on the DAF which is operated based on the concept of flotation. At the latter part of this thesis, a preliminary study on the BF which functions based on the concept of filtration is also included.

1.2.1 History and Concept of Flotation

Over 2000 years ago, the ancient Greeks used a flotation process to separate the desired minerals from the gangue, the waste material (Gaudin, 1957). Crushed ore was dusted onto a water surface, and mineral particles were retained at the surface by surface tension while the gangue settled. In 1860, Haynes patented a process in which oil was used for the separation of the mineral from the gangue (Kitchener, 1984). The mineral floated with the oil when the mixture was stirred in water.

In 1905, Salman, Picard, and Ballot developed the froth flotation process by agitating finely divided ore in water with entrained air. A small amount of oil was added, sufficient enough to bestow good floatability to the sulfide grains (Kitchener, 1984). The air bubbles, together with the desired mineral, collected as foam at the surface while the gangue settled. The first froth flotation equipment was developed by T. Hoover in 1910 (Kitchener, 1984), and except for size, it was not much different than the equipment used today.

Elmore suggested in 1904 the use of electrolysis to produce gas bubbles for flotation. This process, although not commercially used at that time, has been developed into electrolytic flotation (Bratby, 1976). Elmore also invented the dissolved-air (vacuum) flotation (DAF) process, whereby air bubbles are produced by applying a vacuum to the liquid, which releases the air in the form of minute bubbles (Kitchener, 1984). The original patent for the dissolved-air pressure flotation process was issued in 1924 to Peterson and Sveen for the recovery of fibers and white water in the paper industry (Lundgren, 1976).

1.2.1.1 Type of Flotation Process

Flotation is a unit operation used to separate solid or liquid particles from a liquid phase. Separation is brought about by introducing fine gas (usually air) bubbles into the liquid phase. The bubbles attach to the particulate matter, and the buoyant force of the combined particle and gas bubbles is great enough to cause the particle to rise to the surface. Particles that have a higher density than the liquid can thus be made to rise. The rising of particles with lower density than the liquid can also be facilitated (e.g., oil suspension in water). Different methods of producing gas bubbles give rise to different types of flotation processes. These are electrolytic flotation, dispersed-air flotation, and dissolved-air flotation (Lundgren, 1976).

i. <u>Electrolytic Flotation:</u>

   The basis of electrolytic flotation, or electrolytic flotation, is the generation of bubbles of hydrogen and oxygen in a dilute aqueous solution by passing a DC current between two electrodes (Barrett, 1975).

The bubble size generated in electrolytic flotation is very small, and the surface loading is therefore restricted to less than 4 m/h (13.3 ft/h). The application of electrolytic flotation has been restricted mainly to sludge thickening and small wastewater treatment plants in the range 10 to 20 m^3/h (50,000 to 100,000 gpd).

ii. Dispersed-air Flotation

Two different dispersed-air flotation systems are foam flotation and froth flotation (Sherfold, 1984). Generally, dispersed-air flotation is seldom used in municipal wastewater treatment, but it is used in industrial applications for the removal of emulsified oil and suspended solids from high volume of waste or process waters. In dispersed-air flotation systems, air bubbles are formed by introducing the gas phase directly into the liquid phase through a revolving impeller. The spinning impeller acts as a pump, forcing fluid through disperser openings and creating a vacuum in the standpipe (see Fig. 1.1). The vacuum pulls air (or gas) into the standpipe and thoroughly mixes it with the liquid. As the gas/liquid mixture travels through the disperser, a mixing force is created that causes the gas to form very fine bubbles. The liquid moves through a series of cells before leaving the unit. Oil particles and suspended solids attach to the bubbles as they rise to the surface. The oil and suspended solids gather in dense froth at the surface and are removed by skimming paddles (Tchobanoglous et al, 2003). The advantages of a dispersed-air flotation system are: (1) compact size, (2) lower capital cost, and (3) capacity to remove relatively free oil and suspended solids. The disadvantages of induced-air flotation include higher connected power requirements than the pressurized system; performance is dependent on strict hydraulic control, and less flocculation flexibility. The quantities of float skimming are significantly higher than the pressurized unit: 3 to 7 percent of the incoming as compared to less than 1 percent of dissolved-air systems (Eckenfelder, 2000).

