



Literature Review on the Removal Methods of Monoethanolamine (MEA) in the Removal of Contaminants in Wastewater

A. N. F. Akhma, S. R. M. Kutty, L. Baloo, N. N. H. Ismail, M. A. Razali, M. A. H. M. Fauzi, N. Azmatullah, and M. R. Marzuki

Abstract

This paper provides the literature on the investigation of biological organic removals of monoethanolamine (MEA) in an activated sludge system. A total of 31 papers cited and discussed with the purpose of providing information and understanding on the main topic of the research. The content of the paper includes several removal methods of MEA in wastewater, in the removal of contaminants, such as Advanced Oxidation Process, Adsorption Process, Membrane Technologies, and Biological Treatment Process. The Toxicity and Corrosivity of MEA on microorganisms were too discussed. At the end of each discussion made, the essence of research is presented for future researches, which will be useful for academics and practitioners.

Keywords

MEA • Monoethanolamine • Literature review • Methods of removal • Toxicity and Corrosivity

1 Introduction

Monoethanolamine (MEA) is commonly used in both domestic and industrial applications. Aqueous MEA is viscous, colourless, with an odour of ammonia. MEA is a dispersing agent for agricultural chemicals, aids in gas scrubbing in petroleum refineries, and is used to remove sulphur dioxide, carbon dioxide, hydrogen sulphide, and nitrogen dioxide from natural gases and other gases in the

A. N. F. Akhma (✉) · S. R. M. Kutty · L. Baloo · N. N. H. Ismail · M. A. Razali · M. A. H. M. Fauzi · N. Azmatullah
Universiti Teknologi PETRONAS, Bandar Seri Iskandar,
32610 Tronoh, Perak, Malaysia
e-mail: amera_18003186@utp.edu.my

M. R. Marzuki
PCOGD, Kerteh, Malaysia

synthesis of surface active agents and polishes, amongst other things (Lam et al. 1999). MEA is the most common used amine for carbon dioxide absorption among industrially utilized alkanolamines, due to its high solubility, greater absorption capacity, and rapid reaction kinetics (Davidson 2007; Lee et al. 2012). This paper discussed on the various experimental works done by different authors in the removal of contaminants, with the presence of MEA. The role of MEA in this research is to remove carbon dioxide in petroleum refineries via various removal treatments.

There were a total of 11 papers discussing on the removal of MEA via Advance Oxidation Process, 8 papers discussing on the removal of MEA via Adsorption, 11 papers discussing on the removal of MEA via Biological Treatment, and 2 papers discussing on the removal of MEA via Membrane Technologies. A total of 2 papers discussing on the toxicity of MEA on microorganism and bacteria, and 1 paper discussing on the corrosivity of MEA with and without inhibitors.

Method of MEA removal include Advanced Oxidation Process, which helps on the degradation of organics at high concentrations, which involves a very reactive species known as hydroxyl radical $\cdot\text{OH}$. Next, Adsorption method is also discussed. It is a physical separation method used to reduce the concentration of dissolved pollutants in effluents. It is a natural process in which molecules of dissolved compounds are collected and adhered to the surface of an adsorbent solid. Adsorbents such as MEA is commonly use in determining the suitability of MEA to remove or absorbed contaminants. Reverse osmosis, nanofiltration and ultrafiltration membrane technologies were discussed to determine the percentage performance of the separation process towards MEA rejection. Biological Treatment Process is a common method of pollutants removals, via organisms or extracellular enzyme. The treatment comprises of 3 categories including aerobic, anaerobic, and anoxic. Organisms including bacteria, fungi, yeast, algae or plant, is utilized in the removals of pollutants in bio treatment technologies. The

study on the toxicity of MEA were conducted to assess MEA waste toxicity towards microorganisms, in identifying the efficacy of microbiological methods for waste degradation acceleration. The corrosivity of MEA without and with the presence of oxidation inhibitors such as EDTA, formaldehyde, and Na_2SO_3 were discussed. Due to oxidative nature of MEA solvents, inhibitors were added to prevent the oxidation of MEA.

1.1 Objectives

This research aims to determine the extend research developments relating to the main research paper, with the topic: Biological Organic Removals of Monoethanolamine (MEA) in an Activated Sludge System, by providing various information and understanding of the results obtained from the research published to fellow researchers, which may be useful to other researchers for future studies.

2 Literature Review

2.1 Removal of MEA via Advanced Oxidation Process (AOP's)

AOP's are useful to degrade organics at high concentrations that are challenging to handle in a conventional biological oxidation unit. During the operation, a reactive hydroxyl radical $\cdot\text{OH}$ is utilized. The most common methods for the generation of hydroxyl radical include, Fenton's treatment, UV/O_3 , and $\text{UV}/\text{H}_2\text{O}_2$. $\text{UV}/\text{H}_2\text{O}_2$ process has few advantages including high capability on hydroxyl radical production, applicable in wide variation of pH and causes almost to none sludge formation during the treatment (Harimurti et al., 2012). AOP's are efficient in the degradation of MEA, as well as minimizing the toxicity of organic contaminant. Anotai et al. (2012) stipulated that the studies conducted by Sirtori et al. (2009) and Lucas et al. (2007) concluded that using a biological process in conjunction with Fenton's reagent may enhanced the decontamination and degradation process. In $\text{UV}/\text{H}_2\text{O}_2$ process oxidation, Eq. (1) is applicable in generating hydroxyl radical $\cdot\text{OH}$ (Jones 2007).



