Analysis Water Content of Seawater Desalination Technology by Using Multistage Distillation

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ABSTRACT

Desalination technology, which has been the most widely utilized method of meeting the requirement for clean water for the past 50 years, can be employed in attempts to use seawater. The purpose of this study is to ascertain how variations in the composition of distilled water are affected by the multistage distillation of seawater from Cemara Sewu Beach, Bantul, Yogyakarta. LPG gas is used as fuel to heat sea water during the distillation process. To obtain distilled water, the seawater vapor is then condensed. Subsequently, the distillation procedure is executed in three phases, with every phase being evaluated using the distilled water. The overall CaCO3 hardness level in the first stage of distilled water is still high, thus it does not exceed clean water quality criteria. Meanwhile, in the second and third stages, there are two parameters, namely pH and total hardness level, which do not meet the clean water requirements. In general, the first stage of distilled water is sufficient to be processed into clean water with the addition of water hardness treatment. Repeated distillation has a tendency to reduce pH, total hardness, TDS, fluoride, nitrate and detergent.

1. Introduction

Water is the foundation for all biological and human activities. Water is thought to be a limitless natural resource. However, water's availability as a natural resource is limited due to its generally consistent hydrological cycle, resulting in a finite supply. Water quantity on Earth is unequal since it does not increase much over time [1]. More over 70% of the Earth's surface is covered by water, with saline water accounting for more than 97%. Only 0.007% of the world's freshwater is available for home consumption, highlighting the shortage of sustainable supplies [2]. The copious quantity of seawater should be harnessed to address human challenges.

Based on statistics from the World Resources Institute (WRI) regarding freshwater reserves in all countries, Indonesia is rated 51st and faces a significant danger of experiencing a crisis, with a chance ranging from 40% to 80%. Sea water is primarily utilized for desalination to obtain fresh water. Potable water is extensively utilized for agricultural, industrial, domestic, and ecological purposes. For this reason, water must be handled carefully using a thorough integrated approach. Clean water is essential to fulfill human needs to carry out all activities, so it is necessary to know how water can be stated to be clean in terms of quality and may be utilized in sufficient quantities in daily human activities. In order for human survival to run properly, clean water must also be available in enough quantities according to human activities in specific regions and certain periods of time [3].

The supply of clean water can be enhanced by utilizing sea water, but it cannot be used directly because the salt content is still high at 3% [4]. In Indonesia, the majority of people (particularly in rural regions) use groundwater to meet their clean water demands. They use dug wells to extract this groundwater. Well water is generally cleaner than surface water because the water that seeps into the ground has been filtered by the layers of soil through which it flows [5]. drinking water standards based on Decree of the Minister of Health of the Republic of Indonesia No. 492/MENKES/PER/IV/2010 concerning Drinking Water Quality Requirements. Parameter pH value, temperature, turbidity, color and total number of Coliform bacteria are standard contents for drinking water quality stipulated in Minister of Health Decree No. 492 of 2010 [6]. The relevance of employing alternative energy such as sea water to address water needs by investigating technical progress. Abundant saltwater still has complex composition and high concentrations of dissolved salts, therefore it needs to be treated through desalination [7].

The decreasing quantity of fresh water and increasing demand for water for human use, agriculture and industry have spurred the development of seawater desalination technology [8]. Desalination is a technique used to reduce the salt content in water by utilizing water dew droplets produced from water vapor [9], desalination technology aims to separate the salt content from sea water and the clean water product can be utilized for drinking water, industry, and agriculture so that research and development continue to be carried out to generate more cost-effective and efficient technology [10]. Desalination can be done by a thermal or membrane technique. Thermal procedures use techniques such as multi effect distillation (MED) and multi stage flash (MSF), whereas membrane processes use reverse osmosis (RO) and electrodialysis [11].

