The Steps in Preventing, Monitoring and Removing of Fouling Scale on Operation of Evaporator

Zainus Salimin, Lilis Kistriyani, Ratiko:
1Department of Chemical Engineering, Faculty of Industrial Technology, Universitas Islam Indonesia, Yogyakarta
2Radioactive Waste Treatment Centre, Kawasan Puspiptek Serpong, Gedung 50, Tangerang Selatan, Banten

Abstract. Concentrating of solution by evaporation with tubular heating surface evaporator is the effective method for decontamination of radioactive waste. Radioactive matter was concentrate with decontamination factor 104-105 for Cs-137. The evaporation of liquid waste from Serpong Nuclear Facilities having the permanent hardness of CaSO4 and MgSO4 with ratio of 2:1 generates fouling scale. The presence of scale on the evaporator gives the additional cost i.e. increasing of the capital investment cause of oversize of heat transfer surface area, increasing of energy cost for same evaporator capacity due to the presence of fouling heat transfer resistance, the presence of time loosing for maintenance and descaling, the chemical cost for descaling, and decreasing of the production capacity cause of decreasing of production time comparing the condition without the presence of fouling scale. For the problem solution, it is necessary to perform the sequence action starting the prevention of fouling scale formation, than monitoring of the fouling factor (Rd), and finally removing of fouling scale by chemical descaling. The prevention of fouling scale formation is performed by separation of soluble and suspended solid and utilization of chemical inhibitor before evaporation operation. The monitoring of fouling factor is performed during evaporation operation by reading the operating parameter of evaporation on the control panel i.e. mass flow rate of heating steam, mass flow rate of liquid waste, the input and output of steam temperature, and the input and output of liquid waste temperature. The energy for evaporation can be calculated, than the clean and dirty overall heat transfer coefficient can be calculated, so the fouling factor can be obtain. The removing of fouling scale or descaling process is performed by immersion of evaporator circuits using nitric acid solution of 10% weight concentration, and by mechanical brushing during maintenance activity. The prevention, monitoring, and removing of scale fouling on the operation of evaporator is described on the paper.

Keywords: Prevention, Monitoring, Removing, Fouling Factor, Evaporator

1. Introduction

Evaporation is the concentrating process of a matter solution by vaporization of its solvent to obtain the concentrate and distillate. For water as the solvent, the distillate is water condensate. In general, the industrial scale evaporator utilizes saturated steam as heating medium and tubular heating surface for the construction form. This evaporator has the effective and economical heating surface area. The concentrating of liquid radioactive waste by evaporation using tubular heating surface evaporator is effective method for decontamination of liquid waste. Radioactive matters is concentrated on the concentrate giving the decontamination factor (F.D) of 104 - 105 for Cs – 137. The F.D is initial activity of raw liquid waste divided by the activity of distillate result [1,2,3].

The heat giving by heating medium of saturated steam flowing on the shell side to the solution flowing on the tube side through the heat transfer resistance of outside thin film of fluid, metal thickness and inside thin film of fluids is influenced by properties of liquid i.e salting, scaling, fouling, and corrosion. Salting is the formation of chemical salt deposit on the heat transfer surface wall. Thickness of the deposit increases on the increasing temperature. Scalling is the formation of scale
deposit on the heat transfer surface wall cause of permanent hardness salts on the boiling solution. Fouling is the formation of deposit or sediment due to the properties of feed solution to the evaporator. The corrosion is erosion of heat transfer wall due to chemical properties of solution feed. On the corrosion mechanism for heat transfer wall containing iron metals, there is the creating of iron oxide deposit on the wall. The presence of salting, scalling, fouling, and corrosion provoke the process of thickening of heat transfer wall so the heat transfer resistance will increase. The increasing of heat transfer resistance provokes the decreasing of overall heat transfer coefficient, so the consumption of heating steam increases for the constant evaporation capacity. The bigger consumption of heating steam provokes the safety risk of accident [4,5,6,7].