According to Harimurti et al. (2012), the formation rate of $\cdot\text{OH}$ radicals, which influenced by H_2O_2 concentrations and UV exposure, controls the rate of organic pollutant degradation. The usage of Fenton's reagent in AOPs aids in the decomposition of MEA waste (Harimurti et al. 2008, 2010). The Response Surface Method (RSM) used to perform the experiment on optimizing the oxidation process conditions of MDEA. From the investigation on the biodegradability of MEA via AOPs, it was observed that the removal of Total Organic Carbon (TOC) from the wastewater containing MDEA, via $\text{UV}/\text{H}_2\text{O}_2$ process reached up to 85%. The result proved that $\text{UV}/\text{H}_2\text{O}_2$ process improved the biodegradability of partially degraded MDEA. The optimal condition for the degradation of waste containing MDEA at initial concentration of contaminant are tabulated as in Table 1.

Putri et al. (2008); Harimurti et al. (2012) conducted a study on the degradation of salfolen via Fenton's reagent. Apart from that, Omar et al. (2010) conducted another analysis on the impact of Fenton's reagent's continuous addition mode on di-isopropanolamine mineralization (DIPA). In comparison to the one-time addition method, continual addition of Fenton's reagent performed the best. In the meantime, the usage of $\text{UV}/\text{H}_2\text{O}_2$ in AOPs was investigated. Fürhacker et al. (2003) stipulated that during the 28-day test period, MEA was not biodegradable in the batch bioreactor. This explains the effectiveness of advance oxidation processes (AOP's) in the degradation of MEA and reduction of the toxicity of organic contaminants. Amongst other methods of MEA removals, $\text{UV}/\text{H}_2\text{O}_2$ treatment is preferable as no formation of sludge was observed during the removal treatment, besides having a significant removal rate of organic contaminant.

Anotai et al. (2012) conducted a study on the treatment of TFT-LCD wastewater containing ethanolamine using fluidized-bed Fenton and Fenton processes. Fluidized-bed Fenton and Fenton processes experiments were conducted via a Box-Behnken design experiment. From the Fenton process experiment, it was concluded that the best settings of MEA removal at 5 mM is at pH 3, $[\text{Fe}^{2+}] = 5 \text{ mM}$ and $[\text{H}_2\text{O}_2] = 60 \text{ mM}$. 96.4% of MEA concentration and 47% of TOC was removed. In comparison to fluidized-bed Fenton process, MEA removal efficiency was 98.9%, with 62% of TOC removed. The COD removal efficiency was 57.3% for Fenton process and 64.7% for fluidized-bed Fenton method. It was concluded that fluidized-bed Fenton method outperforms the Fenton process.

Table 1 The ideal conditions for the breakdown of MDEA-containing waste

Total organic Carbon (ppm)	Volume (mL)	UV Intensity (mW cm^{-2})	Temperature ($^{\circ}\text{C}$)	pH	H_2O_2 initial concentration (M)	TOC removal after 180 min oxidation (%)
1000	400	12.06	30	9.52	0.23	85.99

The degradation of aqueous MEA using Fenton's reagent in conjunction with biological post-treatment was investigated by Harimurti et al. (2010). Wastewater containing amines, obtained from gas treatment facilities do not degraded easily, hence, the efficiency of Fenton's reagent in treating MEA wastewater was investigated and analysed. In a jacketed glass reactor, degradation tests were carried out. The effects of hydrogen peroxide, ferrous sulphate, and the pH of a solution on the pace of reaction were investigated, with pH 3 being the optimum. The degradation reaction is rather rapid initially, but gradually slows down with time. The author articulated that a larger fractional degradation of the organics in solution occurred when the initial COD of the feed solution is high. In comparison to a single injection of the reagent at the start of the process, a steady addition of H_2O_2 to the reaction mixture boosted COD elimination by 60%. Based on a simplified mechanistic model, a rate equation for amine mineralization was established, and the rate constant for COD elimination was obtained in lumped value. Activated sludge was used to biologically oxidize both partially degraded and "pure" MEA. The former substrate degraded much faster.

Harimurti et al. (2012) observed that aqueous alkanolamines including MEA, DEA, MDEA, and DIPA are commonly utilized for carbon dioxide scrubbing from natural gaseous. A substantial amount of alkanolamine is released into the wastewater during the shutdown of the desorption and absorption columns, as well as during cleaning and maintenance. It was found that conventional wastewater treatments are inadequate to treat the contaminated wastewater containing alkanolamines, therefore, advanced oxidation processes such as UV/ H_2O_2 were introduced. The degradation of MEA waste was investigated in a laboratory setting by using UV/ H_2O_2 . It was hypothesized that biomass acclimatization in partially degraded amine was significantly quicker than that in untreated MEA. Glycine as well as other breakdown intermediates are predicted to stimulate quicker biomass growth (Harimurti et al. 2010).

