Design, Fabrication and Study on Thermodynamic Performance and Energy Balance for a Pure Water Generator using Vacuum Desalination Method

A Project Report

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ABSTRACT

With ever-increasing population and rapid growth of industrialization, there is a great demand for fresh water, especially for drinking, as natural resources are becoming limited. In view of the above, different desalination technologies are evolving with a thrust for utilization of renewable energy sources like solar energy, ocean thermal energy, geothermal energy and waste heat.

Vacuum desalination is one such technology in which fresh water is produced from brackish water by evaporation and subsequent condensation. This desalination technique involves different processes like pressurization of brackish water by a pump, creation and maintenance of a vacuum using vacuum pumps, and evaporation of brackish water at reduced pressure using external heat.

This document reviews one such vacuum desalination system fabricated by us, by varying operational parameters such as vacuum container temperature, total dissolved solids, chamber pressure, and volume of water. The system's principle of operation is by reducing the pressure in a closed container using a vacuum pump the impure water inside the closed container will be converted to steam at low temperature accordingly. Then by condensing the low temperature steam pure water can be obtained by using appropriate equipments and devices.

The pure water recovered from the designed vacuum desalination system was at yield ratio of 10-15%. By decreasing the vacuum chamber pressure we can yield at higher rate comparatively. The temperature inside the vacuum chamber should be high to yield more water from the system. The vacuum chamber used in the vacuum desalination system for experiment was a capacity of 1liter; if the vacuum chamber capacity was high the yield will be more due to air column inside the vacuum chamber would be high. The input energy cost for experiment was differs with the source of heat for increasing the temperature of the water inside the vacuum chamber internally or externally. If the source of heat was free then the energy cost will be very low comparatively. The steam at ambient temperature was not obtained due to vacuum pump with range of 50mm of Hg. With this vacuum pump we could evaporate the water only up to 45°C.

ஆய்வு சுருக்கம்

நாளும் வளர்ந்து வரும் மக்கள் பெருக்கத்தாலும், தொழில் வளர்ச்சியாலும், நல்ல நீரின் நேவை அதிகரித்துக் கொண்டே வருகிறது அதிலும் இயற்கை மூலம் குறைவதால், குடிநீரின் தேவை அதிகரித்துக் கொண்டே வருகிறது. அதானல் புதுப்பிக்கத்தக்க ஆற்றல் மூலங்களான சூரிய ஆற்றல் , கடலலை ஆற்றல் , புவியாற்றல், வீணாகும் வெப்ப ஆற்றல் ஆகியவற்றைப் பயன்படுத்தி உப்புநீரைக் குடிநீராக்கும் பல்வேறு தொழில்நுட்பங்கள் செயல்படுத்தப்பட்டு வருகின்றன.

வேக்குவம் டீசாலினேஷன் என்பது அத்தகு ஒரு முறையே! இதில் அசுத்த நீரானது, நீராவியாக்கல் அதைத் தொடர்ந்து, குளிர்வித்தல் மூலம் சுத்தப்படுத்தப்படுகிறது. இதில் பிராக்கிஷ் நீரானது பம்புகள் மூலம்அழுத்தப்படுகிறது. வெற்றிடம் பம்புகள் மூலம் உருவாக்கப்பட்டு தொடர்ந்து வெற்றிடமாகவே வைக்கபட்டு வருகிறது. அடுத்து குறைந்த அழுத்தத்தில் அசுத்த நீரானது வெளியிருந்து செலுத்தப்படும் வெப்பத்தால் மாற்றப்படுகிறது. இவ்வறிக்கை அது போன்ற ஒரு வெற்றிடம் மூலம் உப்புநீராக்கும் தொழில்நுட்பத்தை பற்றி விவரிக்கிறது. இது எங்களால் வடிவமைக்கப்பட்ள்ளது. பல்வேறு விதமான கரைந்துள்ள அசுத்தங்கள், பல்வேறு வெப்பநிலைகள், அழுத்தல்கள், கொள்ளலவுகள் ஆகியவற்றைக் கொண்டு பரிசோதிக்கப்பட்டது .