Distillation is a separation procedure by boiling seawater to produce water vapor, which is then condensed to produce clean water. In recent years, membrane-based desalination has gained popularity, displacing thermal techniques. Capacitive deionization method for desalination has gained popularity due to the superior ion sorption capacity of porous carbon electrodes [12]. The desalination process employing the distillation method obviously demands thermal energy. Renewable energy is a solution as an energy source [13]. Distillation technology or seawater distillation is the most often used way to create freshwater from seawater [14]. This research aims to determine the effect of multistage distillation on the content of distillate water from sea water to meet clean water needs. This task must be undertaken in light of the absence of any research that examines and investigates the outcomes of distilled water at each stage.

2. Research Methodology

2.1. Materials

The material used in this research are LPG gas from Pertamina and sea water taken on August 7 2023 from Cemara Sewu Beach, Bantul, Yogyakarta. The tools used in this research were a gas stove, a desalination tube, a cooling water tube, a water storage bottle, and a copper hose to circulate the distillate steam.

2.2. Procedures

Fresh Water Synthesis Process from Sea Water Using the Multistage Evaporation Method :

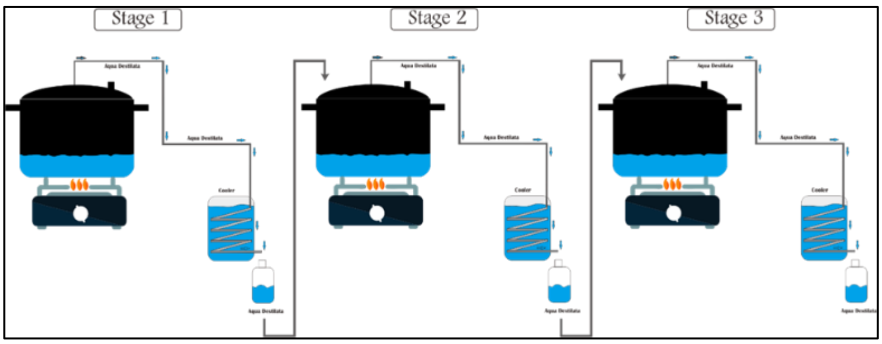

Fig 1. Multistage Distilation Method

The first stage begins with taking sea water. The 2 liters of seawater in the desalination tube are heated so that it evaporates, the resulting steam is channeled through a copper pipe from the desalination tube to a cooling water tube containing cold water. Next, the process of condensation of sea water vapor into distilled water occurs. This distilled water is then collected in a container bottle in stage 1. The sea water evaporation process is carried out until there is no more sea water left in the desalination tube, then the salt at the bottom of the distillate tube is taken and collected. In the second stage, the condensed water from the first stage is put into a desalination tube, then heated until it completely evaporates. The steam obtained is channeled to the cooling water tube so that the steam is condensed into distilled water. The distilled water is then collected in a stage 2 container bottle. Then the salt that is deposited in the desalination tube is collected and taken (if any). In the third stage, the same as in the second stage, the condensation water from the second stage is put into a desalination tube, then heated until it completely evaporates. The steam obtained is channeled to the cooling water tube so that the steam is condensed into distilled water. The distilled water is then collected in a stage 3 container bottle. Then the salt that is deposited in the desalination tube is collected and taken (if any). Next, the volume of distilled water from stages 1, 2 and 3 is measured.

Distilled water testing.

Clean water quality testing from distilled water stages 1,2, and 3. Testing was carried out at the Yogyakarta City Health Laboratory UPT. Jl. Sisingamangaraja No. 21 Brontokusuman, Mergangsan, Yogyakarta. Parameter testing was carried out as stated in Table 1. Meanwhile, testing for salt levels (NaCl) using the gravimetric method is carried out at the Testing and Calibration Laboratory, Health and Calibration Laboratory Hall, Yogyakarta Special Region Health Service, located at MJ III 62, Jl. Ngadinegaran, Mantrijeron, District. Mantrijeron, Yogyakarta City, Special Region of Yogyakarta

