REMOVAL OF IRON AND MANGANESE USING EJECTORS AND ROUGHING FILTER MEDIA

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I hereby declare that all corrections and comments made by the supervisor(s) and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Masalah kualiti air bagi semua sumber air bawah tanah, masalah kualiti air yang paling biasa adalah kehadiran berlebihan besi dan mangan. Kualiti air bawah tanah boleh ditambah baik menerusi proses pelenting dengan cara meningkatkan pemerangkapan udara atau pemindahan jisim oksigen menggunakan pelenting dan proses penapisan dengan menggunakan saiz penapis yang berbeza. Kajian telah dijalankan untuk mengkaji kecekapan pengudaraan dengan menggunakan 2 jenis pelenting yang berbeza dan kecekapan penyingkiran besi dan mangan dengan menggunakan saiz penapis yang berbeza. Pelenting 1 diambil daripada kajian sebelum ini oleh, manakala pelenting 2 direka berdasarkan parameter yang disiasat. Sampel air bawah tanah telah diperolehi daripada Rumah Anak Yatim Nur Kasih, Taiping. Model makmal untuk pelenting telah digunakan untuk proses pengudaraan dan penapis batu kapur digunakan untuk proses penapisan. Dengan menggunakan air bawah tanah, pelenting 1 mampu mencapai kecekapan pengudaraan paling tinggi (E_{20}=0.6005) berbanding pelenting 2 (E_{20}=0.5841). Air bawah tanah didapati mengandungi kecekapan penyingkiran yang paling tinggi untuk besi iaitu 53.4% (kepekatan akhir 1.23 mg/L) dengan menggunakan pelenting 1 dan 89.7% (kepekatan akhir 0.03 mg/L) dengan menggunakan pelenting 2. Bagi mangan pula, kecekapan penyingkiran paling tinggi ialah 50% (kepekatan akhir 0.8 mg/L) dengan menggunakan pelenting 1, manakala untuk pelenting 2 kecekapan pengudaraan paling tinggi ialah 79.3% (kepekatan akhir 1.23 mg/L). Walaupun kepekatan akhir besi dan mangan masih melebihi daripada standard air minuman, iaitu 0.3 mg/L and 0.1 mg/L masing-masing, hasil kajian ini akan menyediakan pengubahsuaian kepada reka bentuk pelenting dan meningkatkan potensinya untuk digunakan sebagai kaedah rawatan untuk air bawah tanah di Rumah Anak Yatim Nur Kasih.

ABSTRACT

From all the water quality problems of groundwater sources, the most common type of water quality problem is the excessive presence of iron and manganese. The quality of groundwater could be improved through aeration process by increasing the air entrainment/mass transfer of oxygen using ejector and filtration process by using different sizes of filter media. An investigation of the ejector was carried out to study the aeration efficiency by using 2 different types of ejector and removal efficiency of iron and manganese by using different sizes of filter media. Ejector 1 was taken from the previous study, meanwhile ejector 2 was designed according to the new parameter investigated. The groundwater samples were obtained from Rumah Anak Yatim Nur Kasih, Taiping. A laboratory model of ejector was used for aeration process and limestone roughing filter was used for the filtration process. Using groundwater, ejector 1 was able to achieve the higher aeration efficiency (E_{20}=0.6005) compared to ejector 2 (E_{20}=0.5841). It was found that the highest efficiency removal for iron was 53.4% (residual concentration of 1.23 mg/L) using ejector 1 and 89.7% (residual concentration of 0.03 mg/L) using ejector 2. For manganese, the highest efficiency removal was 50% (residual concentration of 0.8 mg/L) using ejector 1, meanwhile for ejector 2 the highest was 79.3% (residual concentration of 1.23 mg/L). Although, the residual concentration of iron and manganese were still higher than drinking water standard of 0.3 mg/L and 0.1 mg/L respectively, the results will provide modifications to the design of the ejector and increase its potential to be used as a treatment method for groundwater at Rumah Anak Yatim Nur Kasih.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
DO	Dissolved Oxygen
ESDU	Engineering Science Data Unit
FAO	Food and Agriculture Organization
MOH	Ministry of Health, Malaysia
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

NOMENCLATURES

A_N	Cross Sectional area of nozzles
A_S	Area of suction
A_T	Cross-sectional area of mixing throat
C	Dissolved oxygen concentration
$DO_{d,2}$	Dissolved oxygen concentration downstream of a hydraulic structure
Ci	Initial concentration of the sample at the system inlet
C_o	Final concentration of the sample at the system outlet
C_s	Saturation concentration
$DO_{u,1}$	Dissolved oxygen concentration upstream of a hydraulic structure
D_N	Diameter of ejector nozzle tip
d_n	Diameter of liquid jet nozzle
d_o	Nozzle diameter
D_S	Diameter of suction chamber
D_T	Diameter of mixing throat
E	Aeration efficiency at actual water temperature
E_{20}	Aeration efficiency at 20°C

f	Term to adjust from 20°C to 7°C
g	Gravitational acceleration
L_j	Jet length
l_n	Length of liquid jet nozzle
L_P	Penetration depth of plunging liquid jet
L_T	Length of mixing throat
L_{TN}	Distance between nozzle tip and commencement of mixing throat
m	Mass transfer
PR	Projection ratio L_{TN}/D_T
Q_W	Water flow rate into ejector
T	Water temperature
t	Time
V	Volume of water
v_F	Filtration rate or filter velocity
v_j	Jet velocity at impingement point/ jet impact velocity
v_o	Jet velocity at mixing throat exit
$\theta_{convergent}$	Angle of converging section
$\Theta_{divergent}$	Angle of diverging section

CHAPTER 1

INTRODUCTION

1.1 Background

Ground water is a water under the land surface where it is filling the spaces between grains of sediment and rocks, or filling cracks and fractures in the rocks. roundwater contains iron due to the process of rain filtering through soil, rocks, and minerals. Throughout its descent, the rainwater collects iron from these sources and deposits them in the groundwater. Water acidity and dissolved oxygen play an important role in the quantity of iron collected. Greater acidity and higher levels of dissolved oxygen lead to greater corrosion (Patrick et al., 2011)

Monitoring wells had been established at in Peninsular Malaysia, Sarawak and Sabah. The sites were selected and categorized according to the surrounding land uses which were agricultural, urban/suburban, rural, industrial, solid waste landfills, golf courses, radioactive landfill, animal burial areas, municipal water supply and examining areas (gold mine).