Aqueous monoethanolamine (MEA) are commonly utilized for acid gases scrubbing (Harimurti et al. 2008). Natural gas processing plants may produce significant amounts of alkanolamine waste, which is a challenge to process with conventional biological treatment systems. Therefore, the chemical pre-treatment of MEA via Fenton's reagent prior to biological treatment was studied. COD removal rate by Fenton's oxidation was shown to be substantially dependent on the initial MEA concentration, with 54.5% COD eliminated at the maximum initial MEA concentration employed in the research. Glycine was found to be a degradation by-product in partially degraded MEA via FTIR and HPLC simulations. The aerobic biodegradability of partly degraded MEA in contrast to untreated MEA was explored utilizing

batch mixed culture experimentations to obtain the kinetic constants for aerobic biological treatment after 40% COD degradation via Fenton's reagent technique. The analysis indicated that the biodegradability of partially degraded MEA was greater than that of "pure" MEA, in accordance to the kinetic constants and shortened acclimatization phase. Significant amounts of dissolve ammonia were formed during both biological oxidation and Fenton's oxidation.

Maszelan and Buang (2014) led an investigation on the treatment of MEA via Photo-Fenton oxidation, with the presence of UV light. Various ferrous ion and hydrogen peroxide concentrations were evaluated during the study. According to the findings, the percentage removal of TOC is greater with the presence of UV light in comparison to that in the absence of UV light. The ideal concentration of ferrous ion is concluded to be 0.014 M, whereas the optimal concentration of hydrogen peroxide is 1.6 M, with both providing 99% removal of TOC. The reduction in TOC levels suggested that the Photo-Fenton oxidation process efficiently treated MEA waste. When hydroxyl radicals from the oxidation process reacted with organic substrate in MEA, the organic compounds in the wastewater substantially decreased.

2.2 Removal of MEA via Adsorption

Mohammad-Khah and Ansari (2009) and Kanawade et al. (2010) stipulated that adsorption is a physical method of separation utilized in reducing the concentration of dissolved pollutants in effluents. Adsorption is a natural phenomenon that occurs when molecules of a dissolved compound are attached to the surface of an adsorbent. Adsorption method has an advantage over other approaches due to its sludge free nature (Kanawade et al. 2010). Razali (2013), Razali et al. (2010), Tong (2013), Isa (2014) and Muhammad (2013) have conducted the adsorption of COD, oil and MEA by using different adsorbents, including alum, chitosan, rice husk, banana peel, sugarcane bagasse, etc., in determining the effectiveness of pollutants removal in wastewater.

Razali et al. (n.d.) studied three adsorbents activated carbon, rice husk and sugarcane bagasse and its adsorption performances were compared. Rice husk achieved has better oil and grease removal efficiency compared to activated carbon and sugarcane bagasse without considerable increase of the dosage. Rice husk to be fully utilized for MEA waste treatment as it is environmentally friendly, low cost and easily available for prompt usage rather than activated carbon. Investigated adsorbent did not affect the concentration by the adsorption treatment.

Razali et al. (2010) conducted another MEA investigation to compare the adsorption efficacy of chitosan to activated carbon, alum, and zeolite. From the investigation, it was

discovered that chitosan adsorbed COD, suspended solid and residue oil up to 83%, 57%, and 95%, respectively. Whereas COD was reduced by up to 80%, 73%, and 70% with activated carbon, alum, and zeolite, respectively, while suspended solid was reduced by up to 49%, 43%, and 38% with activated carbon, alum, and zeolite. Activated carbon removed 87% of residual oil, alum 64%, and zeolite 46%. The best adsorption performance was achieved by chitosan, followed by activated carbon, alum, and zeolite. However, MEA concentration was not affected by adsorption treatment.

Tong (2013) synthesized activated carbon from sawdust, which has a larger pore volume and specific surface area, hence it has a higher adsorption rate. According to the results, MEA concentration was lowered by 93%. In this study, banana peels and rice husk were used to treat MEA. Banana peels and rice husk managed to reduce COD and oil by 78.9%, 76.65% and 53.32%, 49.86%, respectively. Both adsorbent were capable to reduce amine concentration below 6% (Razali 2013). Another study was conducted using chitosan, rice husk, and activated carbon. Oil adsorption was 32.14%, 28.14% & 21.43%, respectively. The adsorption treatment had no impact on the MEA concentration in any of the adsorbents utilized in this study (Isa 2014). For the removals of oil, COD and amine concentration, activated carbon, and rice husk were used. The percentage removal efficiency of oil and COD reduction by activated carbon was 43.57% and 66.81%, respectively. While treated rice husk had a lower effectiveness of 37.83% and 53.32% in oil and COD removal, respectively. MEA concentration, on the other hand, remains constant for both adsorbents. Muhammad (2013) stipulated that the most effective adsorbent for oil residue is activated carbon, whereas MEA concentration

remained unchanged. Table 2 display that tabulated results of percentage of contaminants removed with respective adsorbents used.