Table 1. Testing Clean Water Quality Standards

Parameter	Units	Quality Standar	Methods
Odor	-	No Odor	Organoleptis
pH	-	6.5 -9.0	Potensiometri
Iron (Fe)	mg/l	1.0	SNI 6989.4-2009
Manganese (Mn)	mg/l	0.5	SNI 6989.5-2009
Flouride (F)	mg/l	1.5	SNI 06-6989.29-2005
Nitrate (as NO_3-N)	mg/l	10	APHA 2017. Section 4500-NO3 B
Nitrit (as NO_2-N)	mg/l	1.0	SNI 06-6989.9-2004
Total Hardness ($CaCO_3$)	mg/l	500	SNI 06-6989.12-2004
Taste	-	Tasteless	Organoleptis
Color	TCU	50	Fotometri
Turbidity	NTU	25	SNI 06-6989.25-2005
Temperature	^oC	Air temperature ±3° C	SNI 06-6989.12-2005
TDS	mg/l	1000	Potensiometri
Cyanide (CN)	mg/l	0.1	002/SOP.V/LK-KY/VII/2022
Detergen	mg/l	0.05	001/SOP.V/LK-KY/VII/2022

3. Results and Discussion

The experiments carried out at 2000 ml sea water, repeated distillation to make it feasible acquire clean water from the multistage distillation equipment can be seen at Table 2. At stage 1 with the 1st trial; 2; and 3, the distilled water yield was 1450 ml; 1200 ml; and 1120 ml. In stage 2 with the 1st experiment, the results of the 1st experiment from stage 1 were re-distilled, namely 1450 ml and the distilled water yield was 1180 ml, and in the 2nd experiment, the results of the 3rd experiment from stage 1 were re-distilled, namely 1120 ml and the water yield was achieved. distillation of 970 ml. In stage 3, re-distillation was carried out from the results of the 1st experiment from stage 2, namely 1180 ml and 935 ml of distilled water was obtained. The findings from each stage that are not re-distilled will be taken as samples to be examined in the laboratory.

Table 2. The Amount of Distilled Water at Each Stage

Running	Intial Volume (ml)	Volume stage 1 (ml)	Volume stage 2 (ml)	Volume stage 3 (ml)
1	2000	1450	1180	935
2	2000	1120	970	-
3	2000	1200	-	-
4	2000	1550	1270	975
5	2000	1470	1150	-
6	2000	1510	-	-
7	2000	1570	1210	900
8	2000	1480	1050	-
9	2000	1420	-	-

3.2 Results of examination of clean distilled water using multiple stage distillation

Seawater test results show at Table 3, that fluoride, total hardness, total dissolved solid (TDS) and detergent parameters do not meet clean water requirements. Meanwhile, other parameters still meet clean water requirements. The first stage, the distilled water shows good quality with a pH value that is in accordance with clean water quality standards. Although the pH has decreased from 8 to 6.9. and the iron and manganese content also meets clean water standards. What needs to be paid attention to is the decrease in fluoride levels in seawater to first stage distillate water, namely from 1.76 mg/l to 0.33 mg/l.

Table 3. Analysis Quality Testing of Distilled Water

Parameter	Test Result (original)	Test Result Stage 1	Test Result Stage 2	Test Result Stage 3	Quality Standar
Odor	No Odor	No Odor	No Odor	No Odor	No Odor
pH	8	6.9	5.9*	5.4*	6.5 -9.0
Iron (Fe)	<0.009 mg/l	<0.009	<0.009	<0.009	1.0
Manganese (Mn)	<0.001 mg/l	<0.009	<0.001	<0.001	0.5
Flouride (F)	1.760* mg/l	0.333	0.175	0.191	1.5
Nitrate (as NO_3-N)	0.202 mg/l	0.120	0.105	0.006	10
Nitrit (as NO_2-N)	<0.002 mg/l	0.150	0.015	0.009	1.0
Total Hardness ($CaCO_3$)	7140* mg/l	2362.32*	1581*	2162.4*	500
Taste	Salty	Tasteless	Tasteless	Tasteless	Tasteless
Color	0 (TCU)	0	0	0	50
Turbidity	0.76 (NTU)	1.41	2.74	1.75	25
Temperature	24.7 °C	24.7	27.1	27.2	Air temperature ±3° C
TDS	25980* mg/l	342	36	109	1000
Cyanide (CN)	<0.002 mg/l	<0.002	<0.002	<0.002	0.1
Detergen	1.03* mg/l	0.04	<0.009	<0.009	0.05

