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An Extension on Inland Study for Seawater Desalination by Vapor Pipeline

Koosha Aghazadeh[1], Reza Attarnejad [2]
[1]*School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran, Email:*
[2]*School of Civil Engineering, College of Engineering, University of Tehran, PO. Box: 1417613131 Tehran, Iran*
Corresponding Author. Koosha Aghazadeh

Abstract: Nowadays competing on access to water resources is one of the most important issues making some new aspects of challenges for almost any region of the world. To develop water resources and access to new resources with the minimum rate of energy consumption, some attempts should be done for optimizing the management of these changes. The imagination of seawater desalinating by thermo-methods or membrane-methods and also by spending lots of energy, then transporting it to another region facing water shortage by spending another sort of energy is not only inefficient but also is not across the approaches of sustainable environmental goals development. Thus, the overall importance of the issue needs to present some researches or mathematical models using no energy or a small amount of it for both desalination and transportation of seawater simultaneously. In the present research, attempting to operate the process of desalination and transportation of the sub-atmospheric evaporation in pipelines with the minimum rate of energy and money, a new mathematical model named sub-atmospheric evaporation is introduced. It is expected much less energy use in this method rather than other common ones for 1 m3 water. The goal of this paper is to propose a thermodynamic and phenomenological study to produce and transport fresh water from salty water resources.This system required to seawater and mountain for a sufficient temperature difference for transfer process. Therefore the city of Zhenhai (situated in the east of china), as a city with specific features of a warm source and Tinamu mountain with 1480m height as a cold source has been selected for studies.This paper introduce a desalination system by transferring sub-atmospheric evaporation with the lowest energy consumption on the basis of temperature difference in the source and the destination with the mathematical formulation.

Keywords: Water transfer, Seawater desalination, Pipeline system, Temperature difference, compressibility

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I. INTRODUCTION

One of the most important difficulties limiting water resources is the increasing numbers of water consumers. Besides the other effective issues in water shortage and water crisis, environmental demolition made by human-like damages to water resources, excessive intake of water, unnecessary water consumption, lack of sufficient management for water resources operation, climate changes and ground heating process exists. Many believe that future wars may occur in accessing water resources. Nevertheless, it seems that there isn't a political authority to solve the shortage of water and unlike some highfalutin speeches of the international societies, there isn't enough attention to this issue.

Evaporation of seawater in hot areas, transferring it by clouds and finally its condensation in the shape of rain in cold weather is an obvious example of natural seawater desalination that supplies many thousand billion tons of freshwater for different areas of the world every year. The basis of this natural desalination is on the differences between hot sources (the evaporation area or sea) and the condensation areas which is in the focus center of researchers for studying and simulation of desalination with natural potentials [1]. A cold region providing enough temperature difference to transport and condense seawater is of the definite essentials of this method [2].

Known desalination methods of seawater generally content thermo-methods including Multi Stages Flash distillation(MSF) and Multi-Effect Distillation (MED) and also, membrane methods which include Reverse Osmosis (RO). In the membrane method using the most updated membrane, 3 to 5 kW/hr energy is needed for the production of 1m3. On the other hand, the MSF and MED consume 8 to 15 kW/hr for the produce of 1m3 freshwater in the best conditions which rises to 30 to 100 kW/hr.m3 in the third world countries[3-6]

Thermo-methods despite consuming energy has a more simple and independent system rather than the others which makes them suitable for countries rich in oil and gas reserves where can be applied for supplying the required seawater desalination energy by low-pressure output vapor from power generation turbines. In all three mentioned methods, wasting, deterioration, repair and maintenance and also corrosion are the most important financial issues besides the cost of transportation and desalination[7-9].

Moreover, climatically desalination method with the vapor pipeline is useful when transferring from seawater to a cold elevation near the sea is done. A good example of this phenomenon is in Sana'a, the capital of the republic Yemen and El-Ghuren in the margin of the kingdom of Jordan where has more highlands and less temperature rather than the surface temperature of the high sea near them [1]. Many cities and regions in the Middle East have these conditions and water supply by the steam pipe method is a possible solution for them.