2.3 Removal of MEA via Membrane Technologies

Membrane technology is also another treatment for MEA removal. There are three different commercial membranes studied, which include reverse osmosis (RO), nanofiltration (NF), and ultrafiltration (UF). The effect of feed concentration, operating pressure, cross-flow velocity as well as pH towards the membranes were investigated (Binyam et al. 2009). According to Binyam et al. (2009), RO membrane has the greatest rejection, at around 99%, in comparison to the percentage rejection reached by NF and UF membranes, which are at 75% and 35%, respectively. The result obtained explains that RO membrane is applicable and most effective in the removals of MEA from the wastewater (Binyam et al. 2009). Table 3 show the tabulated the rejection separation percentage via different membrane technologies applied.

A study on the removal of MEA from wastewater via reverse osmosis membrane was also conducted by Borhan and Mat Johari (2014). According to the findings of the experiments, the tubular thin film composite polyamide (AFC99) membrane reject up to 98% of MEA when operated at a pressure of 2000 kPa with a feed concentration of 300 ppm at a pH level 4. Due to the efficiency of RO membrane in removing pollutants, it is the most preferred approach for the removal of MEA contaminants from wastewater.

Table 2 Adsorption of COD, Oil, and MEA using different adsorbents

No	Adsorbent	Pollutant	Removal efficiency	Reference
1	Activated carbon	COD & oil	80% & 87%	Razali et al. (n.d.)
			53% & 56%	Razali et al. (2010)
2	Chitosan	COD & oil	83% & 95%	Razali et al. (2010)
3	Alum	COD & oil	73% & 64%	Razali et al. (2010)
4	Sugarcane bagasse	COD & oil	70% & 42%	Razali et al. (n.d.)
5	Zeolite	COD & oil	70% & 46%	Razali et al. (2010)
6	Rice husk	COD & oil	53.32% & 78.9%	Razali (2013)
7	Banana peel	COD & oil	49.86% & 76.65%	Razali (2013)
8	Activated carbon by saw dust	MEA	93%	Tong (2013)
9	Rice husk	Oil	21.43%	Isa (2014)
	Chitosan		28.14%	
	Activated carbon		32.14%	
10	Activated Carbon	Oil & COD	43.57% & 66.81%	Muhammad (2013)
	Treated Rice husk		37.83% & 53.32%	

Table 3 Commercial Membranes with respective Rejection Percentage (Binyam et al. 2009)

Type of Commercial Membranes	Rejection of Separation process (%)
Reverse Osmosis	99
Nanofiltration	75
Ultrafiltration	35

2.4 Removal of MEA via Biological Treatment Systems

Biological treatment is a common method of pollutants removals, via organisms or extracellular enzyme. The treatment comprises of 3 categories including aerobic, anaerobic, and anoxic. Organisms including bacteria, fungi, yeast, algae or plant, is utilized in the removals of pollutants in bio treatment technologies. Composting, bioreactors, bio filters, and other biological treatments have the benefits of low cost, high removal rate, etc. (Boopathy 2000). MEA degradation products are classified into two types: primary and secondary degradation products. In accordance to Fredriksen and Jens (2013), organic acids, aldehydes, and ammonia are the reported compound classes for oxidative degradation of MEA. It was assumed that the products were formed due to autoxidation, which explains the oxidization of MEA in the influent sample. Lee et al., (2010) articulated that the oxidative degradation products of MEA with inhibitors such as EDTA were much lesser in comparison to MEA without the presence of inhibitors. Acetic acid, ammonium, and ethanol are the major breakdown products of MEA biodegradation (Bradbeer 1965; BUA 1994; Jones and Turner 1973; McVicker et al. 1997). Gottschalk (1985) stated that acetic acid and ethanol can be completely degraded via either methanogenesis (anaerobic) or tri carboxylic acid cycle (aerobic).

Urasaki et al. (2019) conducted a study on the electronic industry waste water contains TMAH, MEA, and sulphate. The batch feeding experiment with a single organic source and sulphate, as well as specific activity measurement of retained sludge, were conducted to study the behaviour of methanogenic degradation of MEA in an up flow anaerobic sludge blanket (UASB) reactor operated continuously at mesophilic conditions. The findings revealed that MEA was degraded by a methanogenic pathway with sulphate reduction, implying that MEA waste might be treated with methanogenic treatment with proper reactor handling.

Wang et al. (2013) implemented sequencing batch reactor (SBR) to investigate the influence of MEA inhibition and adaptation on biological degradation, as well as the removal of amine (MEA) at lab scale. It was concluded that 92% of 9000 mg/L of MEA was removed after 10.5 days of hydraulic retention time (HRT).

Mrklas et al. (2004) studied MEA biodegradation by conducting bench scale studies, where significant levels of MEA (31,000 mg/kg) was successfully biodegraded aerobically in the bioreactors. MEA degradation products including ethanol, ammonium, and acetate at approximately 8100 mg/kg, 8800 mg/kg, and 75,000 mg/kg, respectively, has entirely degraded without interfering with aerobic biodegradation.

Waste products are produced after the degradation of MEA. Li (2008) studied the biodegradation of waste amines by conducting a series of BOD tests and nine (9) syringe batch experiments cases under aerobic, micro aerobic, and anaerobic settings. It was observed that waste amines were effectively degraded at high reaction rates under aerobic, anaerobic, and micro aerobic settings, with 90% and more of amine COD removed. The BOD studies demonstrated that amine degradation occurs in first order, with the greatest reaction rate of 1.08/d obtained in reactors containing initial amine concentration of 125 mg/L. If pH was kept at neutral, concentration of amines as high as 2000 mg/L can be degraded. As a result, low-cost biological treatment plants may be proposed to manage waste amines while retrieving energy as CH₄.