இம்முறையில் குறைந்த அழுத்தத்தில், மூடிய கொள்கலனில், வெற்றிட பம்புமூலம், அசுத்த நீரானது குறைந்த வெப்பநிலையில் நீராவியாக மாற்றப்படுகிறது. அடுத்த குறைந்த வெப்பநிலையில் உள்ள நீராவியானது, சுத்த நீராக குளிர்விக்கப்படுகிறது. அதற்குரிய உபகரணங்கள் பயன்படுத்தப்பட்டன.

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CHAPTER - 1

INTRODUCTION

1.1 IMPORTANCE OF WATER CONVERSION

The world is becoming more and more aware of its shortage of fresh water. In more than 50 countries in the world, the shortage of water is already creating a critical situation. A dramatic increase of the world's population will worsen this scenario, In order to overcome this problem; new economical ways for production of potable water at socially acceptable costs have to be established. A techno-economic evaluation of the available desalination technologies shows that more advanced desalination systems to reduce investment and maintenance costs are needed. Growing industrialization of the arid zones does not only mean a steady increase of water consumption, but also new sources of energy that can be used for desalination of seawater. For this reason, some are trying to reclaim waste heat for industrial use while others, located near coastlines, may obtain their water through desalination of seawater using solar energy, although costs can be high. Converting brackish water into potable water is an energy-intensive process. It is only viable if the source of energy is practically free, such as from celestial sources, geothermal sources or industrial waste heat. On the energy side, safe, vacuum pump assisted vacuum desalination system can be used.

The process reported here is vacuum desalination. This technique takes advantage of a drop in the water boiling point at reduced pressure. This vacuum is created by a Vacuum pump. By dropping the saturation pressure exerted on the brackish water to about 0.04bar, the brackish water is evaporated and then by condensing the water vapor the pure water is obtained. This document presents a comprehensive review and description of design, fabrication and installation aspects of the vacuum desalination system with an Energy balance calculation and evaluation of capital costs and. In the design part Tab 6.1 shows the vacuum operating and measuring ranges in millibar and Torr are compared to the specific boiling points of pure water ($H2O$). According to the TDS (Total Dissolved Solids) the boiling points of water will differ. At those stages the vacuum to be created and maintained should be high. The ultimate aim of the project deals that to obtain steam at ambient temperature using vacuum desalination system without external heat source.

1.2 WATER FACTS

Water is the basic substance of life on earth, and it is increasingly in short supply. Water shortages affect 88 developing countries that are home to half of the world's population. In these places, 80-90% of all diseases and 30% of all deaths result from poor water quality. Furthermore, over the next 25 years, the number of people affected by severe water shortages is expected to increase fourfold. Some of this increase is related to population growth, some is related to the demands of industrialization. Currently, water consumption doubles every 20 years, about twice the rate of population growth. Governments throughout the world are beginning to take notice of the looming crisis. There is recognition that future peace and prosperity is intimately tied to the availability of clean, fresh water, and a growing consensus that future wars will probably be fought over water.

In addition to conservation measure, new and low cost methods of purifying freshwater, and desalting seawater, are required to contend with the destabilizing threat of running out of water. With that in mind, the purpose of this document is to provide a broad overview of the current status of desalination technologies, thereby establishing a baseline to which new technologies must be compared.

1.3 WATER RESOURCES – THE BIG PICTURE

There is an almost unfathomable amount of water on earth: about 1.4 billion km^3 (330 million cubic miles). Of this total, less than 3% is fresh water (about 35,000,000 km^3), much of which (about 24,000,000 km^3) is inaccessible due to the fact that it is frozen in ice caps and glaciers (Figure 1.1).

It is estimated that just 0.77% (about 11,000,000 km^3) of all the earth's water is held as groundwater, surface water (in lakes, swamps, rivers, etc.) and in plants and the atmosphere. Similar to fossil energy resources, almost all of this water has slowly accumulated over time and cannot be considered to be renewable.