Other decreases also occurred in nitrate content, Total Hardness ($CaCO_3$), TDS, and detergent and pH. Meanwhile, turbidity was recorded to have increased from 0.76 NTU to 1.41 NTU. In general, no changes occur in odor, color and cyanide levels. The resulting distilled water has no taste. In the second stage, various characteristics in the distilled water alter, including pH, manganese content, fluoride content, nitrate content, nitrite content, total hardness content ($CaCO_3$), turbidity, TDS, and detergent content. pH and total hardness are two parameters that do not meet the requirements for clean water in the second stage.The third stage, the distilled water shows several changes in the values of the existing parameters, where the pH decreases (5.4), resulting in this pH value not meeting the requirements for clean water. Water hardness and TDS actually increase compared to the second stage. The results of the second and third stages of distilled water have two parameters (pH and hardness) that do not meet clean water quality standards. Meanwhile, the results of the first stage of distilled water, only the hardness did not meet the clean water quality standards. The trend of decreasing manganese, fluoride, nitrate, nitrite, turbidity, TDS and detergent content occurred from the first stage to the third stage.

If the standard requirements for clean water quality are not met, it will have a negative impact on health. Manganese is possibly harmful in acidic environments. The high levels of manganese and iron can be felt if they are used to wash white garments and equipment, causing the objects to change color, namely turning yellow [15]. Excessive fluoride content, even at modest levels, can lead to dental and skeletal fluorosis [16]. Whereas nitrites can harm human health by causing methamoglobinemia and other harmful consequences [17]. The nitrite concentration in the water exceeds 0 mg/L. The reservoir water seems brownish and contains silt. Exceeding the cyanide buildup threshold can lead to dizziness, eye discomfort, shortness of breath, and chest pain [18]. High levels of TDS show a negative relationship with several water environmental parameters that cause toxicity on the organisms within [19]. Excessive hard water levels (±500 mg/lt) can pose health risks. Hard water can induce cardiovascular illness (blockage of the heart's blood arteries) and urolithiasis (kidney stones) [20]. A high pH in drinking water can cause metal corrosion, such as dissolving iron, cadmium, lead, and so on, resulting in toxicity in the human body [21]. Based on this test, further processing is still needed regarding the pH level and hardness level of the distilled water.

Table 4. Testing Distilled Water Sold On The Market

Parameter	Distilled water	Units	Quality Standar	Methods
Odor	Odorless	-	No Odor	Organoleptis
pH	7.2	-	6.5 -9.0	Potensiometri
Iron (Fe)	<0.009	mg/l	1.0	SNI 6989.4-2009
Manganese (Mn)	<0.001	mg/l	0.5	SNI 6989.5-2009
Flouride (F)	1.023	mg/l	1.5	SNI 06-6989.29-2005
Nitrate (as NO_3-N)	<0.006	mg/l	10	APHA 2017. Section 4500-NO3 B
Nitrit (as NO_2-N)	<0.002	mg/l	1.0	SNI 06-6989.9-2004
Total Hardness ($CaCO_3$)	8.16	mg/l	500	SNI 06-6989.12-2004
Taste	Tasteless	-	Tasteless	Organoleptis
Color	0	TCU	50	Fotometri
Turbidity	0.82	NTU	25	SNI 06-6989.25-2005
Temperature	23.1	°C	Air temperature ±3° C	SNI 06-6989.12-2005
TDS	9	mg/l	1000	Potensiometri
Cyanide (CN)	<0.002	mg/l	0.1	002/SOP.V/LK-KY/VII/2022
Detergen	<0.009	mg/l	0.05	001/SOP.V/LK-KY/VII/2022

As a comparison of distilled water circulating on the market, clean water quality is tested. The test results are presented in table 4. In general, distilled water circulating on the market meets clean water quality standards. There is a significant difference in values between multistage distilled water and distilled water on the market in the pH and total hardness parameters. Distilled water on the market has a pH of 7.2 and a total hardness of 8.16 mg/L.