The groundwater quality status was determined based on the National Guidelines for Raw Drinking Water Quality from the Ministry of Health (Revised December 2000) as the benchmark. The groundwater that is extracted from the ground is used for many different purposes such as for drinking, cleaning, bathing, cooking and etc.

For groundwater sources, the most common of type water quality problems is the excessive presence of iron and manganese. Iron is the more frequent of these two contaminants, but they often occur together. High levels of these contaminants can result in discolored water, stained plumbing fixtures, and an unpleasant metallic taste to the water (Tekerlekopoulou & Vayenas, 2007).

According to McFarland (2004), The U.S. Environmental Protection Agency has set Secondary Maximum Contaminant Levels (SMCL) for iron and manganese at 0.3 mg/L and 0.05 mg/L, respectively. SMCLs are standards for substances that are not health hazards. Water that contains less than 0.3 mg/L of iron and 0.05 mg/L of manganese should not have an unpleasant odor, taste or appearance and should not require treatment. For these reasons, it is recommended that drinking water should not have more than 0.3 mg/L (or 0.3 parts per million) of iron and less than 0.05 mg/L of manganese.

Estimates of the minimum daily iron requirement range from about 10 to 50 mg/day depending on physiological status, age, sex and iron bioavailability (FAO/WHO, 1988 cited in WHO, 2003). Therefore, consumption of untreated groundwater would not harm human health. Removal of iron is merely an aesthetic issue (Chaturvedi & Dave, 2012).

Normally natural sources of iron and manganese are more common in deeper wells where the water has been in contact with rock for a longer time. Iron and manganese often occur together in groundwater but manganese usually occurs in much lower concentrations than iron. Both iron and manganese are readily apparent in drinking water supplies. Both impart a strong metallic taste to the water and both cause staining. Water coming from wells and springs with high iron and/or manganese may appear colorless initially but orange-brown (iron) or black (manganese) stains or particles quickly appear as the water is exposed to oxygen (Pennsylvania State University, 2017)

1.2 Problem Statement

In order to provide suitable water resources to the Rumah Anak Yatim Nur Kasih, Universiti Sains Malaysia (USM) has constructed a well of 15 meter depth to extract groundwater to be used as a source of water supply which can help to lower the orphanage home’s water bill. But, the groundwater was found having concentrations of iron and manganese more than drinking water standard which is not suitable for daily consumption. Iron can also cause an orange or brown stain in sinks and in the laundry. Manganese often results in a dense black stain or solid but both of these contaminants are not health threatening.

Removal of iron and manganese can be accomplished by several methods for the treatment of groundwater at Rumah Nur Kasih but the method used must be with low cost and possible to comply with the standards. Most method such as water softening (Ion exchange), oxidizing filter, and electrodialysis are expensive (Chaturvedi & Dave, 2012). The most effective method applied for removal of iron and manganese is oxidation-filtration process. Aeration is known as the low cost treatment process for removing these contaminants from groundwater, which is a relatively sufficient method and not involving any uses of chemicals.

Due to high maintenance and risky for the people on low sodium, ion exchange method is not suitable to be applied. Removal using potassium permanganate greensand filtration is costing and not suitable because the rate of required backwash water is very high. Since it is required large filter size two smaller filters might be substituted so that each can be backwashed separately. For electrodialysis, this process will become clogged by any rust particles, Fe/Mn bacteria, silt etc. The treatment membranes cannot be rejuvenated and new membranes will be necessary thus, this equipment is very expensive to purchase and operate.

The quality of groundwater from the existing tube well could be further improved through the aeration process. It would be an advantage if the ejector could provide surplus of dissolved oxygen to overcome insufficient oxygen demand.

1.3 Objectives

The aims of this study area are:

1. To investigate the effects of different size of filter media used in the filtration process.
2. To determine the percentage removal of iron and manganese with flow rate and jet length.
3. To compare the removal efficiency of iron and manganese from groundwater between 2 different types of ejector.

1.4 Dissertation Outline

This dissertation is organized into 5 chapters. Chapter 1 (Introduction) elaborates the subject, give the problem statement as well as the objectives

Chapter 2 (Literature Review) explained the method of aeration-filtration process for removal of iron and manganese. Literature review focuses on the mechanism of aeration of ejector, plunging jet and diffuser. And also literature review elaborates the filtration process by using limestone as a media with several sizes of media.

Chapter 3 (Methodology) includes the details of research methodology such as design of ejector, the experimental setup for laboratory model, the experimental procedures involved and the selected analysis method.

Chapter 4 (Results and Discussion) presents the results from the present study in terms of aeration efficiency and removal of iron and manganese using filtration. The comparison of the efficiency between two different types of ejector is made to assist for better solution to solve the groundwater problem at Rumah Nur Kasih.