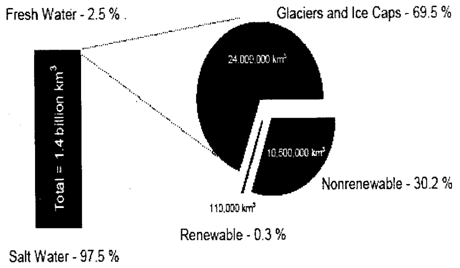


FIGURE 1.1: DISTRIBUTION OF THE WORLD'S WATER

The global water cycle accounts for the only naturally renewable source of fresh water, that is, precipitation that occurs over land (about 110,300 km3/year). Figure 1.2 is a simplified illustration of the global hydrological cycle.

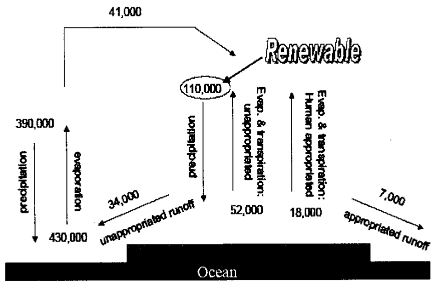


FIGURE1.2: THE GLOBAL WATER CYCLE WITH ESTIMATES OF FLOWS AND HUMAN APPROPRIATION. (UNITS ARE KM^3/YEAR)

Of the precipitation occurring over land, a large fraction (69,600 km^3/year) is recycled to the atmosphere through evaporation and transpiration from plants. About 26% of this part of the cycle (18,200 km^3/year) is appropriated for human use, e.g. through agriculture. The remaining water (runoff) is that which is directly available for other forms of human appropriation. Worldwide, the total annual runoff (including soil infiltration and groundwater replenishment) is estimated to be 40,700 km^3/year. Accounting for geographical remoteness and seasonal issues (e.g. flooding) that limit the accessibility of water, the total annual accessible runoff is only about 12,500 km^3/year. Therefore, it is estimated that about 54% of the accessible runoff and 23% of the total renewable resource (precipitation occurring over land) is currently appropriated for human use in some form. Of course, the resource needs to be able to support both human populations and the rest of the natural environment.

1.4 WATER RESOURCES – DISTRIBUTION AND AVAILABILITY

Fresh water is not evenly distributed across the world. The availability of freshwater varies by geographical region, and with the seasons. The renewable fraction of the earth's freshwater is usually found in the form of surface water (rivers, lakes, streams, etc.) and is very unevenly distributed. As an example, consider that only 4% of the U.S. land mass is covered by rivers, lakes, and streams. It is this uneven distribution over both time and geography that accounts for the fact that only about 30% of the world's annual freshwater runoff is considered to be accessible for human exploitation. It also this uneven distribution that results in almost all water issues arising on a regional basis.

From the standpoint of long term sustainability, it is the renewable resource that is most critical. Table 1 provides an overview of those countries currently experiencing water scarcity or water stress, as well as projections for the year 2025. The estimates of the renewable resource used for Table 1 were taken from *World Resources*, a publication of the World Resources Institute in cooperation with the World Bank and the United Nations, and from the Organization for Economic Cooperation and Development (OECD) Environmental Data Compendium (1999). The population data, along with the high, medium, and low estimates for the year 2025 were taken from United Nations Populations Division's *World Population Prospects: The 2000 Revision.* The data was compiled by Population Action International.

The benchmarks used for water stress and water scarcity in Table 1 were developed by Malin Falkenmark, a Swedish hydrologist, and have been generally accepted by organizations such as the World Bank. A moderately developed country with more than 1,700 m^3/capita-year (1200 gal/person-day) of renewable fresh water (water stress) will generally experience only intermittent or localized water shortages. Below this level, problems tend to become chronic and widespread. When water availability falls below 1,000 m^3/capita-year (water scarcity), the resulting water shortages can interfere with economic development and lead to environmental degradation. These are rough benchmarks, and there are exceptions. For example, some would say that Israel has done well with only 464 m^3/capita-year (Table1.1), although they are experiencing problems such as salt incursion into some of their aquifers. A quick examination of Table 1 reveals that the Middle East and North Africa are the most water scarce regions of the world. These areas are home to about 6.3% of the World's population, but receive only 1.4 % of the earth's renewable freshwater. Population growth in these areas is expected to exacerbate the problem. In contrast to the Middle East, the United States has a relative abundance of renewable fresh water. However, there are areas of the country, especially in the West, where the resource is limited.