Lam et al. (1999) conducted another sequencing batch reactor experimental studies on the investigation on the shock loads of MEA on activated sludge treatment system. From the investigation, it was concluded that mono-ethanolamine (MEA) is readily biodegraded by a mixed culture and is not inhibitory to this community at concentrations below about 1600 mg/L COD. Beyond this threshold, MEA was inhibitory to its own degradation. MEA degradation occurred over the tested temperature range of 15–35 °C with 25 °C being optimum for the culture studied. MEA degradation was little affected by pH from 4.5 to 8.0, but extremes of pH outside this range led to lower rates of degradation.

The investigation confirmed the biodegradation pathways of MEA and its breakdown products using indigenous microbes. The effectiveness of biological treatment in the removals of pollutants were supported by other studies conducted by Huang et al. (2017) and Haritash and Kaushik (2009).

2.5 Toxicity of MEA on Bacteria and Microorganisms

Liuzinas et al. (2007) conducted a laboratory scale study on the investigation on the toxicity of MEA on microorganisms via paper disc and wells methods for the determination of toxicity of MEA waste on bacteria and microorganisms. From the investigation it was observed that the toxicity test using method of wells is more sensitive in comparison to the

Table 4 Sensibility of bacteria to various concentrations of MEA (method of paper discs) (Liuzinas et al. 2007)

MEA concentration (%)	Diameter of sterile zone (mm)		
	Bacillus megaterium	Escherichia coli	Proteus mirabilis
100	8	10	8
75	6	6	5
50	3	4	4
25	3	2	3
10	2	0	3
5	1	0	1
1	0	0	0
0.1	0	0	0

Table 5 Sensibility of microorganism to various concentrations of MEA (method of wells) (Liuzinas et al. 2007)

MEA concentration (%)	Diameter of sterile zone (mm)				
	Acremonium roseum	Cladosporium herbarum	Fusarium culmorum	Penicillium expansum	Trichoderma harzianum
100	20	15	7	15	20
75	17	10	5	12	18
50	15	8	4	10	10
25	10	5	2	4	5
10	2*	3*	0	4*	5*
5	1*	2*	0	2*	4*
1	0	0	0	0	0
0.1	0	0	0	0	0

* Fungistatic effect

method of disc. *Escherichia coli* was the most sensitive for higher concentrations of MEA among the investigated bacteria. It was observed that the toxicity of MEA is higher in bacteria. MEA at concentrations of 5–25% have influence on some bacteria: fungistatic influence at 5% and fungicidal influence at 25%. Addition of MEA waste at various concentrations were made onto the bacteria and microorganisms and the results were tabulated as in Tables 4 and 5, respectively.

Repečkienė et al. (2010) conducted a toxicity test on microbial development by adding various concentrations of MEA waste onto it. The test was conducted by using paper disc technique, according to the diffusion of the tested substance to the medium. Sterile filter paper discs were soaked in MEA concentrations, which was appropriate for the experiment. Table 6 displays the responsiveness of microorganisms to numerous MEA loading waste. The author mentioned that MEA waste mixture is ecotoxic and environmentally harmful. Toxicity of MEA waste was assessed based on the resistance of various microorganism strains. The impact of MEA waste on bacterial growth was rather significant, as bacteria growth was inhibited when MEA level was at 1% and greater. At MEA concentrations up to 25%, *Escherichia coli* was the least impacted, while MEA concentrations 25% onwards inhibited all bacteria

alike. MEA waste inhibits the more sensitive bacterial strains at lowest concentrations of 5%. Amongst the treated yeast-like and yeasts fungi, Repečkienė et al. (2010) discovered that *Aureobasidium pullulans* was susceptible to MEA the most. MEA concentration ranging from 75 to 25% inhibited *Candida lipolytica* and *Geotrichum fermentans*. From concentration of 25% MEA, *Rhodospiridium diobovatum*, and *Rhodotorula rubra* growth was observed to be inhibited. To summarize, bacteria were more susceptible to MEA harmful effects than fungi.

2.6 Corrosivity of MEA with Various Presence of Inhibitor

Lee et al. (2012) studied the corrosivity of MEA with and without the presence of oxidation inhibitors by conducting corrosion tests, in accordance to ASTM G31. Due to oxidative nature of the alkanolamine solvents, inhibitors such as EDTA, formaldehyde, and Na_2SO_3 was added to the solution to avoid the solvents from oxidizing. The test was performed on stainless steel 304 specimens with the dimensions; 20 mm × 13 mm × 3 mm that had been polished with Al_2O_3 sand paper, rinsed with acetone, and let dried. An analytic balance with an initial weight precision of

Table 6 Sensibility of microorganisms to MEA waste concentrations (Repečkienė et al. 2010)