The main source of producing freshwater in nature is in ocean whirlwinds which cause pressure reduction in a large volume and high speed, and also evaporate the water in the normal temperature of the ocean. This evaporated water is transported to elevations above tornado and the movement of whirlwind evacuates the desalinated water in the shape of wind or rain above the oceans and countries [10-13].

In Desalination journal 2006 a formulation was proposed making desalination and efficient transport of freshwater simultaneously possible based on heat pipe principles. That work was done in a static status considering an incompressible condition for gas which resulted in low velocity. While, here according to what was mentioned and in order to improve this method covering a general condition, gas is considered compressible in a dynamic status due to obtaining a higher velocity. Transporting freshwater in a system without using any external energy (such as electricity and fossil fuels) is the unique feature of the desalination pipe method. Construction of a pipe having enough power of bulking, even if in low internal vacuum conditions between sea or a salty lake region (evaporation region) with a very small heat range and a condensation area located in a dry land results in a quick temperature rise due to radiation cooling. The pipe is completely evacuated from the air and filled with steam. In the condensation part, steam flows toward the end direction because of the steam pressure difference due to temperature difference. In this part, water is condensed and extracted as freshwater from the pipe. Empirical representation of this research besides calculating a capable desalination model on the basis of real data from environment and weather conditions of the goal region is done in order to validate the desalination pipes and estimate the production rate of freshwater by this formulation.

The development of distillation method at low temperatures is presented by the following researchers for all Middle East countries and North Africa. In this method, solar energy is used for the initial distillation supply.

A paper is available about the possibility of steam transport due to temperature difference, including long transferring length without the feature of removing non-evaporated gases in final condensed water [14].

A paper available in the Desalination journal in 2008 has discussed desalination with a low rate of energy consumption. This innovation is included two ten-meter vertical pipes, one of them designed and installed as evaporator and the other one as condenser [15-17].

These methods which are considered in energetic desalting industries categories, subsequently have developed to conventional energy consumption by condensation sub-atmospheric evaporation method [18].
Sub-atmospheric evaporation transport technology has some other advantages such as:

- Desalination of seawater with minimum energy consumption
- Decrease or elimination of the energy of water transport
- Preserving chemical and microbial quality of water
- Disappearing of risks of corrosion
- Not needing to membrane replacement (comparing to membrane methods)
- Maximizing the possibility of construction of parts and related facilities inside the country
- Not needing to instrumentation
- Possibility of freshwater transport from high elevations to consumption areas by gravity potential
- Using provided facilities in Kyoto and Copenhagen conversation about not producing carbon dioxide point.

As mentioned in the introduction, there are water-soluble gases such as carbon dioxide and oxygen which can disrupt the process of evaporation and transmission by effecting evaporation pressure and one of the main goals of this research is to condensate water without thesegases. Adding carbonated tanks to the initial section(before the evaporation part) removes raw water soluble gases which may remain from the initial step to the condensation step [19].

Seawater is not the same as pure water because of the capability of being a strong electrolyte due to its salty contents. High salts usually including sodium chloride and carbonated contents, sometimes extend its electrical conductivity to 40000 s/cm. theseawater deviation index from pure water is excessive energy of Gibbs. A mixture is considered thermodynamic ideal when its Gibbs is equivalent to zero.Features of ideal dilution which is content of water dissolver are the same as pure water. Thus this study also pays attention to presentation and usage of related theories to determine thermodynamic features of water such as water pressure in equilibrium temperature, the specific heat capacity of salty water, viscosity and density [20].