Chapter 5 (Conclusion and Recommendations) summarizes and concluded the results of the study and proposes the recommendations for further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The conventional and most commonly applied for the removal of iron and manganese would be to apply the oxidation-filtration processes, which is a relatively simple process. Water aeration can be achieved through various hydraulic structures, but only the ejector with two different types will be discussed in this chapter. For geometrical design of the ejector, many studies were performed to achieve higher air entrainment and mass transfer and increasing dissolved oxygen concentration.

For this study, the aeration of groundwater forms precipitates thus, insoluble oxides of iron and manganese that would require removal. In the present study, limestone media with two different sizes will be used for filtration process. Therefore, literature review focuses on fundamental roughing filter, operating condition and effectiveness.

The purpose of the present study is to improve groundwater quality using the simplest and most cost-effective ejectors.

2.2 Mechanism of Aeration

Aeration is a low cost of oxidation process using oxygen from the atmosphere as an oxidizing agent and is commonly applied in water treatment process for groundwater purification to improve its chemical and physicals quality. The exchange of air between flowing water and the atmosphere is termed air entrainment, air bubble entrainment or self-aeration. Air bubble entrainment is caused by turbulence fluctuations acting next to the air-water free surface. Through this interface, air is continuously tapped and released. Air entrainment occurs when the turbulent kinetic energy is large enough to overcome both surface tension and gravity effects. Hydraulic structures can increase dissolved oxygen levels by creating turbulent conditions where small air bubbles are carried into the bulk of the flow (Baylar et al., 2009).

Mass transfer processes through gas-liquid interfaces are important in areas such as mechanical engineering, chemical, geophysical and environmental systems. In these system, gaseous substances may be directly exchanged between air and water in either direction across the gas-liquid interface (Chanson, 2013).

Aeration can increase dissolved oxygen when levels become deficient. The concentration of dissolved oxygen is an important indicator of water quality. A higher dissolved oxygen level indicates better water quality. The physical process of oxygen transfer from the atmosphere acts to replenish the used oxygen. Aeration implies adding air to water. Air contains 21% oxygen and aeration adds oxygen vital to the sustained health of ponds and lakes, reversing lake degradation. Water jet aeration is a very effective way of aeration

This aeration system based on the air entrainment by a water jet is attractive compared to conventional aeration systems for several reasons: it does not need an air compressor; it is simple in construction and operation and it is free of operational difficulties such as clogging in air diffusers (Baylar & Ozkan, 2006).

2.3 Hydraulic Structures in Water Aeration

The hydraulic structures were divided into two groups as the high-head flow systems and the free-surface flow systems. The high-head flow systems were circular and venturi nozzles, pipe with venturi tube, and high-head conduit, and the free-surface flow systems were weir, stepped cascade, and free-surface conduit (Baylar et al., 2010)

Hydraulic structures can significantly improve dissolved oxygen levels by creating turbulent conditions where small air bubbles are carried into the bulk of the flow (Baylar & Ozkan, 2006). Aeration performance of hydraulic structures has been studied experimentally by a number of investigators and these are reviewed by Wilhelms et al. (1993), Chanson (1995), Gulliver et al. (1998), and Ervine (1998). Also, Baylar et al., (2010) studied the hydraulic structure in water aeration process. Within the last few years there has been a growing interest in the air entrainment by water jets plunging into pools. A substantial number of research workers have studied air entrainment by plunging water jets. Experimental studies on air entrainment by plunging water jets were carried out by Ahmed (1974), van De Sande and Smith (1973, 1976).

2.3.1 Aeration by plunging jet

Liquid plunging jets are moving columns of liquid (water) that pass through some gaseous headspace before impinging on the free surface of the receiving liquid. Gas entrainment may be observed at the intersection of the plunging jet and the liquid surface, free surface instabilities develop (Ohkawa et al., 1986). According to Bin (1993), for the gas entrainment to take place, the jet impact velocity has to exceed a characteristic velocity that is a function of the plunging flow conditions. Compared to conventional aeration system, this type of aeration system is advantageous because it has a simple construction, easy to operate, does not require an air compressor, free from operational problems such as air diffuser clogging and compact design that utilize less floor space (Baylar & Ozkan, 2006). For small jet velocities (at the nozzle outlet) that are larger than the threshold velocity (the onset velocity), air is entrained in the form of individual air bubbles, while large packets of air are entrained and broken up subsequently in the shear flow at higher jet velocities (Bin, 1993; Chanson et al., 2004). Air entrainment by plunging liquid jets in water bodies has potential applications in many chemical and wastewater treatment processes (Baawain et al., 2012).

Mass transfer created by a typical plunging jet aerator can be distinguished among three different regions; i) through the turbulent free liquid jet shearing through an air layer; ii) through the free liquid surface of the water pool; and iii) between bubble dispersion and water pool (Bin, 1993). The experimental observations show that dispersed bubbles towards the bottom of the jet ejector cause highly non uniform volume distribution in the jet ejector. The gas volume fraction, the interfacial area, and the bubble diameter are the three important parameters that characterize the internal flow structure of gas-liquid flows in the jet ejector (Ekambara et al., 2012).

Gas entrainment produced by plunging liquid jets belongs to the last group of example, although depending on the jet hydrodynamic parameters, mechanism of air entrainment prevailing for other examples may also significantly contribute to the total gas entrainment. Mechanical penetration through an interface as a result of their mutual interaction is frequently encountered in practice. During aeration of free liquid jets as a result of their instability which leads ultimately to atomization; as gas entrainment by plunging solid bodies or plunging liquid and gaseous jet through a free liquid surface. It can be observed during aeration in open channels (Bin, 1993).