Ground waters tend to be far more evenly distributed than surface waters, and the resource is vast (Figure1.1). However, as previously indicated, much of this water is a non-renewable fossil resource that is subject to local depletion. The "safe yield" of an aquifer is that which can withdraw without ultimately depleting the aquifer that is the portion of the water that is renewable. When more than this amount is withdrawn, the aquifer recedes and a number of undesirable effects can result. In addition to risk of completely draining an aquifer, there may be incursion of inferior water, e.g. brine, into the aquifer, or the land may sink (subsidence).

The Ogallala aquifer is often cited as an example of an important fossil water resource that is being rapidly depleted. This aquifer stretches from Southern South Dakota to Northwestern Texas and supplies as much as 30% of the groundwater used for irrigation in the United States. By 1990, 24% of the Texas portion of the aquifer had been depleted (164 billion m^3), primarily to grow grain to feed to cattle. In recent years the rate of depletion has slowed, and is now only 88% of the depletion rate in the 1960s. About a third of this decrease can be traced to improved methods of irrigation, but two thirds are the result of a decrease in irrigated area that resulted at least in part from increased pumping costs.

TABLE1.1: DISTRIBUTION OF RENEWABLE FRESH WATER RESOURCES ON A PER CAPITA BASIS. BLUE SHADING INDICATES WATER SCARCITY, GREEN SHADING INDICATES WATER STRESS.

Country	Renewable Water (m^3/year)				
	Total (km^3/yr)	Per capita (2000)	Per capita (2025 low)	Per capita (2025 med.)	Per capita (2025 high)
Kuwait	0	0	0	0	0
United Arab Emirates	0	77	61	58	55
Saudi Arabia	2	118	63	59	56
Jordan	1	142	87	81	76
Libyan Arab Jamahiriya	1	151	107	100	95
Yemen	4	223	89	85	82
Oman	1	394	196	185	177
Tunisia	4	412	348	316	291
Israel	3	464	354	330	310
Algeria	14	478	361	335	313
Burundi	4	566	303	291	281
Rwanda	6	828	509	489	471
Kenya	30	985	739	673	624
Morocco	30	1004	779	714	665
Egypt	69	1009	789	723	666
Denmark	6	1116	1133	1107	1083
Zimbabwe	14	1117	820	755	700
South Africa	50	1154	1251	1142	1052
Lebanon	5	1373	1117	1048	992
Haiti	12	1486	1114	1048	989
Korea, Rep	70	1493	1378	1341	1307
Czech Republic	16	1558	1675	1645	1617
Belgium	16	1561	1602	1568	1535
Poland	63	1632	1728	1691	1656
Malawi	19	1645	1022	952	907
Burkina Faso	20	1690	808	773	745
Ethiopia	110	1749	1020	970	932
Somalia	16	1789	778	741	714
Pakistan	255	1805	1063	1016	973
Iran (Islamic Republic of)	129	1827	1400	1293	1206
India	1908	1891	1511	1411	1323
Germany	178	2170	2299	2256	2215
China - all included	2830	2206	2028	1912	1823
Bulgaria	18	2290	3027	2971	2917
Eritrea	9	2405	1302	1246	1196
Nigeria	280	2459	1454	1380	1312
United Kingdom	147	2474	2456	2400	2346
Dominican Republic	21	2508	2057	1922	1805
Tanzania	89	2534	1592	1474	1377
Lesotho	5	2556	2486	2337	2203
Sri Lanka	50	2642	2370	2219	2084
Togo	12	2651	1524	1460	1402
Moldova, Republic of	12	2724	3010	2887	2776
Ghana	53	2756	1852	1720	1609
Syrian Arab Republic	45	2761	1754	1631	1524
Armenia	11	2799	2916	2837	2791
Spain	112	2809	3049	2998	2950
Ukraine	140	2816	3603	3528	3458
El Salvador	18	2819	2120	1972	1842
Uganda	66	2833	1294	1228	1179
France	170	2870	2783	2709	2642
Afghanistan	65	2986	1507	1438	1382
Niger	33	3000	1326	1263	1216
United States	2478	8749	7439	7145	6775

CHAPTER - 2

WATER RESOURCES – A ROLE FOR DESALINATION?