Evaporation System on the Radioactive Waste Management Installation Serpong having the thermosiphon circulating thermal evaporator type is utilized for treatment the liquid radioactive waste having the maximum activity of $2 \times 10^{-2}$ Ci/m$^3$ to becomes the radioactive concentrate of 1 Ci/m$^3$ and normal water distillate. The feed of liquid radioactive waste contains the main radionuclides of Cs-137 and Co-60 on the pH about 7, and the salt of permanent hardness CaSO$_4$ and MgSO$_4$ on the ratio of 2 : 1. The evaporation operation is performing from Monday morning to Friday afternoon only. The heat transfer resistance of scale of permanents hardness deposit is the main heat resistance on the evaporator[1,2,3].

The presence of scale on the evaporator gives the unprofitable conditions i.e increasing of the capital investment cause of the evaporator oversize due to bigger heat transfer surface area, increasing energy cost for same evaporator capacity cause of the presence of fouling heat transfer resistance, the presence of time loosing for maintenance and descaling, the chemical cost for descaling, and the decreasing of production capacity cause of decreasing of production time comparing the condition without fouling [8,9,10]. Preventive step to prevent the formation of scale fouling can be performed by utilization of chemical inhibitor for establishment of the complex compound of Ca and Mg. The prevention of scale fouling formation is the best step comparing the removing of scale fouling [9,10,11,12,13]. The next sequence of action performing during evaporation operation is monitoring of fouling factor RD by reading of operating parameter and then calculating operating the value of RD. After the previous step of prevention and then monitoring of scale fouling, next action is the removing of formed scale fouling on the circuit of evaporator by immersion of the circuits evaporator using nitric acid 10% during 2.5 days from Friday afternoon to Monday morning, following washing with water [7]. This method is performing on the evaporator after operation perioide in which the value of fouling factor from monitoring calculation is superior than its minimum value. The second method of scale removing is mechanical cleaning by brushing of inside tube wall of evaporator performing during period of maintenance or overhaul of installation.

2. Theory

2.1. Scale Fouling Forming

Scale fouling forming is the process of complex crystallization by sequences of nucleation, diffusion, mass transfer, chemical reaction, and conformity of geometric pattern for molecules and atoms of scale fouling crystals, etc. For the salts of permanent hardness, its solubility decreases by increasing of temperatures, as shown on the Figure 1 [9,10]. On the concentration value of solubility, the solution has on condition of saturated in which nucleation and crystal core already exist.
On the increasing temperature, the saturated solution changes to supersaturated solution in which mass transfer of solute or component occurs from solution to crystall core. According to the Figure 1, unsaturated solution on point A will be becomes saturated solution on point B by solution heating. When solution heating continued to point C, the saturated solution on point B changes to supersaturated solution on point C, mass transfer of solute from solution to crystall core occurs, and the crystall core grows rapidly and to becomes big size dimension and then setting down by gravitation. After separation of crystall form solution, the obtaining of saturated solution is represented by point D. The schema of scale fouling formation is shown on the Figure 2. The Figure 2 indicates that the soluble mineral solution after having supersaturated condition, the growing of crystall and then scale fouling formation occurs [9,10,11].
2.2. *Prevention of Scale Fouling Formation*

Utilization of chemicals additive can influence to the retardation of crystall growing on the solvent media of water. The chemical method for prevention of scale fouling formation related with effect of additive to negate the processes of nucleation, precipitation, and solut sticking on the heating surface. The chemicals utilizing for scale inhibitor functions by mechanism of chelating sequestration, complexation, anti precipitation etc. Chelating is bonding of molecules of organic or anorganic to metals ions to form soluble or non soluble complex compound. Sequestration is bonding between organic compound and metal ions as in a chelate complex that is capable of removing or inactivating the formation of scale fouling. Chelation and sequestration processes began by adsorption mechanism of metals ion with organic compound following the complex formation for inactivating the formation of scale fouling [9,11,12,13,14,15,16].