As a vertical liquid jet plunges into a liquid surface after passing through a surrounding gas phase it entrains a large amount of gas bubbles into the receiving pool, and forms a large submerged two-phase region with a considerable interfacial area. Also, the bubble penetration depth was found to increase with the jet velocity and nozzle diameters. The entrainment rate tended to increase when the jet velocity increased and its functional dependence was divided into three regions depending on the jet velocity. In order to take place the gas entrainment, the jet impact velocity has to exceed a characteristic velocity (the inception or threshold velocity) which is influenced by the plunging flow conditions (Bin, 1993).

Aeration efficiency is influenced by water temperature hence, a temperature correction factor was typically employed by researchers (Gulliver et al., 1990; Baylar & Bagatur, 2000). Gulliver et al. (1990) applied previous theoretical discussion and developed the relationship for transfer efficiency at 20°C, which can be expressed as:

$$1 - E_{20} = (1 - E)^{\frac{1}{f}} \qquad 2.1$$

Where E is the transfer efficiency at the water temperature of measurement, E_{20} is the transfer efficiency at 20°C and f is the exponent expressed by:

$$f = 1.0 + 0.02103(T - 20) + 8.261 \times 10^{-5}(T - 20) \qquad 2.2$$

Where T is water temperature (°C).

2.3.1.1.Effect of Depth of Penetration

The penetration depth (H_p) of a plunging free jet is defined as the distance between the liquid surface and the deepest point reached by air bubbles during the entrainment process, see Figure 2.1 (Kramer et al., 2016). One of the important magnitudes in the plunging jet systems is the penetration depth (H_p) of the entrained bubbles, which affects the size of the submerged two-phase region where the transfer processes occur. The performance of the aeration process resulting from air entrainment due to plunging jets is highly affected by the residence time of the entrained bubbles. Therefore, the residence time is related to the bubble penetration depth (H_p) into the water tank (Harby et al., 2014).

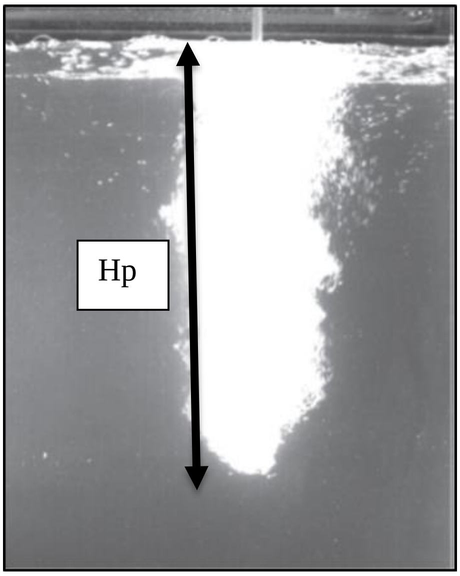

Figure 2.1: Penetration depth of a plunging liquid jet (Kramer et al., 2016).

Vertical plunging jets have been investigated by Kramer et al. (2016), Harby et al. (2014) and Qu et al. (2013). Kramer et al. (2016), conducted the study using a higher range of flow rates of the plunging liquid jets compared to the study by Harby et al. (2014) and Qu et al. (2013), as presented in Figure 2.2 and Table 2.1.

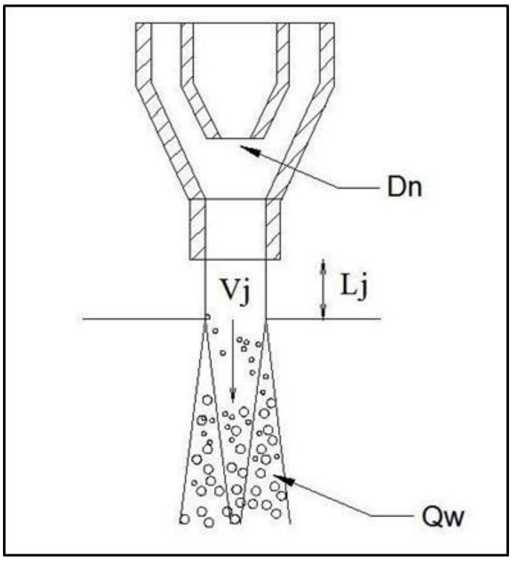

Figure 2.2: Photograph of the impinging jet (Kramer et al., 2016)

Table 2.1: Experimental conditions of different studies on the penetration depth of plunging jet

Reference	Diameter of liquid jet nozzle, d_n (mm)	Jet impact velocity, v_n (m/s)	Water flow rate, Q_w (l/s)	Jet length, L_j (cm)
Kramer et al. (2016)	13.0-81.9	5.0, 7.0	0.3 – 35.4	20,60,100
Qu et al. (2013)	4.0-12.0	3.5 - 9.9	0.1 – 0.9	30
Harby et al. (2014)	6.0	0.66 - 3.59	0.01 – 0.25	1-20

Kramer et al. (2016) and Harby et al. (2014) showed that penetration depth increased with decreasing jet length and increasing momentum flows. However, at higher momentum flow, the characteristic relationship between momentum flows and penetration depths was not significant.

2.3.1.2. Effect of Jet Length

The jet length L_j, is defined from the nozzle outlet to the water surface as shown in Figure 2.3. When the distance from the pipe outlet to the water surface (Lj) is short, the surface of the water jet is not disturbed by the shear forces induced by the surrounding air, and, thus, many small bubbles are generated and dispersed in the whole water body. If Lj is long, the surface of the water jet becomes highly disturbed and wavy, then relatively large bubbles are generated and dispersed in a localized region in the water beneath the pipe exit. These two patterns occur simultaneously for an intermediate distance.