II. MATERIALS AND METHOD

2.1 Evaporation

In this part, temperature of the raw water is decreased due to evaporation firs, next the water flows and warm water replaces coldness of raw water. In this process, temperature decrease due to extracted amount of heat from raw water is equal to the latent heat of vaporization and the following equal is driven:

$$C_p\left(T_s - T_{l,e}\right)M =$$

In the above equation, $C_p$is the specific heat of row water (J / K.kg), T_s is the temperature of the original row water (K), $T_{l,s}$ is the liquid (cooled row water) temperature around the evaporation surface (K), M is the circulated mass flow rate of row water (Kg/s), m is the evaporation rate (Kg/s), and λ is the latent heat of vaporization of water (J/Kg).

2.2 transportation

Transport part is after the evaporation part, which occurs naturally due to the heat driven from the water around. Two major factors in which increase efficiency evaporation are the inlet water to pipelines resulting in less need to water increase, and this temperature difference that results in increasing of evaporation rate due to increase in temperature difference between seawater and the water inside the pipeline in a constant inlet water rate.

In this part, basic equations are simplified and lead to the desired shape. In order to write suitable code, some preparations are described.

On the other hand it was driven that the total pressure difference (ΔP) in the two sides of the pipe balances with the sum of the pressure loss due to the friction (ΔP_V) and the hydrostatic pressure difference (ΔP_H).

$$|\Delta P| = \Delta P_V + \Delta P_H \quad (2)$$

It is remarkable that ΔP is a positive value in above equation, unlike the equation 21 that has a negative value due to pressure loss caused by moving through the pipe.

Hydrostatic pressure equation is given by:

$$\Delta P_H = \rho g H \quad (3)$$

$$\Delta P_V = |\Delta P| - \rho g H \quad (4)$$

2.3 Condensation

In condensation part, to the aim of using no energy the pipe insulation is removed so the steam will condenses and converts to distilled water by getting heat from the environment.

The latent heat of condensation is driven from the water vapor and the condensation occurs in sort of crossover flow in this part due to the loss of heat Q. precise formulas based on theory and analysis for condensation and evaporation of crossover flow is presented in literature review [21].

$$(5)\,Q = \frac{T_{l,c} - T_f}{\frac{1}{2\pi r_1 h_c} + \frac{\ln(r_2/r_1)}{2\pi k_p} + \frac{1}{2\pi r_2 h_f}}$$

In above equation, $Q$is the amounted heat flow extracted per unit length of this part (W/m), r_1 is the internal radius of the pipe (m), $r_2$is the external radius of the pipe (m), k_p is the thermal conductivity of the pipe material (W/mK), h_c is the average heat-transfer coefficient between the water vapor in the pipe and the inner wall of the pipe (W/m^{2}K), h_f is the convective heat-transfer coefficient between the outside air and the outer wall of the pipe(W/m^{2}K), $T_{l,s}$ is he liquid temperature around the condensation surface (K), and T_f is the outside temperature(K).

As water and steam are exist in the condensation pipe, all converted heat is consumed on condensation of the water vapor while the water temperature stays constant and therefore gives the following equation for the equilibrium between (m) the amount of the heat flow exhausted to outside and the latent heat released by condensation of the steam (Kg/s).

$$m = \frac{Ql}{\lambda}$$

Where l is the length of condensation is part (m), and λ is the latent heat of condensation of water (J/kg).

III. PROCESS OF CALCULATION

Repetitive calculation algorithm to estimate the production of distilled water:

Figure 19 shows the repetitive calculation algorithm. With temperature of seawater and the outside air of the condensation part, temperature of evaporation and condensation can be assumed. As the inside fluid of pipe is an ideal gas, using thermodynamic relations and temperature gives the pressure in two sides of the pipe.

(P_c, P_e)the rate oftransported water vapor is estimated $m_t = Mass\ of\ Transport$. Calculating the rate of transported flow in pipe is the main part of calculation algorithm in process of obtaining rate of flow in the evaporation and the condensation parts.

According to the conservation of mass, produced mass in three parts of evaporation, transportation and condensation is equal. ($m_t = m_e = m_c$)Considering of the slight error and wasted amount, $m_e$is always smaller than m_t and m_c and the difference assumed as the safety factor.