Microorganisms	MEA Concentrations (%)							
	100	75	50	25	10	5	1	0.1
<i>Acremonium roseum</i>	17	5	3	2	0	0	0	0
<i>Aureobasidium pullulans</i>	10	9	8*	6*	6*	8*	8*	6*
<i>Bacillus megaterium</i>	8	6	3	3	2	1	0	0
<i>Cladosporium herbarum</i>	12	8	4	2	0	0	0	0
<i>Candida lipolytica</i>	10	8	6	4	0	0	0	0
<i>Escherichia coli</i>	10	6	4	2	0	0	0	0
<i>Fusarium culmorum</i>	5	2	0	0	0	0	0	0
<i>Geotrichum fermentans</i>	15	10	10	8	0	0	0	0
<i>Proteus mirabilis</i>	8	5	4	3	3	1	0	0
<i>Penicillium expansum</i>	5 + 10*	10*	8*	6*	4*	2*	0	0
<i>Rhodosporidium diobovatum</i>	10	13*	8*	0	0	0	0	0
<i>Rhodotorula rubra</i>	8	6	0	0	0	0	0	0
<i>Trichoderma harzianum</i>	2 + 20*	10*	10*	10*	4*	3*	0	0

* Fungistatic effect

0.0001 g (W_0) was used to weighed the dried specimens. After being submerged in the test CO_2 saturated solutions at 120 °C for 48 h, the corroded specimens were withdrawn from the solutions, cleaned, and dried. The removal of CO_2 gas into fresh solution for 8 h was done to prepare the CO_2 saturated solution. The samples were reweighed and the final weight (W) were recorded. Equation (2) was applied to identify the corrosion rate (CR) [mm/y].

$$\text{CR} = \frac{(W_0 - W)}{(A \times t \times D)} \quad (2)$$

where:

W_0 [kg] = Initial weight
 W_1 [kg] = Final weight
 A [m²] = Surface are of specimens (exposed).
 t [y] = Submerged time.
 D [kg/m³] = Density of the specimens.

According to the test results, the rate of corrosion for MEA solution without inhibitor was 1.52 mm/y, whereas the corrosion rate of MEA solution with EDTA as the inhibitor was 1.46 mm/y. The results explain that oxidation inhibitors such as EDTA and Na_2SO_3 decreases the rate of corrosion. However, formaldehyde inhibitor increased the rate of corrosion slightly. Hence, the rate of corrosion of MEA with the presence of inhibitors was in the sequence of formaldehyde > EDTA > Na_2SO_3 . Several studies agreed that there is a connection between oxidation inhibitors and the degradation, as well as the corrosivity of MEA (Goff et al. 2006; Lee et al. 2012).

3 Summary of the Papers

From the literature review on the removal of MEA via AOP's, the significant information was listed:

- AOP's are efficient to the degradation of MEA, as well as to the reduction of the toxicity of organic contaminant. This is because of the absence of sludge formation during the treatment, apart from having high capability of producing hydroxyl radical. Also, AOP's are applicable in wide variation pH.
- Combination of Fenton's reagent and biological process may enhance the decontamination and degradation process.
- AOP's are effective in MEA degradation, as well as in reducing the toxicity of organic contaminant.
- In comparison to other wastewater treatment methods, UV/ H_2O_2 offers other advantages including zero formation of sludge during the process, apart from producing a high rate of organic pollutant removal.
- COD is removed efficiently via fluidized-bed Fenton process in comparison to Fenton process.
- Degradation of MEA waste via UV/ H_2O_2 indicated that the rate of biomass acclimatization was higher in partially degraded amine in comparison to pure MEA. Biomass growth accelerates due to glycine and other degradation intermediates.
- Treatment of MEA via Photo-Fenton oxidation with the presence of UV light resulting to higher TOC removal percentage than that in the absence of UV light.

From the literature review on the removal of MEA via Adsorption Method, the significant information was listed:

- (a) Rice husk has better oil and grease removal efficiency compared to activated carbon and sugarcane bagasse without considerable increase of the dosage.
- (b) Activated carbon by sawdust absorbent exhibited higher rate of adsorption, with concentration of MEA reduced by 93%, in comparison to other absorbents, where MEA concentration remain constant or as lowest as 6%.

From the literature review on the removal of MEA via Membrane Technologies, the significant information was listed:

- (a) RO membrane is practical and desirable in the removal of MEA contaminants from wastewater as it has the highest rejection separation process percentage amongst other commercial membrane.

From the literature review on the removal of MEA via Biological Treatment System, the significant information was listed:

- (a) In a study on the electronic industry waste water contains TMAH, MEA, and sulphate, it was found that MEA was degraded via methanogenic pathway with sulphate reduction which proved that methanogenic treatment was applicable to MEA waste.
- (b) In a sequencing batch reactor (SBR) study on the influence of inhibition and adaptation of MEA on biological degradation as well as the removal of amine, it was concluded that the removal efficiency of 9000 mg/L MEA was 92% at 10.5 days of HRT.
- (c) In a study of the biodegradability of MEA in laboratory bench scale bioreactors, where it was observed that substantial levels of MEA (31,000 mg/kg) was successfully biodegraded aerobically in the bioreactors. MEA degradation products including ethanol, acetate, and ammonium at certain concentrations may completely degraded without interfering with aerobic biodegradation.
- (d) To investigate the biodegradation of waste amines, a series of BOD tests and nine cases of syringe batch experiments were carried out under aerobic, micro aerobic, and anaerobic settings. Waste amines effectively decomposed with high reaction rates in all conditions mentioned, and more than 90% of amine COD was removed, according to the findings. If the pH is kept at neutral, high concentrations of amines, up to 2000 mg/l can be degraded.