3.3 The Amount of Salt Content in Distilled Water

Salt deposits accumulate in the lower part of the seawater distillation tube during the initial stage. The gravimetric testing results indicate that the salt content (NaCl) value obtained was 76.32%. However, the distillation tube's second and third phases are devoid of any salt content. The absence of salt in the distilled water from the first stage is evident as no salt residue was detected at the bottom of the distillation tube in the succeeding stages**.**

4. Conclusion

Desalination is one way to meet clean water needs. Desalination can be carried out in several stages. This is very good for reducing salt levels, total hardness, TDS, and certain minerals such as fluoride and nitrate. The attained characteristics for clean water at each stage encompass mineral content such as iron (Fe), manganese (Mn), nitrate, nitrite, turbidity, total dissolved solids (TDS), and other factors. However, it is not possible to attain the desired levels of pH and total hardness ($CaCO_3$). The attainment of pure air pH is only achieved in the first distillation, whereas the total hardness is not yet achieved in the distillation of all levels. Therefore, this distilled water not only fails to meet the requirements for clean water (class I), but also does not meet the standards for water classes II, III, and IV according to Government Regulation No. 82 of 2001. Although the results of research using this multistage distillation method offer enormous potential in seawater desalination, it still requires additional treatment such as adjusting pH and reducing total hardness levels. Meanwhile, distilled water circulating on the market meets clean water quality standards.

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References

[1] M. Djana, “Analisis Kualitas Air Dalam Pemenuhan Kebutuhan Air,” J. Agroqua, vol. 8, no. 32, pp. 81–87, 2023.

[2] M. A. Ahmed, S. Amin, and A. A. Mohamed, “Fouling in reverse osmosis membranes: monitoring, characterization, mitigation strategies and future directions,” Heliyon, vol. 9, no. 4, p. e14908, 2023, doi: 10.1016/j.heliyon.2023.e14908.

[3] B. Kuntoro and Hardjono, “Pengelolaan Air Bersih Daerah Perbukitan Di Prambanan, Sleman, Yogyakarta,” Ekp, vol. 13, no. 3, pp. 1576–1580, 2017.

[4] G. Y. Dewantara, B. M. Suyitno, and I. G. E. Lesmana, “Desalinasi Air Laut Berbasis Energi Surya Sebagai Alternatif Penyediaan Air Bersih,” J. Tek. Mesin, vol. 07, pp. 3–6, 2018.

[5] H. T. P. Mbusa, “Manajemen Pelayanan Air Bersih di Desa Maropokot Kecamatan Aesesa Kabupaten Nagekeo Provinsi Nusa Tenggara Timur,” Molecules, vol. 2, no. April, pp. 1–58, 2020.

[6] U. Atikah, R. Purnaini, and G. C. Asbanu, “Analisis Kualitas Air Baku dan Kualitas Air Hasil Produksi pada Instalasi Pengolahan Air (IPA) Unit Mukok PDAM Tirta Pancur Aji Kota Sanggau,” J. Teknol. Lingkung. Lahan Basah, vol. 11, no. 2, p. 297, 2023, doi: 10.26418/jtllb.v11i2.64525.

[7] N. Muhamad and I. Kurnia, “Potensi Air Laut sebagai Sumber Air Tawar dan Pembangkit Energi,” Teknol. Bandung, no. December, pp. 0–12, 2015.

[8] Yaningsih, T. Istanto, and W. E. Juwana, “Pengaruh Kecepatan Putaran Kompresor Terhadap Produktivitas Unit Desalinasi Berbasis Pompa Kalor Dengan Proses Humidifikasi dan Dehumidifikasi,” Mechanical, vol. 5, no. 2, pp. 23–28, 2014.