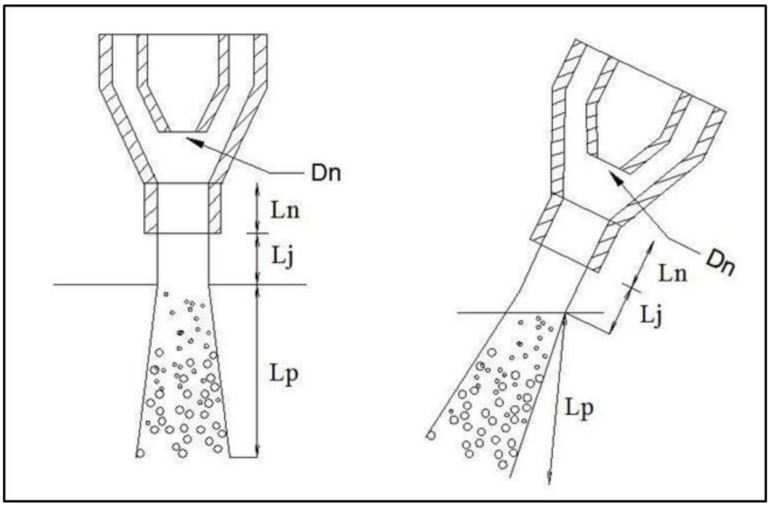

Figure 2.3: Schematic diagram of plunging liquid jet impingement Baawain et al., 2012)

Furthermore, the nozzle length to diameter (L_n/d_o) ratio is an important factor in nozzle design (Bin, 1993; Ohkawa et al., 1986). Maximum jet impact velocities between the impinging jet ($L_j > 0$) and the submerged jet ($L_j = 0$) show a 20% difference. This difference is directly influenced by the free-falling jet length (Qu et al., 2013).

2.3.1.3. Effect of Angle of Inclination

One of the factor that effects mass transfer is angle of jet inclination. A reduction of the mass transfer factor by 10% and 20% was observed by changing the jet inclination from 90° to 60° and 30° respectively (Van de Sande, 1974).

2.3.1.4. Effect of Jet Nozzle Length to Diameter Ratio

According to Bin (1993), the nozzle length to diameter (l_n/d_n) ratio is an important factor in nozzle design. It was found that when $l_n/d_n \geq 15$, the values of penetration depth and gas entrainment rate changed according to the jet velocity at the nozzle exit, nozzle diameter and jet length but these values were almost independent of l_n/d_n. The gas entrainment rate was high when the jet nozzle length-to-diameter ratio was large (Ohkawa et al., 1987).

2.3.2 Aeration by Ejector

Ejectors are well-known and accepted devices in several industrial applications. Currently, ejectors are used as pumps, mixers, heaters, coolers, as devices to generate vacuum, and also as bubble generators. Ejectors can be built from any sort of moldable material which, depending on the requirements, can be chemically resistant (Perry, 1997). An ejector is basically constituted by three components: a nozzle, a suction chamber, and a discharge pipe, also called diffuser or venture as shown in Figure 2.4. The feed flow is brought into the ejector through the nozzle, which should have an outlet diameter (D_N) much smaller than the feed pipe diameter. The maximum liquid-jet velocity takes place in the straight section of the diffuser, with diameter D_T, where the pressure on the liquid is lower than at the inlet. Therefore, the formation of micro-bubbles of dissolved air takes place in the straight section of the diffuser. Furthermore, the vacuum created by the high-velocity flow rate of the liquid-jet promotes the suction of air through the suction chamber, implying in the formation of bubbles bigger than the bubbles formed from the dissolved air in the effluent (Puget et al., 2000).

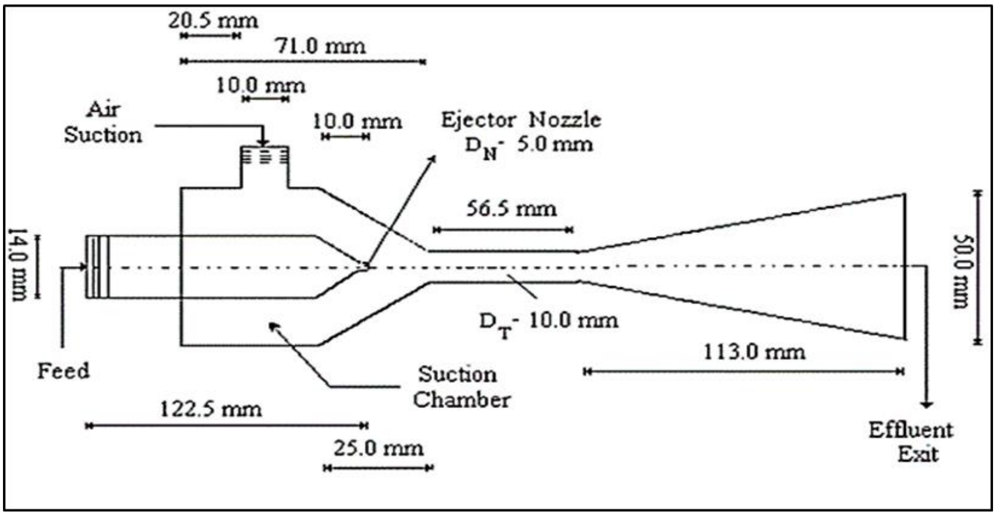

Figure 2.4: Schematic diagram of a typical ejector (Puget et al., 2000)

As explained by Patel el al., (2016) jet ejectors use high kinetic energy of the operating fluid jet to promote break-up of the distribution of the suction fluid into small droplets/bubbles and to pull the gas through the system and push through the connected outlet. The gas is accelerated to atomize the scrubbing liquid in the convergent section to reach a higher velocity in the throat. Ejectors work according to Bernoulli’s principle that utilizes kinetic energy from a high-velocity liquid jet to enable gas entrainment to generate a fine gas liquid dispersion. The interaction of liquid and gas occur in the throat of the ejector (Ali et al., 2012).