2.1 IMPORTANCE OF DESALINATION

Increasingly, water scarcity will challenge human populations. Lack of water hinders economic development, devastates human health, leads to environmental degradation, and foments political instability. Parts of the Middle East and North Africa are already experiencing the effects that water shortages bring. A number of research agendas have been developed to address the water problem. Ultimately, a number of parallel approaches will be necessary to limit the effects of water shortages including improving the efficiency of water use, implementing technologies and policies to encourage water conservation and reuse, slowing population growth, and tapping nontraditional sources of freshwater such as seawater, fog water, atmospheric water vapor, and water "produced" in conjunction with fossil energy or other resource recovery operations. Inland saline aquifers will likely be tapped and treated, and water will increasingly be "reclaimed" for use from waste treatment operations.

Within the different approaches, any numbers of specific measures and policies have been suggested. Typically these focus on efficiency and conservation, rather than "growing the supply." For example, proposals for the Middle East include reallocating water away from agriculture towards domestic and industrial sectors, altering crop selections, installing efficient technologies such as drip irrigation, improving distribution efficiencies, educating the public about conservation measures, implementing economic penalties and incentives, instituting legal reforms, and slowing population growth.

From the perspective of growing the global supply, Postel et al. have noted that the most practical way of increasing the renewable water supply is to build new dams and reservoirs. They estimate that this could increase the amount of accessible runoff by 10% over the next 30 years. Although they acknowledge a role for desalination, they predict that high costs will be limited to the production of domestic water in energy rich nations, and that it

will have only a minor impact on the overall global water supply. In fact, this is the current situation for desalination. The total capacity of the more than 12,000 desalination plants in the world, overwhelmingly located in wealthy and energy rich nations, is equivalent to only 1.6% of the total daily freshwater usage in the United States alone. Furthermore, the production of potable water in the United States by membrane processes accounts for less than 0.5% of the total potable water delivered. However, this analysis neglects the fact that on a local basis desalination can have an overwhelming impact. For example, Kuwait derives virtually its entire freshwater supply from desalination. Unfortunately, many at-risk developing nations do not possess the wealth or energy resources required to install and operate large desalination plants. Economic improvements will be necessary if desalination (or other schemes for harvesting water from nontraditional sources) is to have a similar impact in many other areas experiencing need.

Even without major advances, the United States is well positioned to benefit from desalination. By 1996, there were 180 desalination and membrane softening plants in the U.S., primarily reverse osmosis (RO) units treating brackish (slightly saline) water . At that time the annual growth rate of brackish water RO capacity in the U.S. was about 18%, and the annual growth rate of brackish water electro dialysis capacity was 25%. However, seawater RO was (and is) not a significant factor in the water supply.

In conclusion, countering current and impending water shortages will require the implementation of any number of conservation and efficiency measures. From the global perspective, desalination will have only a small impact on the fresh water supply. However, on a local basis, desalination (coupled with other measures) will play a pivotal role. Wealthy nations will be able to capitalize on desalination as necessary, using currently available technology. Improvements in the economics are required before desalination will be widely implemented in the developing world.

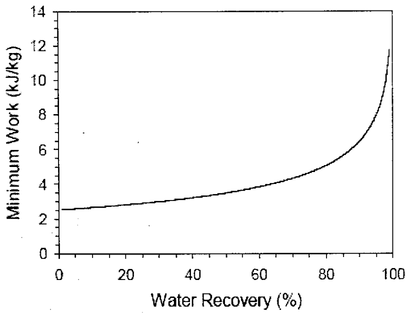
CHAPER – 3

DESALINATION BASICS

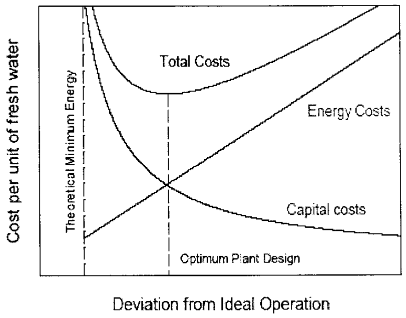
3.1 GENERAL DESIGN CONSIDERATIONS AND LIMITATIONS

