

Decreasing In Freshwater Production Due To Vacuum Pressure Decreasing On Multi Effect Distillation Installation

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Abstract

A case study in a steam power plant has been conducted and reported. There was a case of decrease in the freshwater production rate in multi effect distillation installations that may disrupt the operation of the power plant. The cause was suspected by the drop in vacuum pressure in the evaporation chamber. The study was conducted by studying the MED installation process diagram and performing the theoretical calculations of energy and mass equilibrium in each chamber. To make it easier to find the properties of water in the energy calculation then add ins water_97 in Microsoft Excel is added. Calculations were undertaken in two modes, commissioning period and 2016 operation mode. The difference of the two modes was vacuum pressure level in each chamber. Vacuum pressure level in 2016 operation mode was lower than commissioning mode. The calculation at commissioning mode resulted in a production rate of 133.56 ton/h, while the actual condition at that time was 127 ton/h. Calculations in 2016 operation mode produced a theoretical fresh water production rate of 101.37 ton/h.

Keywords: MED installation, vacuum pressure, evaporation chamber, commissioning period.

Abstrak

Kata kunci:

I. INTRODUCTION

Circulating freshwater in the steam power plant cycle is the product of the MED (multi effect distillation) or MSF (multi stage flashing) installation. In the MED installation, sea water is processed into freshwater through a series of multi chamber distillations. Each chamber is subjected to a vacuum pressure to enlarge the evaporation of seawater. The change of sea water into freshwater in MED installation embraces flashing desalination system [1].

The flashing desalination process works under vacuum pressure to allow the evaporation process to take place at lower temperatures. The desalination process takes place from one chamber to the next and the resulting of freshwater is the accumulation of production in each chamber [2].

In one of the steam power plants in Indonesia, the MED installation produces 127 ton/hour of freshwater during commissioning test [1]. Several years after commissioning in

2016, there has been a significant decrease in freshwater production and only 50 - 55 ton/h remaining.

The MED installation consists of 8 vacuum chambers with varying vacuum pressure levels. The vacuum environment inside the chamber is generated by vacuum ejector acting at an output pressure of 7.1 kPa. Sea water as feed water is firstly supplied to the chamber-8 and sprayed inside the chamber. On the other hand, the auxiliary steam from the boiler is supplied to the pipe inside the Chamber-1. As a result of sea water spray to the tube wall containing steam, steam inside the tube is condensed and sea water is evaporated. Condensation of steam produces freshwater condensate and evaporated sea water flows into the tube of the second chamber. In the second chamber, seawater is sprayed and make in contact with evaporated vapor pipe in the first chamber. The sea water particle evaporates and the vapor inside the pipe condenses. Then the vapor flows into the pipe in the third chamber and so on [1].

The vapor fraction within each chamber affects the production of freshwater condensate. The vapor fraction itself

is affected by the vacuum pressure in each chamber. The higher the vacuum pressure the greater the vapor fraction and freshwater production. The declining rate of freshwater production within MED installations are suspected by decrease of vacuum pressure in each chamber. This decrease in freshwater production rate is then compared with freshwater production during commissioning test.

Theoretically, the rate of freshwater production during commissioning can be calculated by applying the principle of energy equilibrium in each chamber and knowing the state in each chamber. Likewise, when MED is operated in 2016, freshwater production rates may be predicted. Both are compared in order to know whether the decrease of vacuum pressure in the chamber is one cause of the decrease in freshwater production.

II. RESEARCH METHODOLOGY

To prove the hypothesis of the decrease of freshwater production in the MED installation, the first step was to collect MED-operation data at commissioning, 2016 operation and process diagram of the MED installation. The operating data collected was presented in Table 1 and the MED process diagram was shown in Figure 1.

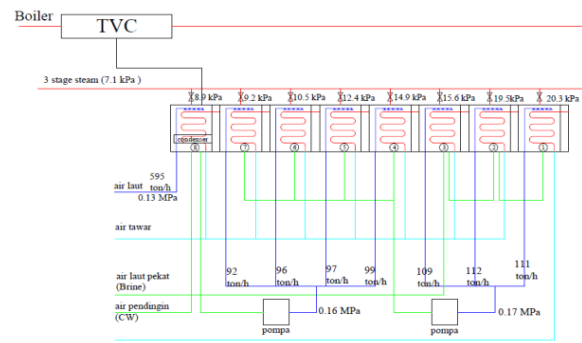
The data presented in Table 1 clearly showed that the vacuum pressure in each chamber decreases, as well as the feed water flow. Whether this decrease affects the rate of freshwater production needs to be proven by thermodynamic calculations. Calculations in each chamber were undertaken then the result was accumulated and compared with the actual operation data.