Mass transfer occurs when there is contact between the gas and liquid phase which is a function of ejector geometry, operating conditions, bubble size and bubble size distribution in the mixing throat, physicochemical properties of the two phases and liquid jet penetration (Agrawal, 2013; Patel et al., 2016).

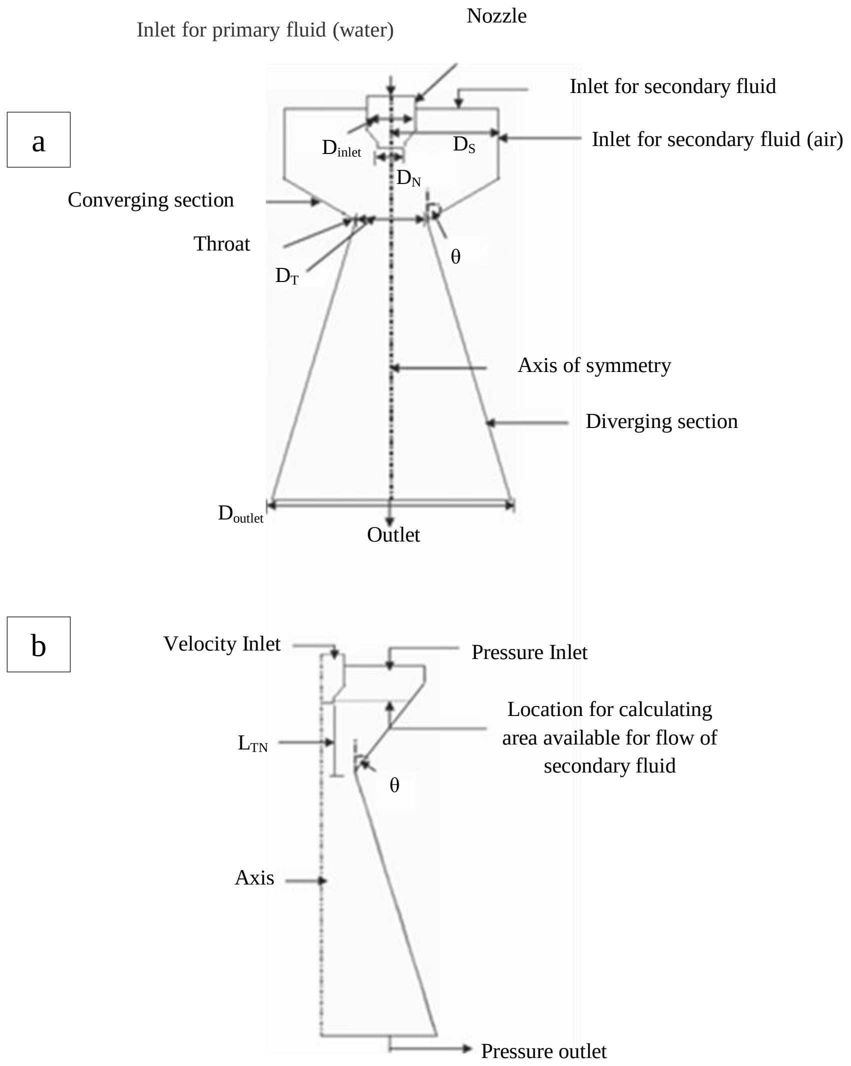

Figure 2.5: (a) Schematic geometry of ejector (b) Geometry used for simulation along with boundary condition (Yadav et al., 2008)

Figure 2.5 shows the typical ejector system in which the jet of primary fluid issuing out of a nozzle creates a low pressure region around it. The pressure differential between the entry point of the secondary fluid and the nozzle tip provides the driving force for entrainment of the secondary fluid. Here a part of the kinetic energy of the flow is dissipated in the shock creating the gas-liquid dispersion. The mixing shock results into generation of small bubbles and consequently creation of high interfacial area *(~ 2000m^2/m^3)*. Key components of an ejector (Figure 2.5 (a)) are (a) Inlet for primary fluid, (b) Suction chamber, (c) Inlet for the secondary fluid, (d) Converging section of diffuser, (e) Throat of diffuser and (f) Diverging section of the diffuser. The geometry of ejector can be expressed in terms of (a) Throat aspect ratio (L_T/D_T), i.e., length of throat/diameter of throat, (b) Angle of converging and diverging sections of the diffuser, (c) Projection ratio (PR) (L_{TN}/D_T), i.e., distance between nozzle tip and entry to throat and (d) Suction chamber area ratio $(A_S/A_N) = ((D^2{}_S - D^2{}_N)/D^2{}_N)$. All these parameters are known to influence the performance of ejectors.

2.3.2.1. Effect of Throat Aspect Ratio

The throat aspect ratio is the length-to-diameter ratio of mixing throat (L_T/D_T). The optimum performance of ejector occurred when mixing of both motive and entrained fluids was located just upstream of the mixing throat exit i.e., at the entrance of diffuser (Das & Biswas, 2006). Due to significant effect on the mixing of the primary and secondary flows, the mixing tube length has been paid close attention in the research. According to Dirix and van der Wiele (1990), the mixing tube length seems to have no obvious effect on the ejector and the length to diameter ratio (L_T/D_T) varying from 2 to 10 results in equal performance of the system.