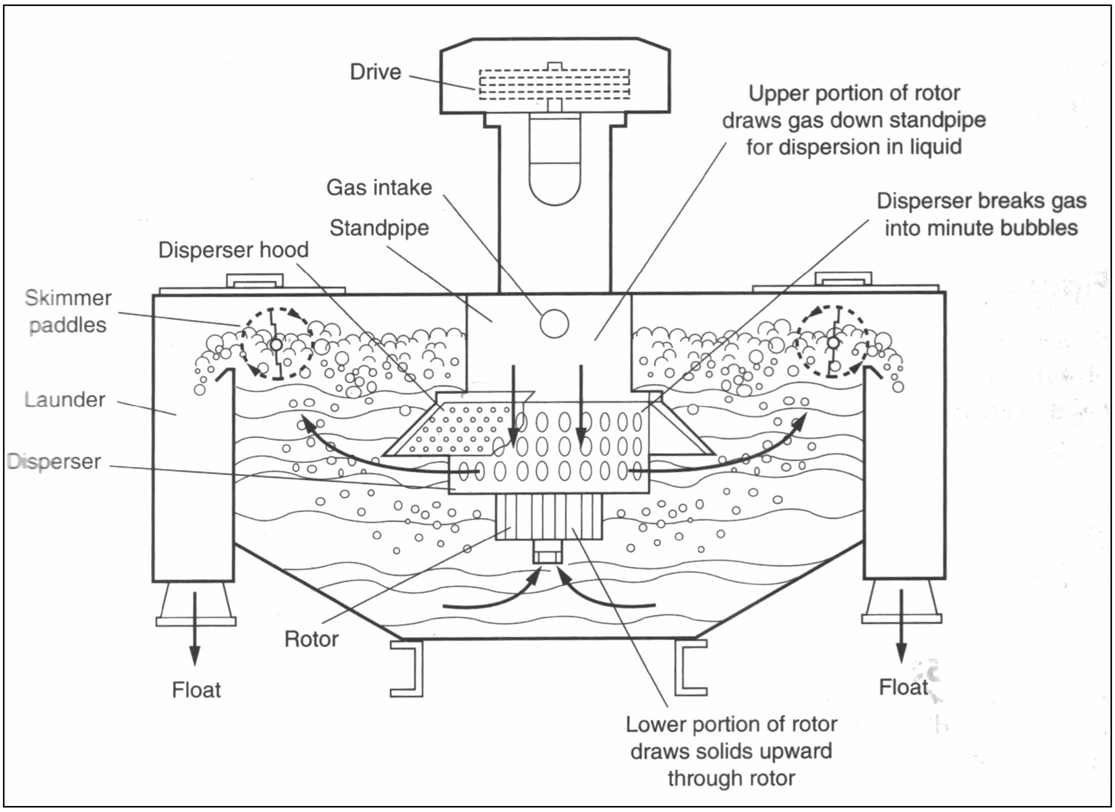

Figure 1.1: Dispersed-air flotation unit. Air is induced and dispersed into the liquid by pumping action of the inductors. (Courtesy Eimco) (Tchobanoglous et al, 2003).

iii. Dissolved Air Flotation (DAF)

There are three main type of DAF, and it is known as vacuum flotation (Zabel and Melbourne, 1980), microflotation (Hemming, Cottrell, and Oldfelt, 1977), and pressure flotation (Barrett, 1975). Of these three, pressure flotation is currently the most widely used. In pressure flotation, air is dissolved in water under pressure. Three basic pressure DAF processes can be used: full-flow, split-flow, and recycle-flow pressure flotation (Zabel and Melt, 1980). For water treatment applications requiring the removal of fragile floe, recycle flow pressure flotation is the most appropriate system. Further details on the DAF description will be explained later in Section 2.4.

1.2.2 History and Concept of Filtration

Filtration is a process that is widely used for removing particulate matter from water. Besides raw water treatment, the filtration concept is beginning to be popularly utilized in wastewater treatment process. In raw water treatment, nearly all surface water treatment facilities and some groundwater treatment facilities employ some form of filtration. Most surface waters contain algae, sediment, clay, and other organic or inorganic particulate matter, and filtration improves the clarity of water by removing these particles. More importantly, all surface waters contain microorganisms that can cause waterborne illnesses, and filtration is nearly always required in conjunction with chemical disinfection to assure that water is free of pathogens. Groundwater is often low in microorganisms and particles but may require filtration when other treatment processes (such as oxidation or softening) generate particles that must be removed. In wastewater treatment, filtration is commonly being used to achieve supplemental removals of suspended solids (including particulate BOD) from wastewater effluents of biological and chemical treatment processes to reduce the mass discharge of solids and perhaps more importantly, as a conditioning step that will allow for the effective disinfection of the filtered effluent.

Filters have been used to clarify water for thousands of years. Medical lore written in India, dating to perhaps 2000 BC, mentions filtration through sand and gravel as a method of purifying water. Venice, Italy, used rainwater stored in cisterns as a freshwater supply but drew the water from wells in sand that surrounded the cisterns (Baker, 1948). In 1852, the first regulation mandating filtration was passed, required all river water supplied by the Metropolitan District of London to be filtered. The regulation was prompted by rampant pollution in the Thames River and suspicions that cholera was transmitted by water (Fuller, 1933), a suspicion confirmed by Dr. John Snow in his famous investigation of a cholera outbreak in London just 2 years later.