Some important factors effecting on producing optimization rate of distilled water are pipe diameter, fluid velocity and the length of condensation part. So that, the rate of produced distilled water increases with increase in the diameter of the pipe to 4 (m) that is the maximum efficient size with considering the economic and industrial aspects in order to insulate and create vacuum state.

In considered calculation algorithm, mass flow of raw water (M)is assumed and then is check on the basis of 1st thermodynamic low:

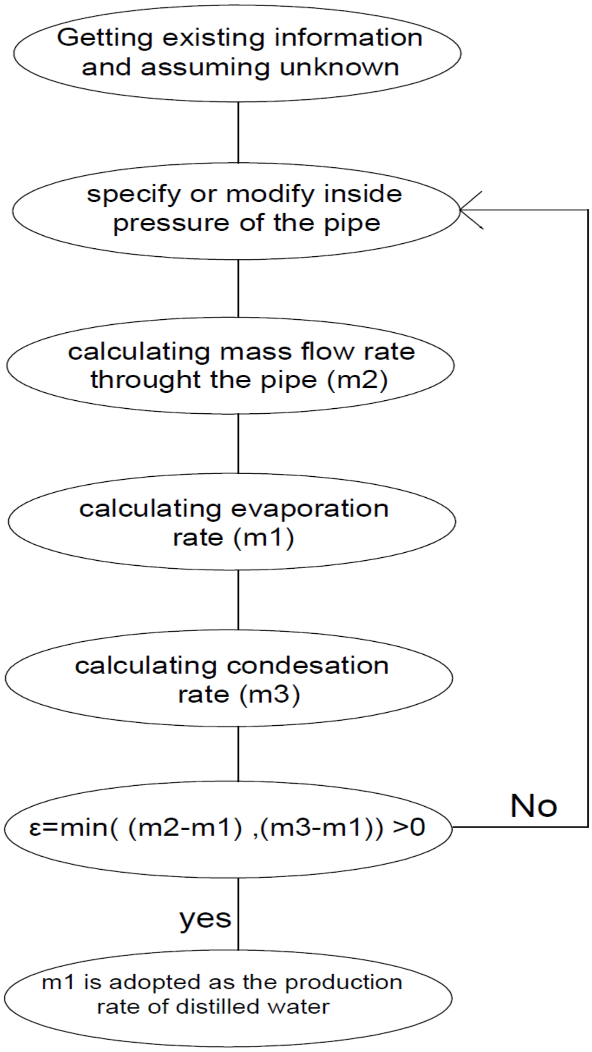

Fig.1. calculation algorithm$m_1 = m_e, m_2 = m_t, m_3 = m_c$

In present calculation, as the pressure loss in condensation process (ΔP_c)is ignored because it is less than (<1/4) the pressure loss due to friction resistance (ΔP_v).

A suitable pressure for evaporation part (P_e) and condensation part (P_c) are assumed in a realistic range determined by the local temperature.

The process of mass flow through pipe in transport part (m) is calculated based on the assumed equations of pressure difference above.

In evaporation part, pressure loss due to evaporation (ΔP_e) is calculatedbased on the mass flow process of evaporation in the transport part. Fluid temperature in the surface evaporation($T_{l,e}$) is driven from the pressure vapor curve. Then amount of evaporation (m) is calculated using equation (1) in the process of the mass circulation of raw water flow (M) and temperature difference between main raw water (T_s) and fluid temperature insurface evaporation ($T_{l,e}$).

Above process is continued until the rate of evaporation is less than the rate of transport and condensation and if the rate of evaporation was slightly higher than the rate of transport and condensation, system will face to trouble and evaporation won't occur due to increase of water vapor inside the pipe. According to above equality of continuity rate in all three parts doesn't have any conflicts with the previous ones since the system is considered in just one moment. The possible highest rate of evaporation due to the temperatures and valid information should be considered as basis of designing of the transport part and the condensation part. It is inevitable that evaporation capacity sometimes is much less than transport capacity. Asthe system is expected to be workable in the future, future weather should be studied and using safety factor is strongly recommended in this way.

$$\varepsilon = m_2 - m_1$$

The safety factor will be more if the considered values according to above are more. So, the transport and condensation parts transfer all the distilled water vapor and convert it to fluid.