TABEL I
OPERATING DATA MED INSTALLATION [3, 4]

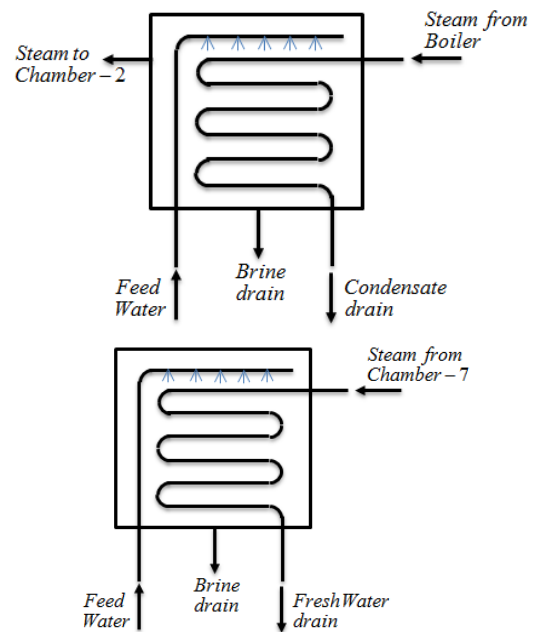
CHAMBER	COMMISSIONING		2016 OPERATION	
	Vacuum Pressure (kPa-a)	Feed Water Flow (ton/h)	Vacuum Pressure (kPa-a)	Feed Water Flow (ton/h)
1	20,3	111	27,2	103
2	19,5	112	24,9	103
3	15,6	109	22,5	118
4	14,9	99	17,2	100
5	12,4	97	19,0	82
6	10,2	96	16,9	76
7	9,2	92	15,7	67
8	8,9	595	10,6	595

The process in the MED installation as shown in Figure 1 exhibited the feed water transfer, steam and vacuum air transfer routes. Pressurized seawater as feed water at 0.13 MPa and 30°C was first supplied to chamber-8 (condenser). The remaining seawater in chamber-8 was then discharged by a 0.16 MPa (gage) pressure pump to chamber 4, 5, 6 and 7. Similar to chamber 8, in other four chambers the water evaporated and the remains was collected in the bottom of the chamber. The remaining non-evaporated seawater was a concentrated solution (brine). The accumulation of concentrated seawater was redistributed by other pumps with a pressure of 0.17 MPa (gage) to chamber 1, 2 and 3. Thus in chamber 1, 2 and 3, the water evaporated and the remaining

fell down at the bottom of the chamber and accumulated to form concentrated seawater and removed from the MED installation.



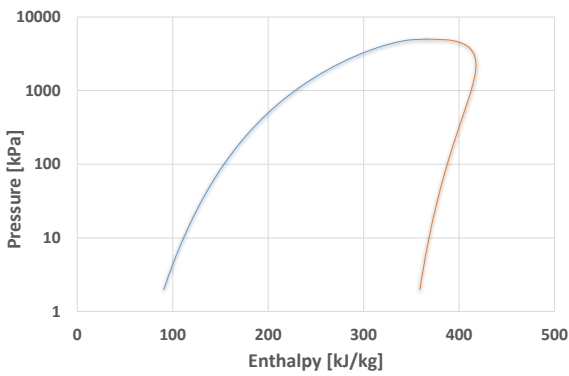
Gbr. 1 MED Process Diagram [1]



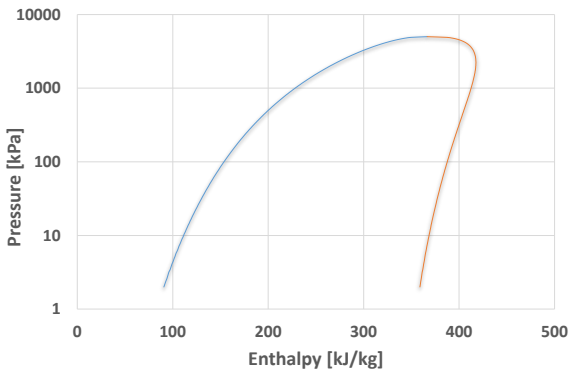
Gbr. 2 MED Process Diagram [1]

Steam as a fluid which is transformed to freshwater was firstly supplied from Boiler to chamber-1 inside the tubes. In the other side, seawater was evaporated outside the tubes due to contact with the hotter tube wall. Seawater particles evaporated rapidly in the vacuum environment. Generated steam was then discharged to chamber-2 and experienced the same phenomenon as chamber-1, and so on respectively occurs in chamber 3, 4 until the last chamber.