[9] R. F. Gani, N. A. Putri, S. S. Habibi, and ..., “Desalinasi Dengan Metode Evaporasi Sebagai Penyedia Air Bersih Di Desa Kurandak,” J. Pasopati …, vol. 4, no. 4, pp. 226–230, 2022, [Online]. Available: https://ejournal2.undip.ac.id/index.php/pasopati/article/view/16126%0Ahttps://ejournal2.undip.ac.id/index.php/pasopati/article/download/16126/8261

[10] G. R. Ersa, “Kajian Alternatif Teknologi Desalinasi Dalam Produksi Air Tawar Untuk Desa Labuan Bajo, Ntt,” J. Purifikasi, vol. 20, no. 1, pp. 1–14, 2021, doi: 10.12962/j25983806.v20.i1.400.

[11] J. Kavitha, M. Rajalakshmi, A. R. Phani, and M. Padaki, “Pretreatment processes for seawater reverse osmosis desalination systems—A review,” J. Water Process Eng., vol. 32, no. August, p. 100926, 2019, doi: 10.1016/j.jwpe.2019.100926.

A. N. Angelakis et al., “Desalination: From ancient to present and future,” Water (Switzerland), vol. 13, no. 16, 2021, doi: 10.3390/w13162222.

[12] S. H. Abdulloh, “Desalinasi Air dengan Memanfaatkan Energi Terbarukan,” Pengolah. Air dengan Menggunakan Energi Terbarukan, no. December, pp. 1–8, 2015.

[13] M. Marjuni, O. Minarto, and S. C. Wahyono, “Modifikasi Sirkulasi Air Pendingin Alat Destilasi pada Proses Pembuatan Akuades,” J. Fis. Flux J. Ilm. Fis. FMIPA Univ. Lambung Mangkurat, vol. 18, no. 1, p. 16, 2021, doi: 10.20527/flux.v18i1.8888.

[14] L. Febrina and A. Ayuna, “Studi Penurunan Kadar Besi (Fe) dan Mangan (Mn) dalam Air Tanah Menggunakan Saringan Keramik,” J. Teknol., vol. 7, no. 1, pp. 36–44, 2014, [Online]. Available: https://jurnal.umj.ac.id/index.php/jurtek/article/download/369/341

[15] A. Maulina Najib and C. Nuzlia, “Uji Kadar Flourida Pada Air Minum Dalam Kemasan (Amdk) Dan Air Sumur Secara Spektrofotometri Uv-Vis,” Amina, vol. 1, no. 2, pp. 84–90, 2020, doi: 10.22373/amina.v1i2.43.

[16] Ita Emilia, “Analisa kandungan nitrat dan nitrit dalam air minum isi ulang menggunakan metode spektrofotometri uv-vis,” J. Indobiosains, vol. 1, no. 1, pp. 38–44, 2019, [Online]. Available: http://univpgri-palembang.ac.id/e_jurnal/index.php/biosains

[17] Rachmat, P. Sidebang, and I. Purwandari, “pada air baku dan penilaian risiko kesehatan masyarakat di Kecamatan Babakan Madang Kabupaten Bogor,” J. Cimmunity Med. Public Heal., vol. 35, no. 3, pp. 97–105, 2019.

[18] W. Krisno, R. Nursahidin, R. Y. Sitorus, and F. R. Ananda, “Penentuan Kualitas Air Minum Dalam Kemasan Ditinjau Dari Parameter Nilai Ph Dan Tds,” Semin. Nas. Penelit. dan Pengabdi. Masy. 2021, no. 416, pp. 188–189, 2021.

[19] U. Nurullita, R. Astuti, and M. Z. Arifin, “Pengaruh lama kontak karbon aktif sebagai media filter terhadap persentase penurunan kesadahan caco 3 air sumur artetis,” J. Kesehat. Masy. Indones., vol. 6, no. 1, pp. 48–56, 2013, [Online]. Available: http://jurnal.unimus.ac.id48

[20] J. A. Wijayanti, D. Anita, E. Dewi, and S. Yuliati, “Produksi Air Minum Dari Air Pdam Dengan Cara Dimasak Dan Menggunakan Metode Reverse Osmosis,” Pros. Semin. Mhs. Tek. Kim., vol. 1, no. 1, pp. 55–61, 2020.