- (e) Another sequencing batch reactor experimental studies on the investigation on the shock loads of MEA on activated sludge treatment system shows that MEA is readily biodegraded by a mixed culture and is not inhibitory to the microbes at concentrations below 1600 mg/L COD. Beyond this threshold, MEA was inhibitory to its own degradation. MEA degraded within 15–35 °C, with 25 °C being the optimal temperature for the culture investigated. MEA degradation was slightly affected by pH ranging from 4.5 to 8.0, however, extreme pH outside the range resulted to lower rates of degradation.

From the literature review on the toxicity and corrosivity of MEA, the significant information was listed:

- (a) Toxicity test using method of wells is more sensitive in comparison to the method of disc. *Escherichia coli* was the most sensitive at higher concentrations of MEA among the investigated bacteria. It was observed that the toxicity of MEA is higher in bacteria.
- (b) Oxidation inhibitors such as EDTA and Na₂SO₃ decrease the corrosion rate, whereas, Formaldehyde slightly increased the rate of corrosion. Hence, the sequence of the rate of corrosion of MEA with the presence of inhibitors is as follow; formaldehyde > EDTA > Na₂SO₃.

To conclude, amongst the methods provided in the research study, the most common method conducted, on the removal of MEA in the removal of contaminants is via Biological Treatment Process. However, some authors agreed that the combination of 2 or more methods of removals resulting to a higher efficiency in the removal of MEA compounds, in the removal of contaminants. It was concluded that MEA is corrosive and toxic to microorganisms at lower concentrations.

References

- J. Anotai et al., Treatment of TFT-LCD wastewater containing ethanolamine by fluidized-bed Fenton technology. *Bioresour. Technol.* **113**, 272–275 (2012)
- S. Binyam, H. Mukhtar, L. Leong, Flux and rejection of monoethanolamine (MEA) in wastewater using membrane technology, in *Thirteenth International Water Technology Conference, ITWC* (2009)
- R. Boopathy, Factors limiting bioremediation technologies. *Biores. Technol.* **74**(1), 63–67 (2000)
- A. Borhan, M.M. Mat Johari, Removal of monoethanolamine from wastewater by composite reverse osmosis membrane. *Jurnal Teknologi* **68**(5) (2014)