In 1880, rapid filtration had its origin in the United States. Elements of modern design, such as mechanical or hydraulic systems to assist with cleaning the media during backwashing, appeared during that decade. The first municipal plant employing coagulation and other critical elements of rapid filtration was in Somerville, New Jersey, in 1885 (Fuller, 1933). Both slow sand and rapid filters were common in early filter installations (Fuller, 1933), but by the middle of the twentieth century, rapid filters were commonplace and slow sand filters were rarely used.

By the latter part of the twentieth century, most surface water was filtered before municipal distribution. Nevertheless, the Surface Water Treatment Rule (SWTR), passed in 1989, was the first regulation in the United States requiring widespread (but not universal) mandatory filtration of municipal water (U.S. EPA, 1989), with the recognition that chemical disinfection alone was ineffective for protozoa such as Giardia lamblia and Cryptosporidium parvum. Rapid filters were used in almost all cases (99 percent), but the SWTR caused a resurgence of interest in slow sand filter, particularly among small utilities that had unfiltered water

Since passage of the SWTR and more recently the Interim Enhanced SWTR (IESWTR) (U.S. EPA, 1998) and Long Term 1 Enhanced SWTR (LT1ESWTR) (U.S. EPA, 2002), finished water turbidity requirements have become more stringent and the remaining utilities with unfiltered surface water supplies have been under increasing pressure to install filtration. In short, filtration is and will continue to be a central feature in surface water treatment plants.

1.3 Problem Statements

DAF, being one of the important physico-chemical separation devices, is being used currently in the primary treatment stage of industrial WWTP at the coffee production factory, HACO Asia Pacific Sdn. Bhd. Since the actual pollutant concentration and loading discharged from the factory is higher than the designed loading, this physico-chemical separation device is facing a great challenge to remove the pollutant concentration up to the expected requirement. Furthermore, due to the upset of the bacteria in the secondary biological treatment system after the DAF treatment at the early stage of the operation, it is very important to ensure a sufficient and consistent pollutant removal before the wastewater is being transferred into the biological treatment system. As such, a process performance improvement study and performance monitoring needs to be carried out on the DAF. Firstly, it is important to carry out a process performance improvement study to maximize the performance of the DAF and to determine the most effective operating parameters; then, to analyze the pollutant concentrations before and after the DAF treatment. The results from this study were very important for the plant designer, i.e. CST Engineering Sdn. Bhd. to propose solutions to the clients.

At the later stage of the study, a newly invented equipment, the Band-pass Filter (BF) test unit will be tested out for its performance. This test unit performs the same functions as DAF and had been brought in by CST from Denmark. A comparative performance study shall be carried out between the DAF and the BF due to the availability of the facility at the site.

1.4 Objectives of the Study

This study is aimed at improving and monitoring the performance of the installed DAF and the existing physico-chemical treatment system and process. The objectives of the study are as follows:-

i. To determine the most effective operating parameters of the existing DAF.

ii. To determine methods to improve the performance of DAF process.

iii. To determine the effectiveness of DAF in the primary treatment stage of the WWTP in the coffee production factory.

iv. To compare the performance effectiveness between the DAF and BF in the primary treatment stage.

1.5 Scope of the Study

The first target of the study was to perform a process performance improvement study on the DAF and to determine the most effective operating parameters. This is to find out all the possible design improvement modification if any. Then, it was followed by a performance monitoring study on DAF. The study consists of a through on-site monitoring works at Haco Asia Pacific's factory at Kota Kemuning, Shah Alam using the installed DAF unit in the wastewater treatment plant. The study shall focus on the determination of the Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS) and Oil and Grease (O&G) reduction efficiencies of the DAF.

At the later stage of the study, a BF test unit shall be brought to HACO Asia Pacific S/B, Shah Alam. A comparative performance study was carried out between the DAF and the BF to compare the removal efficiencies of COD, O&G and TSS.

1.6 Significance of the Study

In the portion of the process improvement study, the results from the study can be used to operate the DAF more effectively and always in the peak performance. These effective operating parameters shall be determined and adjusted during the performance monitoring works.

As previously stated, this performance monitoring study was very important especially in determining the COD, BOD_5, TSS and O&G. before and after the DAF treatment. By measuring and knowing these values, the removal efficiencies can be determined and a judgment can be made on the performance of the DAF unit.

At the later stage of the study, the BF offers a very good opportunity to study an emerging design from overseas. It will give an alternative choice that can be adopted in the WWTP design. More importantly, the results from the comparative performance study between the DAF and BF are very helpful for the project design and management team of CST Engineering Sdn. Bhd. in the WWTP design decision making.