Sequestring agent utilizing for removing the formation of scale fouling is usually nitrilotriacetic acid (NTA), ethylene diamin tetraacetic acid (EDTA), hydroxyethyl ethylene diamine triacetic acid (HEDTA), etc. When sequestring agent is added to the solution containing the permanent hardness salt so the complex compound formed, the complex formation can remove the scale fouling formation.

When there are two or more metal ions on the solution so the competition between metals to sequestring agent occurs. Metal having the superior affinity will be firstly taked to adsorption by sequestring agent. The sequence of affinity power for diverse ions are indicated as follows [9,11]

\[ \text{Na}^+ < \text{Ba}^+ < \text{Mg}^{2+} < \text{Ca}^{2+} < \text{Fe}^{2+} < \text{Cu}^{2+} < \text{Fe}^{3+} \]  

(1)

The reaction of complex formation between EDTA and metal ions shows by the following reaction:

\[ 4 \text{M}^{n+} + \text{H}_4\text{EDTA} \rightarrow \text{M}_4(\text{EDTA})^n + 4 \text{H}^+ \]  

(2)

The EDTA forms the complex compound with the ion of Ca^{2+} more than the complex compound with Mg^{2+}. For complex formation of one ppm of ion Mg^{2+} needs the EDTA on the quantity of 12 ppm, the concentraton of EDTA and other sequestring agent needed for complex formation of the diverse ion are indicating on the Table 1.

| Complexation Matter                  | Solubility g/100 ml H_{2}O-79F | Number (ppm) needed for complexation of 1 ppm ion of Mg, Ca, and Ba |
|--------------------------------------|-------------------------------|---------------------------------------------------------------|
| EDTA                                 | 0.02                          | Mg\^{2+}  Ca\^{2+}  Ba\^{2+}                                     |
| Disodium ethylene diamine tetraacetic dihydrate | 11.10                        | 12.0  15.4  9.5  2.1                                          |
| Trisodium ethylene diamine tetraacetic monohydrate | 57.00                        | 15.6  9.6  2.8                                              |
| Tetrasodium ethylene diamine tetraacetic dihydrate  | 103.90                       | 16.9  10.4  3.0                                             |

2.3. *Monitoring of Fouling Factor During Evaporation Operation*

The existing evaporator on the Radioactive Waste Management Installation (RWMI), Serpong, Tangerang Selatan is a single pas tubular evaporator exchanger type, the liquid waste flows through tube-side and heating steam through shell side. Specifications of the evaporator on RWMI are stainless steel 316 L of material construction, 43 pieces of tube number, 42.4 mm of tube outside diameter, 35,05 mm of tube inside diameter and 2670 mm of pipe length as shown on the Table 2 [2,17]

| Complexation Matter                  | Solubility g/100 ml H_{2}O-79F | Number (ppm) needed for complexation of 1 ppm ion of Mg, Ca, and Ba |
|--------------------------------------|-------------------------------|---------------------------------------------------------------|
| EDTA                                 | 0.02                          | Mg\^{2+}  Ca\^{2+}  Ba\^{2+}                                     |
| Disodium ethylene diamine tetraacetic dihydrate | 11.10                        | 12.0  15.4  9.5  2.1                                          |
| Trisodium ethylene diamine tetraacetic monohydrate | 57.00                        | 15.6  9.6  2.8                                              |
| Tetrasodium ethylene diamine tetraacetic dihydrate  | 103.90                       | 16.9  10.4  3.0                                             |