But Bando et al., (1990) have reported increasing entrainment rate with an increase in mixing tube length, when the L/D ratio is in the range of 20 –30, the entrainment rate reaches the maximum value, and it then decreases with any further increase in (L_T/D_T). However, the experiment conducted by Havelka et al., (1997) shows that as (L_T/D_T) ratio increases the suction rate increases first and then reaches a plateau when (L_T/D_T) is greater than 6. On the other hand, the CFD modeling by Kandakure et al., (2005) and Balamurugan et al., (2007) indicated that the entrainment rate is the highest when the ejector (L_T/D_T) ratio is equal to zero, i.e., no constant-area mixing tube at all. From these researches, it is clear that the optimum length varies greatly with the operation conditions and it is difficult to find a universal value that meets all the conditions. The length of mixing throat of the ejector, either too long or too short, can result in additional viscous losses or be disadvantageous to pressure recovery, which increase entrainment efficiency (Li & Li, 2011). Obviously the performance of an ejector depends on its working condition and geometry design.

2.3.2.2.Effect of Nozzle to Mixing Throat Diameter Ratio, Suction Chamber Diameter, Projection Ratio and Angle of Converging Section.

In a gas-liquid as the diameter of the ejector nozzle approaches the diameter of the mixing throat, air entrainment decrease because the area available for the liquid to flow decreases resulting in the throat getting entirely filled with liquid (Balamurugan et al., 2008). The highest rate of liquid entrainment occurs when there is an optimum ratio of nozzle–to-mixing throat diameter D_N/D_T and was found that the optimum ratio is 0.4 (Cramers & Beenackers, 2001). Yadav & Patwardhan (2008) suggested that the design of the suction chamber should be optimized recirculation within the converging section.

Witte (1969) proved experimentally that high entrainment ratios were obtained by means of multi-orifice nozzles and a relatively long mixing throat. Most of the investigators investigated the effects of the angle of converging section, angle of divergence diffuser, diameter of the suction chamber and the projection ratio. A number of investigators, e.g., Mellanby (1928) and Watson (1933), Kroll (1947), Zahradnik et al. (1982), Henzler (1983) have pointed out that the performance of a liquid jet ejector is a function of the geometry of the nozzle, size and shape of the chamber where the gas is introduced (suction chamber) and geometry of the diffuser (its outlet cross-section area, total length and cone angle). For a given value of throat length if PR is increased, jet may breakup much earlier than at the end of the throat. Thus a large amount of energy will be lost. Similarly for small PRs the jet may not break in the throat due to lower rates of momentum transfer between the two fluids.

Henzler (1983) supported the above observations and suggested that low values of PR result in poor pressure recovery in the diffuser. He compiled the experimental data of different investigators. The optimum PR suggested by him was in the range of 0.4--0.9. It was also suggested that the optimum PR depends on the geometry of the entrance to mixing tube (angle and height of the converging section) and length of the mixing tube.

Yadav & Patwardhan (2008) conducted a study for three PRs (2.5, 5.0, 14.5). The areas available for water flow i.e., $(D_S^2-D_N^2)/D_N^2$, varied from 4.8 to 28.8 with constant nozzle and mixing throat diameter at 8 and 16mm respectively. It was observed that for PR=0, the areas available for air flow is low and resulted in a lower entrainment rate. By increasing PR, the area available for air flow increased resulting in an increase in entrainment rate until PR=5. Beyond PR=5, where area available remains constant, the entrainment rate levels off.

Henzler (1983) suggested that angle of converging section should be well rounded, bell mouthed to have a good ejector performance. A conical or tapered entry with an angle greater that 20° was recommended. This was to avoid the creation of objectionable shock and eddy losses at the convergence inlet (Mellanby, 1928). Yadav

& Patwardhan (2008), recommended that the $\theta_{convergent}$ be in the range of 5°-15°. They were found that for $\theta_{convergent}=2.5°$, the entrainment rate is low and increased until it reached the highest value for $\theta_{convergent}=10°$. Further increase of the converging section angle caused a decrease of secondary fluid entrainment rate because of the increase in radial flow generated in the suction chamber, which resulted in an increase on the pressure drop for the entrained fluid.

2.3.2.3. Diffuser

According to Balamurugan et al., (2007), a diffuser section after the mixing tube or throat helps in the pressure recovery. The motive fluid jet performs two functions; one, it develops the suction for the entrainment of the secondary fluid and the second, it provides energy for the dispersion of one phase into the other. Throat is used for interaction of liquid and gases. In the diffuser section the gas is slowing down allowing some recovery of pressure (Ali et al., 2012; Costa et al., 2005). Das & Biswas (2006) stated that the suitable angle of divergence is 8.6°. Although there were many studies on the hydrodynamics of ejectors mentioning the diverging angle of the diffuser, the studies did not emphasize on this configuration. It was noted ejectors in the experimental studies were used in loop reactors, mostly in the upflow position. Hence, having a diffuser is necessary. Angle of diverging section, $\theta_{divergent}$, used by different researchers varied by 2° and 10° (Yadav & Patwardhan, 2008).

2.4 Filtration by Roughing Filter

Roughing filtration can be considered as a major pre-treatment process for wastewater, since they efficiently separate fine solids particles over prolonged periods without addition of chemicals. For suspensions with particulates that do not readily settle, roughing filtration provides superior treatment to basic sedimentation methods (Wegelin, 1996). The natural water treatment potential was adopted long before chemical water treatment methods, such as chlorination and flocculation, were discovered and applied. When a particle in the water passes through a gravel bed filled up with gravel there is a chance to escape the particle either on the left side or on the right side or a chance to settle at the surface of the gravel. Hence the probability of chance of the success of removal and the failure is 1/3 and 2/3 (Nkwonta & Ochieng, 2009). The high solid retention of roughing filter makes them suitable for groundwater treatment to remove iron and manganese (Pacini et al., 2005). Given the high solid retention capability of roughing filtration, this process was considered likely to be an appropriate treatment for the removal of Fe and Mn from groundwater.