Evaporation of seawater particles inside the chamber was accelerated by vacuum environment. The vacuum environment was generated by a steam ejector. When commissioning period was analyzed, output pressure of the ejector achieved to 7.1 kPa and produced difference level of vacuum pressure in every chamber. Higher vacuum pressure of 8.9 kPa occurred in chamber-8 and lower in chamber-1. The data's of vacuum pressure in every chamber was shown in Table 1.



Gbr. 3 Thermodynamic Diagram of Throttling Process in Chamber-8



Gbr. 4 Thermodynamic Diagram of Throttling Process in Chamber-1

The flow of feed water, vapor and brine was clarified through the flow conditions within each chamber as in Figure 2. In chamber-1, the steam from the Boiler was supplied to the chamber via tubes and condensed inside the tubes. The condensate was not a freshwater product that will be accommodated and accumulated with other freshwater. Feed water was supplied to the chamber and sprayed into water particles which then evaporated and most of them fell down into the brine basin. The resulting vapor was used to supply water vapor into chamber-2. The process diagram in chamber-8 was shown in Figure 2. The difference with chamber-1 lied in where the water vapor supply comes from and the resulting freshwater product.

The calculation of freshwater production from the MED installation was carried out by the analysis of thermodynamic equilibrium in each chamber with refer to the principle of energy and mass equilibrium as shown in Figure 2 and Figure 3. The volume of produced freshwater in a chamber was the vapor fraction generated from the throttling process. The volume of the throttling process in the chamber illustrated by the P-h diagram was shown in Figure 3 and Figure 4. From the diagram, the vapor fraction in the chamber may be calculated and the quantity was the volume of produced freshwater. Each chamber showed a different vapor fraction due to the difference in vacuum pressure.

To account for the vapor fraction (x) and enthalpy (hf and hg) was sought with refer to the vacuum pressure (Pvac) in each chamber. The enthalpy value was found by MS Excel with add-ins water97_v13.xla function which refers to IAPWS

standards (International Association for the Properties of Water and Steam) [5].

$$\begin{aligned} s_f, s_g &= s(P_{vac}) \\ h_f, h_g &= h(P_{vac}) \end{aligned} \quad (1)$$

For calculating vapor fraction, Equation 2 may be used. Enthalpy (h) was a property of sub-cooled feed water at upstream pressure and temperature of throttling process. Due to iso-enthalpy process within throttling process, the enthalpy value would be same at upstream and downstream state.

$$x = \frac{h - h_f}{h_g - h_f} \quad (2)$$

Vapor and brine product can be calculated by using Equation 3 and Equation 4. Each chamber has feed water flow value () and multiplied by vapor fraction to obtain water vapor product (). The brine product () itself was difference of feed water flow and vapor product.

$$\dot{m}_{steam} = x \times \dot{m}_{FW} \quad (3)$$

$$\dot{m}_{brine} = \dot{m}_{FW} - \dot{m}_{steam} \quad (4)$$

III. RESULT AND DISCUSSION

Thermodynamic state calculation of MED installation was carried out in two mode operations: commissioning mode and 2016 operation mode. The commissioning mode calculations were shown in Table 2 and Table 3, while 2016 operation mode calculations were presented in Table 4 and Table 5. Vapor and brine product calculation as seen in Table 3 and Table 5 referred to mass balance principle in each chamber.

TABEL 2
THERMODYNAMIC STATE CALCULATION IN COMMISSIONING MODE

CHAMBER	Feed Water			
	Flow (ton/h)	Pressure (bar-a)	Temp (°C)	Enthalpy (kJ/kg)
1	111	2.7	Sat.	546.25
2	112	2.7	Sat.	546.25
3	109	2.7	Sat.	546.25
4	99	2.6	Sat.	540.88
5	97	2.6	Sat.	540.88
6	96	2.6	Sat.	540.88
7	92	2.6	Sat.	540.88
8	595	2.3	30	125.32

CHAMBER	Vapor				
	Press (kPa-a)	T (°C)	hr (kJ/kg)	hg (kJ/kg)	X (%)
1	20,3	Sat.	252.75	2609.51	12.5
2	19,5	Sat.	249.11	2608.00	12.6
3	15,6	Sat.	229.34	2599.73	13.4
4	14,9	Sat.	225.36	2598.06	13.3
5	12,4	Sat.	209.67	2591.45	13.9
6	10,2	Sat.	193.43	2584.58	14.5
7	9,2	Sat.	185.04	2581.01	14.9
8	8,9	Sat.	182.36	2579.87	0

From Table 2, the feed water state in each chamber was considered as saturated water except in chamber-8 was treated

as sub-cooled water. By applying iso-enthalpy principle in throttling process, it would yield vapor fraction in each chamber.