Table 2. Specification of evaporator on Radioactive Waste Management Installation[2,17]
No | Specification of Evaporator | Operational Data from Evaporator Control Panel
--- | --- | ---
1. | Material Construction | Stainless Steel 316 L | Mass flow rate of steam 950 kg/h
2. | Number of tubes (Nt) | 43 pieces | Inlet temperature of steam (T₁) 120°C (=248°F)
3. | Length of tubes (Lt) | 2670 mm | Outlet temperature of condensate (T₂) 120°C
4. | Outside diameter of tubes (OD) | 42 mm | Latent heat of condensation steam (λs) 1164 Btu/lb
5. | Inside diameter of tubes (ID) | 35.05 mm | Inlet temperature of liquid waste feed (t₁) 30°C (86°F)
6. | | | Outlet temperature of liquid waste (t₂) 100°C (212°F)

The quantity of heat needed for evaporation of liquid waste (Q) is given by the following equation [18,19]:

\[ Q = m_F \times C_p F \times ((BP)_F - t_1) + m_F \times \lambda_F = m_F \times \lambda_s \]  

Where:
- \( m_F \) = mass flow rate of liquid waste,
- \( C_p F \) = heat capacity of liquid waste,
- \( (BP)_F \) = boiling point of liquid waste,
- \( t_1 \) = inlet temperature of liquid waste,
- \( \lambda_F \) = latent heat of vaporization for liquid waste,
- \( m_s \) = mass flow rate of steam,
- \( \lambda_s \) = latent heat of condensation of steam.

The value of \( Q \) can be calculated by utilizing operational data of \( m_s \) and \( \lambda_s \).

The quantity of overall heat transfer is given by the following equation [19]:

\[ Q = U_D \cdot A \cdot \Delta T \]  

Where:
- \( U_D \) = overall heat transfer coefficient on dirty condition,
- \( A \) = surface of heat transfer,
- \( \Delta T \) = temperature difference of hot fluid and cold fluid.

The surface area of heat transfer \( A \) is calculated according the following equation:

\[ A = \pi D L_t \cdot N_t \]  

Where:
- \( D \) = tube diameter,
- \( L_t \) = Length of tube,
- \( N_t \) = number of tube.

The overall heat transfer coefficient on dirty condition \( U_D \) is being calculated by equation 4 is defined by the following equation [19]:

\[ \frac{1}{U_D} = \frac{1}{U_c} + R_D \]  

Where:
- \( U_c \) = overall heat transfer coefficient on clean condition,
- \( R_D \) = Fouling factor.
The overall heat transfer coefficient on clean condition $U_c$ is defined by the following equation [19]:

$$\frac{1}{U_c} = \frac{1}{h_i} + \frac{1}{h_o}$$  \hspace{1cm} (7)

Where:
- $h_i$ = inside surface heat transfer coefficient
- $h_{io}$ = inside surface heat transfer coefficient modified
- $h_o$ = outside surface heat transfer coefficient, has value of zero for steam as heating medium.

The value of $h_i$ is determined by the following equation [19]:

$$h_i = J_n \frac{k}{De} \left( \frac{C_p \mu}{k} \right)^{\frac{1}{3}}$$  \hspace{1cm} (8)

Where:
- $K$ = conduction heat transfer coefficient of liquid
- $De$ = equivalent tube diameter
- $C_p$ = heat capacity of liquid
- $\mu$ = viscosity of liquid

The value of $J_n$ is determined from Figure 24 of Kern in which the Reynold number (Re) first to be calculated.

The Reynold Number is calculated by the following equation [19]:

$$Re = \frac{Gt \cdot De}{\mu}$$  \hspace{1cm} (9)

Where:
- $Gt$ = mass flow rate of liquid (lb/h.ft$^2$), $De$ = equivalent diameter of tube (ft)
- $\mu$ = liquid viscosity (lb/h.ft$^2$)

3. Material And Method

3.1. Material

Materials for the experiment are pro-analysis chemicals from E.Merck i.e powders of MgSO$_4$, CaSO$_4$, NaOH, HNO$_3$, and EDTA.

3.2. Equipment

The equipment utilizing on the experiment are pH meter, atomic absorption spectrophotometer(AAS), and evaporator.