- C. Bradbeer, The clostridial fermentation of choline and ethanolamine I. J. Biol. Chem. **240**, 4669–4674 (1965)
- BUA, Beratergremium fuer Umweltrelevante Altstoffe, Ethylene glycol, S. Hirzel Wissenschaftliche Verlagsgesellschaft Stuttgart, Germany (1994)
- R.M. Davidson, Post combustion carbon capture from coal fired plants—solvent scrubbing, IEA GHG Report CCC/125, London, UK (2007)
- S.B. Fredriksen, K.-J. Jens, Oxidative degradation of aqueous amine solutions of MEA, AMP, MDEA, PZ: a review. Energy Procedia **37**, 1770–1777 (2013)
- M.A. Fürhacker Pressl, R. Allabashi, Aerobic biodegradability of methyldiethanolamine (MDEA) used in natural gas sweetening plants in batch tests and continuous flow experiments. Chemosphere **52**(10), 1743–1748 (2003)
- G.S. Goff, G.T. Rochelle, Oxidation inhibitors for copper and iron catalyzed degradation of monoethanolamine in CO₂ capture processes. Ind. Eng. Chem. Res. **45**, 2513–2521 (2006)
- G. Gottschalk, *Bacterial Metabolism*, 2nd edn. (Springer, Berlin, Germany, 1985)
- S. Harimurti, I.F.M. Arief, R.M. Ramli, P.F. Khamarudin, B.K. Dutta, Biodegradability of monoethanolamine after Fenton treatment, in *Proceedings of the International Conference on Environment*, December 15–17, 2008, Universiti Sains Malaysia, Penang, Malaysia
- S. Harimurti, B.K. Dutta, I.F.B.M. Ariff, S. Chakrabarti, D. Vione, Degradation of monoethanolamine in aqueous solution by Fenton's reagent with biological post-treatment. Water Air Soil Pollut. **211**, 273–286 (2010)
- S. Harimurti, A. Rahmah, A. Omar, T. Murugesan, Application of response surface method in the degradation of wastewater containing MDEA using UV/H₂O₂ advanced oxidation process. J. Appl. Sci. **12**(11), 1093–1099 (2012)
- A. Haritash, C. Kaushik, Biodegradation aspects of polycyclic aromatic hydrocarbons (PAHs): a review. J. Hazard. Mater. **169**(1–3), 1–15 (2009)
- D. Huang, C. Hu, G. Zeng, M. Cheng, P. Xu, X. Gong, R. Wang, W. Xue, Combination of Fenton processes and biotreatment for wastewater treatment and soil remediation. Sci. Total Environ. **574**, 1599–1610 (2017)
- S.Z. Isa, *Kinetic Study of Adsorption Process Using Chitosan, Activated Carbon, and Rice Husk for Monoethanolamine (mea) Wastewater Treatment Via Batch Process*. UMP. (2014).
- A. Jones, J.M. Turner, Microbial metabolism of amino alcohols. Biochem. J. **134**, 167–182 (1973)
- C.W. Jones, *Applications of Hydrogen Peroxide and Derivatives*. (Royal Society of Chemistry, 2007).
- S.M. Kanawade, R. Gaikwad, A. Misal, Low cost sugarcane bagasse ash as an adsorbent for dye removal from dye effluent. Int. J. Chem. Eng. Appl. **1**(4), 309 (2010)
- P.N.F.M. Khamarudin, S. Harimurti, I.F.M. Arief, R.M. Ramli, B.K. Dutta, Degradation of amine based absorbent using Fenton's oxidation (ICENV, Penang Malaysia, 15–18 December 2008)
- Y. Lam, R.M. Cowan, P.F. Strom, in *The Treatability of Monoethanolamine (MEA) in Nitrifying Activated Sludge*, ed. by N. Nikolaidis, C. Erkey, B.F. Smets (1999)
- I.Y. Lee, N.S. Kwak, J.H. Lee, K.R. Jang, J.G. Shim, Degradation and corrosivity of MEA with oxidation inhibitors in a carbon dioxide capture process. J. Chem. Eng. Jpn. **45**(5), 343–347 (2012)
- Y. Li, Biodegradation of waste amines under anaerobic, micro-aerobic and aerobic conditions. Høgskolen i Telemark (2008)
- R. Liuzinas, K. Jankevicius, M. Salkauskas, R. Jakubenas, A. Paskevicius, M. Mikalajunas, Biological method for the detoxification of spent monoethanolamine solutions. Linnaeus Eco-Tech 881–888 (2007). <https://doi.org/10.15626/eco-tech.2007.094>
- M.S. Lucas, A.A. Dias, A. Sampaio, C. Amaral, J.A. Peres, Degradation of a textile reactive azo dye by a combined chemical–biological process: Fenton's reagent-yeast. Water Res. **41**(5), 1103–1109 (2007). <https://doi.org/10.1016/j.watres.2006.12.013>
- C.N. Maszellan, A. Buang, Monoethanolamine (MEA) wastewater treatment using photo-fenton oxidation. Appl. Mech. Mater. **625**, 792–795 (2014). <https://doi.org/10.4028/www.scientific.net/amm.625.792>
- L. McVicker, D. Duffy, V. Stout, Microbial growth in a steady-state model of ethylene glycol-contaminated soil. Curr. Microbiol. **36**, 137–147 (1997)
- A. Mohammad-Khah, R. Ansari, Activated charcoal: preparation, characterization and applications: a review article. Int. J. Chem. Tech. Res. **1**(4), 859–864 (2009)
- O. Mrklas, A. Chu, S. Lunn, L.R. Bentley, Biodegradation of monoethanolamine, ethylene glycol and triethylene glycol in laboratory bioreactors. Water Air Soil Pollut. **159**(1), 249–263 (2004)
- N. Muhamad, *Study on the Adsorption Process of Monoethanolamine (MEA) Wastewater Using Activated Carbon and Treated Rice Husk*. UMP. (2013)
- A.A. Omar, R.M. Ramli, P. Khamaruddin, Fenton oxidation of natural gas plant wastewater. Can. J. Chem. Eng. Technol. (2010)
- M.E. Razali, *Study on Batch Adsorption Process of Monoethanolamine (MEA) Wastewater Treatment Using Rice Husk and Banana Peels*. UMP (2013)
- M.N. Razali, N.A.M. Salehan, M.A.M. Khairu, Feasibility study on adsorption treatment of monoethanolamine (MEA) wastewater using bio-adsorbents (n.d.)
- J. Repečkienė, D. Pečiulytė, A. Paškevičius, O. Salina, K. Jankevičius, R. Liuzinas, Microbiological reduction of monoethanolamine waste toxicity. J. Environ. Eng. Landsc. Manag. **19**(4), 287–295 (2010)
- C. Sirtori, A. Zapata, I. Oller, W. Gernjak, A. Agüera, S. Malato, Decontamination industrial pharmaceutical wastewater by combining solar photo-fenton and biological treatment. Water Res. **43**(3), 661–668 (2009). <https://doi.org/10.1016/j.watres.2008.11.013>
- Y.Y. Tong, *Monoethanolamine (MEA) Wastewater Treatment via Adsorption using Activated Carbon Derived from Sawdust* (2013)
- K. Urasaki, H. Sumino, T. Danshita, T. Yamaguchi, K. Sytsubo, Biological treatment of electronic industry wastewater containing TMAH, MEA and sulfate in an UASB reactor. J. Environ. Sci. Health. Part A, **54**(11), 1109–1115 (2019). <https://doi.org/10.1080/10934529.2019.1631655>
- S. Wang, J. Hovland, R. Bakke, Anaerobic degradation of carbon capture reclaimer MEA waste. Water Sci. Technol. **67**(11), 2549–2559 (2013)