IV. CASE STUDY

The case study has been carried out for two target regions in china. The transfer of distilled water by cold water vapor has been studied from Zhenhai (a coastal warm city in east of china), to the cold mountain of Tinamu with an altitude of 1480 meters. Mount Tianmu, or Tianmushan is a mountain in eastern China. It is made up of two peaks: West Tianmu (1,506 meters) and East Tianmu (1,480 meters) [22]. In this investigation, East China Sea near the Zhenhai city chosen as case studied seawater. Meteorological data related to the mean sea temperature in the coastal city, the temperature of Zhenhaiand the ambient temperature at the elevations of Tianmu are given in Table 1 [23].

Table1

Air temperature and seawater temperature for target regions.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum seawater temperatures in Zhenhai	12	12	14	16	19	22	25	26	26	21	19	14
Maximum Zhenhai seawater temperatures	17	17	20	22	27	28	29	29	29	29	25	22
Zhenhai seawater average temperature	14.5	14.5	17	19	23	25	27	27.5	27.5	25	22	18
Tianmu mountain average temperature	7	8	9	11	14	15	18	17	17	15	14	10

V. RESULTS

5.1. Zhenhai results

Increasing in the temperature difference between the input and the output leads to increase in the efficiency. Also reduction in transport length results in reduction in the rate of transport. Thus, "Zhenhai" was chosen as the case study due to its short distance to high sea and its conditions.This city has a warm and humid weather in which in early November to early April, last April to mid-Jun and last Jun to last

As an assumed temperature is constant in a month, equations are used in static status and there aren't any changes with time. The table below shows the results in different months with different diameters.

Table .2.Information of a pipe with 1(m) diameter in static status

D=1m	m (kg/s)	lc (km)
Jan	0.12	10
Feb	0.13	10
Mar	0.17	12
Apr	0.23	13
May	0.31	16
Jun	0.29	15
Jul	0.32	16
Aug	0.28	15
Sep	0.21	12
Oct	0.24	13
Nov	0.16	11
Dec	0.12	10

Table.3. Information of a pipe with 2(m) diameter in static status

d=2m	m (kg/s)	lc (km)
Jan	1.41	14
Feb	1.42	14
Mar	1.81	16
Apr	2	18
May	2.02	18
Jun	2.14	18
Jul	1.87	17
Aug	1.75	16
Sep	1.34	13
Oct	1.36	13
Nov	1.25	13
Dec	1.29	13

According to the tables, the amount of distilled water increases due to the increase in pipe diameter. Also, the rate of production change is much more than the rate of change of pipe diameter. In shortest transport length, the shorter joint is more effective and produces pure water in higher velocity. Also increase in diameter of the pipe leads to increase in the velocity of water vapor and shows that the rate of production change is more than changes of pipe diameter.

Reports say that the maximum length of the pipe should be considered as the length of the condensation part which is 16 (km) and 18 (km) for pipe with 1 (m) diameter and 2 (m) diameter respectively. According to observations, the system may operate with a shorter pipe length but considering a sufficient operation during a whole year leads to choose a bigger size of diameter. For improvement in condensation part the water vapor can be used in MED method of refinery which converts both water vapor and other exist waters into fluid water.

In this status, a function titled temperature-time is driven from the minimum and maximum temperatures in every month. Results are driven from above mentioned equations and it is expected having nosignificant differences with past steps due to using of interpolation for obtaining of temperature.

5.2. Assessment of the existing parameters:

5.2.1.The length of the pipe:

The length of the pipe is definitely the most effective parameter on the velocity and the amount of outlet water. According to what mentioned before, the joint will be shorter if the length of the pipe is shorter. So the pressure difference has a more effective role on the velocity and also the production rate of water will increase in a constant temperature and diameter. Table 4 shows the amount of outlet in pipes with different length in a similar condition.