3.3. Method

3.3.1. Prevention of scale fouling formation

Weighed 8.333 g CaSO$_4$, 4.167 g MgSO$_4$ and 28.3 g EDTA. Thats three substances are mixed, and introduced to the three-neck rounded flask, then added the distilled water until the mixture volume of 500 mL. The pH condition is arranged to be 7 by addition of NaOH solution on the three-neck rounded flask, then the solution is heated to 100°C using electrical heater. During boiling of solution, the solution levels is made constan by addition of solution for replacing the vaporized water. After boiling period of 1; 1½; 2; 2½; and 3 hours, the each solution is passed over the cation exchanger resin column for binding the rest of free cation (uncomplex cation). The solution then is analyzed its cations concentration of Ca$^{+2}$ and Mg$^{+2}$. The result value of concentration of Ca$^{+2}$ and Mg$^{+2}$ are the complexation cations.

3.3.2. Method for Monitoring of Fouling Factor During Evaporation Operation

The $R_{D_{min}}$ obtaining from Table 12 Kern, is the sum of $R_{Di}$ that is fouling factor for liquid waste and $R_{do}$ that is fouling factor for pure steam. The value of $Q$ is calculated by utilization of equation 3 and the operational data of ms and $J_s$. The heat transfer surface area $A$ is calculated using equation of 5.
and dimension of tube data. The overall heat transfer coefficient $U_D$ is calculated from equation 4. The overall heat transfer coefficient $U_C$ are obtained from equation of 7 in which the value are obtained from equation of 7 in which the value of $h_i$ calculated from equation of 8, and the value of $h_{io}$ from equation of 10. The value of calculated $R_D$ is obtained from equation 11.

### 3.3.3. Method for Descaling Process

The descaling process is performed when the calculated $R_D$ being superior to $R_D_{min}$ by immersion of 43 pieces of inside tube wall and its circuit using nitric acid of 10% during 2.5 days from Friday afternoon to Monday morning, following washing with water. After that immersion during 2.5 days, the nitric acid is drained from circuit of evaporator. On the shutdown of plant that the overhaul is performed, the descaling operation is undertook by mechanical brushing of inside tube wall of evaporator.

### 4. Result and Discussion

Preparation result of simulation liquid waste giving the liquid waste contains permanent hardness salt of 2.5% on the ratio of CaSO$_4$ to MgSO$_4$ 2 : 1, contents of Ca and Mg 4.902 and 1.693 ppm respectively. From Table 1, the needs of EDTA to complex calcium ion and Mg ion are 36.273 and 20.316 ppm of EDTA respectively. The total needs of EDTA is 56.594 ppm, so the needs of EDTA for 500 mL of solution is 28.3 ppm. During boiling of solution on 100°C will occur the reaction of EDTA and ions of Ca and Mg to form complex compound of EDTA-Ca and EDTA-Mg. The result experiment of complex formation between EDTA and ions of Ca and Mg as a function of time are shown on the Table 2.

#### Table 2. Relation between evaporation time and number of complexation cation

| Evaporation Time (h) | 0    | 1    | 1.5  | 2    | 2.5  | 3    |
|----------------------|------|------|------|------|------|------|
| Number of complexation cation, ppm | 7.595 | 3.500 | 4.500 | 5.500 | 4.800 | 2.200 |

On the Table 2, it is indicated that the number of complexation cation increases on the increasing of evaporation time. The optimum result is evaporation time of 2 h giving the number of complexation cation of 5.500 ppm or 72.42% of initial concentration. Evaporation time of 2 h can be interpreted of residence time of solution on the evaporator. According to the Table 2, the increasing of evaporation time gives the increasing of complexation cation number. After evaporation time 2 hour there is decreasing of complexation cation number when the evaporation time increases, it is indicated that complexation reaction is exothermic. Before utilization of chemical inhibitor EDTA, the prevention of scale formation is performed by separation of soluble and suspended solid.