Dastanaie et al., (2007) stated that horizontal-flow rough filtration is an applicable alternative for supplying drinking water because having the capability of simultaneous sedimentation and filtration. The process of filtration continues through the multiple compartment of the HRF more of the particles get settled. So, along the flow path the quantity of the settled particles get reduced in the multistage layers when it enters the filter (Mukhopadhay et al., 2009).

Typical filtration rates for roughing filters are between 0.3 and 1.5 m/h (Hendricks 1991). The filter is comprised from three different parts which are inlet, outlet and filtration. There are two types of roughing filter i.e., vertical-flow and horizontal-flow. Figure 2.6 shows different types of roughing filters. Vertical-flow roughing filters operate either as down flow or up flow filters. The vertical flow roughing filters incorporates a simple self-cleaning mechanism and occupies minimal floor space when compared to horizontal flow roughing filters. The top should be covered by a layer of coarse stones to shade the water and thus prevent algal growth often experienced in pretreated water exposed to the sun.

Meanwhile, horizontal roughing filters have a large silt storage capacity. Solids settle on top of the filter medium surface and grow to small heaps of loose aggregates with progressive filtration time. When cluster of suspended solids will drift towards the filter bottom or be retained but the subsequent filter layers, horizontal-flow roughing filter also react less sensitively to filtration rate changes. Thus, it is less susceptible than vertical-flow filters to solid breakthrough caused by flow rate changes (Nkwonta & Ochieng, 2009).

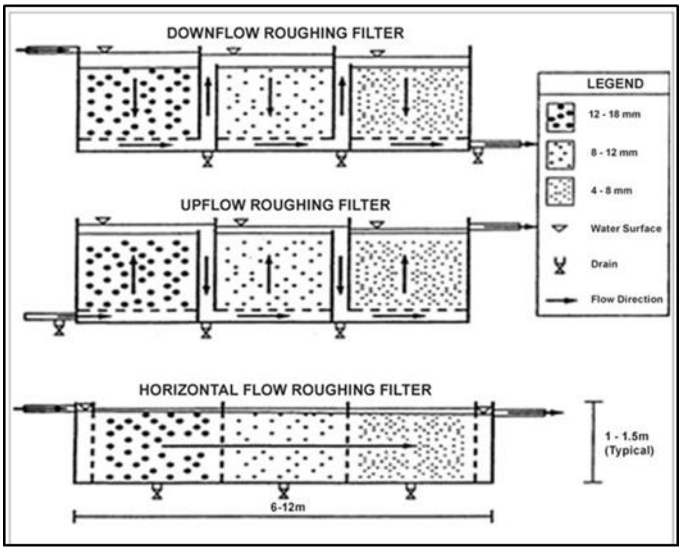

Figure 2.6: Diagram of horizontal, upflow and downflow roughing filters (Wegelin, 1996).

The size of filter media decreases successively in the direction of water flow and ideally the uniformity of filter media fractions is maximized to increase filter pore space (storage capacity) and aid in filter cleaning (Boller, 1993). Larger media provides larger storage capacities, whereas small media offers high removal efficiencies. To enhance the sedimentation process taking place in the roughing filter and high porosity, the filter material should have a large specific surface to allow the accumulation of the separated solids. Common grades of media used in roughing filters shown in Table 1.1.

Table 2.2: Different sizes of roughing filter media (Wegelin, 1996)

Roughing filter media description	First compartment (mm)	Second compartment (mm)	Third Compartment (mm)
Coarse	16-24	12-18	8-12
Normal	12-18	8-12	4-8
Fine	8-12	4-8	2-4

Filtration media for roughing filter usually consists of relatively coarse material ranging from about 4mm to 25mm in size (Wegelin, 1996). Filtration rate also has a significant influence on the treatment removal. Good removal in roughing filters are best achieved with low filtration rates because low filtration rates are critical to retain particles (Boller, 1993). Wegelin (1986) found that at increased filtration rates (2 m/h), coarse particles penetrate deeper into the bed and these will cause decrease in filter efficiency. Horizontal flow roughing filter is capable of removing metals like iron, manganese, turbidity and colour at a filtration rate of 1.8 m/h (Dastanaie, 2007). A study by Sanusi (2015) found that iron and manganese removal from groundwater could achieve 96.9% and 84.2%, respectively by aeration and subsequently filtration via a horizontal roughing filter with limestone media.

2.5 Summary

Aeration system is advantageous because it has simple construction, east to operate, does not required an air compressor, free from operational problems such as air diffusers clogging and hence suitable to be used for water and wastewater treatments. The design of an ejector has varying objectives, depending on its area of application, for instance, to achieve greater secondary fluid entrainment to yield intense mixing between two fluids and to pump fluids from a low-pressure to a high-pressure region. In the suction chamber, low pressure region is created when a high-velocity feed flow or motive fluid is pumped through the nozzle. The ejectors were equipped with a diverging section (diffuser) after the mixing throat to aid in pressure recovery. The gas-liquid dispersion exits into a reactor such as bubble column or a tank that are dispersed in a localized region in the water beneath the nozzle exit. Dispersion of one liquid into another is dependent on factors such as the geometry of nozzle, velocity of liquid jet, pressure difference etc. A higher concentration of dissolved oxygen in water indicates better water quality. However, many studies were carried out using tap water have shown that different water quality yields different aeration efficiency.