Table (4): the rate of outlet water related to different length

L(m)	M(kg/s)	U(m/s)
5	7.95	108.6
10	4.7	69
20	3.15	42.6
30	2.42	36.4
40	2.28	39.6
50	2.1	35.4
60	1.8	27.8
70	1.62	24.6
80	1.56	23.7
90	1.45	22.1
100	1.28	17.2

5.2.2. The height of the hot and cold sources

This parameter only is effective on the pressure difference. Although, it is negligible rather than the length of pipe, results show that the decrease of height leads to increase in the velocity of pipe due to reduction in the mass force and also reduction in pressure difference due to the height and increase in pressure difference caused by the friction.

5.2.3. The diameter of the pipe

The diameter of the pipe is one of the most important and effective factors that its increases leads to increase in efficiency of all the three parts and the transport velocity. Following table shows information of changes of the rate of outlet water with the changes of the pipe diameter in similar conditions (other parameters are constant).

Table (5): the rate of outlet water relative to the changes in the diameter of pipe

D(m)	M(kg/s)	U(m/s)
4	16.1	56.9
3.5	11.2	50.9
3	7.36	44.7
2.5	4.11	42.7
2	2.41	36.4
1.5	1.21	31.26
1	0.43	28.7

Following figure indicate that changes in the pipe diameter have more effects on the rate of production besides the fact that the pipes with large diameters also have some disadvantages, too.

5.2.4. The temperature differences and changes in hot and cold sources

Increase in the temperature difference between hot and cold sources leads to increase in the pressure difference, the velocity of transport and rate of production.

Temperature difference of the previous paragraph means to increase the temperature of both of the hot and cold sources by keeping the temperature difference constant. Relative results are shown in the below table (5). It shows the temperature of the cold source that has a constant difference of 20℃ with the hot source in all steps.

Table (5): the rate of the outlet water relative to the temperature changes (temperature difference 20℃)

T(cool)©	M(kg)	U(m/s)
0	0.89	45
5	1.1	44
10	1.4	41
15	1.9	42
20	2.4	37
25	3.7	53
30	5.1	44
35	6.75	41
40	8.2	43

As expected,the rate of production increases with increase of the changes of temperature but the velocity isn’t a precise function of these changes and is a little bit unexpected.

VI. CONCLUSION

This study discusses the status of the governing flow in transferring pipe of fluid which proposes a formulation to produce water in three steps of evaporation, transportation, and condensation. To this aim, choosing suitable temperatures in the two sides of the pipe plays the main role in which a lower initial temperature (pressure) leads to a more evaporation rate and a higher temperature at the end of pipe leads to a more economical result. So, it is important to monitor the system with a similar rate in all three parts while in fact, the rate of evaporation is a little bit less than the rate of transportation and condensation. So the strategy is to balance production with months of low shipping rates by increasing the pressure difference on both sides of the pipe and against the month with high shipping rates.

According to results viscosity, effects can be neglected in short pipes and nozzles while it has a significant effect in long pipes due to the effect of friction in the internal walls of pipes. With considering a limited volume of pipe under the influence of viscosity effects, existed forces are assessed and all the governing equations are presented. The main goal is achieving to required formulas for transporting water vapor in order to desalinate and transporting it in pipelines. To this aim, the basic continuity and momentum formulas are used.

After simplification of formulas to the aim of increasing the accuracy and efficiency of the simulation of the pipeline, the fluid should be considered incompressible then, by considering pipeline into little elements and fractional solving equations, analysis of transport and relative parameters such as density, velocity, temperature, and pressure in each position is assessed. In past works, Mean velocity and density were used and the fluid was considered incompressible so some errors appeared in the formulation and the analysis parts.

This study results in a method for natural desalination and transport of water by spending an initial cost and without needing to consume lots of energy for operating.

As other achievements of this study, methods of increasing the production of raw water and effective parameters are presented and then the effect of each parameter on the rate of water production and the velocity of the fluid in the pipe are enumerated.

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