From the operating condition process of evaporation is given the following available data from control panel:

- $m_s = 950$ kg/h = 2,094.26 lb/h; $T_1 = 120\, ^\circ C = 248\, ^\circ F$; $T_2 = 248\, ^\circ F$, $t_1 = 28\, ^\circ C = 82.4\, ^\circ F$; $t_2 = 100\, ^\circ C = 212\, ^\circ F$, $\lambda_s = 1164$ BTU/h

Using equation 3 and that’s above data, the value of $Q = 23,437,835.04$ BTU/h, by using equation 5, $A = 136.0167$ ft$^2$, by using equation 6, $U_0 = 211.038$ BTU/h.ft$^2$.F, for steam as heating medium, $h_o = 1500$ BTU/h.ft$^2$.F

The value of $U_C$ can be calculated using equation of 7, it is obtained $U_C = 391.7469$ BTU/h , determined by the following steps :

- From the Table 10 Kern, the value flow area per tube $A = 1.54$ in$^2$, total flow area for 43 pieces of tube = 0.4599 ft$^2$.
- The value of $G_t = 4794.0362$ lb/h; $De = 0.1166$ ft; $\mu = 0.06292$ lb/ft.h and $Re = 888.4053$.

From Figure 224 Kern using $Re = 888.4053$, the value of $JH = 40$

From equation 8, $hi = JH \left[ \frac{CP\,i}{\lambda} \right]^{1/3}$
Where: \( k = \) Conductivity of liquid waste = 0.398 BTU/h.ft²; \( C_p = 1 \) BTU/lb.°F

The value of calculated \( h_i = 716.0935 \) BTU/h.ft².°F

\[
\frac{1}{U_c} = \frac{1}{595.3066} + \frac{1}{1500} \\
U_c = 391.7469 \text{ BTU/h.ft}^2.°F \\
R_d = \frac{U_c - U_D}{U_c} = 0.00218
\]

Calculated fouling factor \( R_D = 0.00218 \)

From Table 12 Kern:

\( R_{D_i} = 0.001 \) (For liquid waste)

\( R_{D_o} = 0 \) (For steam)

\( R_{D_{min}} = R_{D_i} + R_{D_o} = 0.001 \)

According the value of calculated \( R_D > R_{D_{min}} \), it is necessary to descaling the circuit of evaporator.

The descaling process is performed by immersion of the evaporator circuit during 2.5 days or 60 hours using nitric acid 10%, after that the solution is draining and then the circuits are washing with service water. On Monday morning, the initial operation is beginning, first by filling of the evaporator with liquid waste and then heating the solution by flowing of heating steam and putting the operation configuration. After the continuous operation, the monitoring of fouling factor is repeated again to know the value of exist fouling factor of the calculation results. On the shut down conditions in which the overhaul of plant be performed, there are dismantling of the installation, on parallel activity, the descaling operation is undertook by mechanical brushing of inside tube wall of evaporator.

5. Conclusion

The evaporation system in Radioactive Waste Management Installation, Serpong, processes 75 m³/h of liquid waste having a maximum activity of 2 x 10⁻² Ci/m³ into radioactive concentrate with the maximum activity of 1 Ci/m³ and non contaminated water distillate. The prevention of scale fouling formation is performed first by separation of soluble and suspended solid by sedimentation process on the storage tank.

The second step of scale prevention is by utilization of chemical inhibitor of EDTA in which the dose of EDTA mixing with the liquid waste to the quantity of 56.594 ppm. The scale deposit accumulating all along the inside wall of tube of evaporator heat exchanger controlled by evaluation of the fouling factor \( R_D \). The value of \( R_D \) minimum according the type of fluid on Table 12 Kern, \( R_{D_i} \) for liquid waste flowing through the tube-side valuable \( 0.001 \) and \( R_{D_o} \) for steam flowing through shell-side valuable \( R_{D_{min}} = 0.001 \). So when the value of calculated \( R_D \) being significant superior to \( R_{D_{min}} \), the descaling process must be performed by chemical rinsing methode using nitric acid 10% or by mechanical method.