TABEL 3
VAPOR AND BRINE PRODUCT IN COMMISSIONING MODE

CHAM BER	Feed Water Flow (ton/h)	Vapor Fraction (%)	Vapor Product (ton/h)	Brine Product (ton/h)	Fresh Water Production (ton/h)
1	111	12.5	13.82	97.18	0
2	209.18	12.6	26.36	182.82	13.82
3	291.82	13.4	39.11	252.71	26.36
4	99	13.3	13.17	85.83	39.11
5	97	13.9	13.49	83.51	13.17
6	96	14.5	13.95	82.05	13.49
7	92	14.9	13.66	78.34	13.95
8	595	0	0	595	13.66
TOTAL					133.56

Vapor fraction calculation in each chamber yielded vapor product for the next chamber. For instance, generated vapor in chamber-1 will flow inside the tubes in chamber-2 and will be condensed to produce freshwater. This freshwater was water product of chamber-2. The equal process occurred in the next chambers with the same principle. From those calculations, all freshwater products in each chamber were accumulated as freshwater production in MED installation. This would yield 133.56 ton/h freshwater production. When it compare with actual data, the freshwater production was only 127 ton/h. The difference might be come from the error of measurement reading of temperature, pressure and flow sensor in local. In every reading error will yielded deviation in freshwater product calculation of each chamber. Another source of error may came from many assumptions in calculation, for instance the feed water state was considered as saturated water when it came in throttling process. Unavailability of feed water temperature sensor in local to force the calculations was performed with that assumption.

TABEL 4
THERMODYNAMIC STATE CALCULATION IN 2016 OPERATION MODE

CHAM BER	Feed Water			
	Flow (ton/h)	P (bar-a)	T (°C)	H (kJ/kg)
1	103	2.0	Sat.	504.68
2	103	2.0	Sat.	504.68
3	118	2.0	Sat.	504.68
4	100	2.6	Sat.	540.88
5	82	2.6	Sat.	540.88
6	76	2.6	Sat.	540.88
7	67	2.6	Sat.	540.88
8	595	1.9	30	125.96

CHAM BER	Vapor				
	Press (kPa-a)	T (°C)	h _f (kJ/kg)	h _g (kJ/kg)	X (%)
1	27.2	Sat.	279.87	2620.72	9.6
2	24.9	Sat.	271.55	2617.29	9.9
3	22.5	Sat.	262.15	2613.41	10.3
4	17.2	Sat.	237.91	2603.32	12.8
5	19.0	Sat.	246.78	2607.02	12.5
6	16.9	Sat.	236.36	2602.67	12.9
7	15.7	Sat.	229.90	2599.97	13.1
8	10.6	Sat.	196.60	2585.00	0

For 2016 operation mode, operating data of MED installation was presented in Table 4. When it was compared with commissioning data, it might be seen that the vapor fraction was low. The influence of vacuum pressure played an important role to decrease vapor fraction in each chamber.

TABEL 5
VAPOR AND BRINE PRODUCT IN 2016 OPERATION MODE

CHAM BER	Feed Water Flow (ton/h)	Vapor Fraction (%)	Vapor Product (ton/h)	Brine Product (ton/h)	Fresh Water Production (ton/h)
1	103	9.6	9.89	93.11	0
2	200.18	9.9	19.49	176.62	9.89
3	300.82	10.3	30.39	264.23	19.49
4	100	12.8	12.81	87.19	30.39
5	82	12.5	10.22	71.78	12.81
6	76	12.9	9.78	66.22	10.22
7	67	13.1	8.79	58.21	9.78
8	595	0	0	595	8.79
TOTAL					101.37

Freshwater production as seen in Table 5 was 101.37 ton/h and this value was higher than the actual data which was only in between 50 – 55 ton/h. Once, the difference might be come from the error of instrumentation reading. However, the more important thing was the decrease of freshwater production influenced by decreasing of vacuum pressure in chamber. It has been a significant decline of freshwater production comparing with commissioning period. The declining will indeed impacted to the steam power plant operation due to freshwater supply from MED installation was disturbed. For maintaining fresh water supply to power plant in the future, the root cause and solution of vacuum pressure decreasing should be found.

IV. CONCLUSION

1. It has been proved that the cause of the decrease in fresh water production in the MED installation is due to the decrease in vacuum pressure.
2. From theoretical calculations in commissioning mode, all freshwater products in each chamber are accumulated as freshwater production in MED installation and yield 133.56 ton/h. When it compare to actual data, the freshwater production is only 127 ton/h.
3. In 2016 operation mode, calculated freshwater production is 101.37 ton/h. When it compare to actual data, the freshwater production is only 50 - 55 ton/h.

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