6. References

[1] SALIMIN, Z., SUPARDI, and YANTO, “Basic Design of Evaporator for Treatment of Radioactive Liquid Waste, Raising from Reactor Facility and Its Supporting Laboratory in PPBMI – BATAN”. Proceedings of The Symposium for Nuclear Fuel Element Technology and Reactor Technology, Bandung, Oktober 1982.

[2] SALIMIN, Z., “Low and Medium Level Radwaste Processing Treatment in Serpong Nuclear Facilities”, Proceeding of The Symposium on Waste Management at Tucson, Arizona, February 27 – March 3 1994.

[3] SALIMIN, Z., “Evaporation of Liquid Radioactive Waste Containing Detergent Using Silicone Oil Antifoaming”. Proceedings of The Symposium for Wasted Treatment Technology I. Serpong, 10-11 December 1997.

[4] HASSON, DAVID, AVRIEL and WILLIAM, “Mechanism of CaCO3 Scale Deposition on Heat Transfer ufaces”, I and EC Fundamental, Vol. 7. No. 1, 1968.

[5] HASSON, DAVID and ZAHAWL, “Mechanism of Calcium Sulfate Scale Deposition on Heat Transfer Surfaces”, 1 nd EC Fundamental, Vol. 9, No. 1, 1970.

[6] SALIMIN, Z., “Identification of: Heat Transfer Resistance for Scale Deposit on Evaporator of
Serpang Radioactive Waste Treatment Installation. Proceedings of The Symposium and Scientific Presentation of Basic Knowledge and Nuclear Technology, Yogyakarta, 25-26 July 2000.

[7] SALIMIN, Z., “Problem Solving of Evaporator Operation on Treatment of Radioactive Liquid Waste in Serpong Nuclear Facilities”, Proceedings of The Symposium on Waste Management at Tucson, Arizona, February 27 - March 3, 2000.

[8] THACKERY, P.A., “The Cost of Fouling in Heat Exchange Pant”, Effluent and Water Treatment Journal, Vol. 20, 1980.

[9] ELLIOT, M.N., “The Present State of Scale Control in Sea Water Evaporator”, Desalination Vol. 6, No. 87, 1969.

[10] SALIMIN, Z., “Cost of Heat Exchanger Fouling of Evaporator for Treatment of Radioactive Liquid Waste”, Proceeding of The National Symposium on Technology and Safety of Nuclear Power Plant and Other Nuclear Facilities, Surakarta, October 17th, 2009.

[11] OTHMER, K., Encyclopedia of Chemical Technology, Crystalization”, Vol. 6, John Wiley and Sons, New York, 1965.

[12] Betz Handbook of Industrial Water Conditioning, 6th Ed, Betz Laboratories Inc., Trevose, 1962.

[13] SEEL, “Industrial Water Pretreatment”, Chemical Engineering, February 26, 1973.

[14] BOZEMAN, H.C and FINN, P.A, “What You Need to Know About Chemical Cleaning of Processing Equipment, The Oil and Gas Journal, Vol. 59 No. 2, 1965.

[15] LOUCKS, C.M, “Boosting Capacities With Chemicals”, Chemical Eng. Deskbook Issue, Feb. 28, 1973.

[16] SPIEGLER, K.S., “Salt Water Purification”, John Wiley and Sons, Inc., New York, 1962.

[17] SALIMIN, Z., and GUNANDJAR, “Utilization of EDTA as Prevention of Scale Fouling Formation on Evaporation of Wasted Liquid Radioactive”. Proceedings of Result and Activities of year 2006 in PTLR. Tangerang, 21-22 March 2007.

[18] BADGER, W.L. and BANCHERO, J.T., “Introduction to Chemical Engineering”, 28th Ed, McGraw-Hill Book Co., Singapore, 1985.

[19] KERN, D.Q., “Process Heat Transfer”, Mc.Graw Hill Book Co, Singapore, 1984