The theoretical minimum energy for desalination of seawater, with an incremental recovery of freshwater, is a little less than 3kJ/kg water. Although this value can be arrived at in a number of ways, it is perhaps easiest to think of the minimum requirement as the free energy change associated with the process of salt dissolution. This energy change is linked to any number of physical phenomena, including boiling point elevation, freezing point depression, and osmotic potential (or pressure). Assuming a process where fresh water is recovered from a salt solution (as opposed to recovering the salt from the water), it is clear that as the recovery of freshwater is increased, the remaining solution becomes ever more concentrated, thereby further elevating the boiling point, etc. Thus, as the recovery increases, the energy required to perform the operation must also increase. The relationship between recovery and the theoretical minimum energy requirement is shown in Graph 3.1.

As a practical matter, we know that desalination processes (or any process for that matter) can not operate with perfect efficiency. Furthermore, design considerations teach us that systems operating with nearly perfect energy efficiency (near thermodynamic reversibility) will be large in size, and will therefore have high capital costs. Conversely, processes that use energy less efficiently can be smaller and will thus tend to have lower capital costs. Thus, for most practical applications, there is a tradeoff between capital costs and energy costs that leads to an optimum plant design and minimum product water cost. In short, the best process design is not necessarily the most energy efficient design (Graph 3.2). Keep in mind that for special applications, other design parameters, e.g. size and weight, may also need to be considered.



GRAPH 3.1: THE THEORETICAL MINIMUM ENERGY FOR DESALTING SEAWATER AS A FUNCTION OF FRESHWATER RECOVERY



GRAPH 3.2: THE TRADE-OFF BETWEEN CAPITAL COSTS AND ENERGY CONSUMPTION FOR PRACTICAL DESALINATION SYSTEMS

Recovery rates are an important design consideration for many reasons in addition to the impact on the energy required for the separation itself. As the recovery rate increases, the potential for scale formation (see below) also increases. This and the increasing energy requirements tend to drive designs towards low recoveries. There are, however, a number of other considerations that drive the design towards maximizing recoveries. First, depending on the plant location, significant energy may be spent transporting the feed to the plant. Then, all of the feed stream, including the fraction that will ultimately be rejected must be pretreated. Therefore it makes economic sense to recover as much water as possible from the feed to minimize transport and pretreatment costs. In addition, energy losses and inefficiencies in the desalination process tend to increase with increasing water rejection. For example, heat is often rejected from a system with the concentrated brine, and energy is lost when concentrated RO brines are depressurized. Another important factor is that significant costs (energy or otherwise) are usually associated with the disposal of the concentrated brine. A good design achieves a balance between all of these factors.

Scaling, i.e. the precipitation on working surfaces of salts due to the concentration process, is always an important design consideration for desalination plants. Fouling of heat or mass transfer surfaces can greatly reduce the capacity and efficiency of a process. Typically, calcium salts, and in particular $CaSO_4$ and $CaCO_3$, are major (but not the only) concerns. In developing a design it is important to understand the chemistry of the specific water that will be treated. There are a number of strategies for preventing scale formation including limiting the operating temperature (calcium salts tend to have retrograde solubility), limiting the water recovery to prevent saturation, chemical pretreatment (e.g. the addition of acids or polyphosphates) to alter the solubility or onset of precipitation of scale formers, and lime or lime-soda softening to remove potential scale formers. In addition, many systems are designed to limit the occurrence or impact of scale and to allow easy maintenance. For example, seed crystals may be added to nucleate the precipitation of scale in the liquid phase or in a specially designed contact bed rather than on critical heat transfer surfaces.

A final criteria important to the design of a desalination system is the quality of the final product water. For example, water that will be used in a semiconductor fab must be virtually contaminant free; while the safe limit for the salinity of drinking water is usually about 1000 ppm (the voluntary EPA standard is 500 ppm [26]). Most crops require water with a salinity of less than 2000 ppm. Distillation processes typically produce water of a higher quality than membrane processes. Chemical processes, e.g. ion exchange, are typically employed to achieve extremely high levels of purity. When considering the quality of water derived from a desalination process, it is important to consider the fact that it may be blended with water form other sources. Depending on the quality of the other sources, this may have the effect of relaxing the specifications for the water produced by the desalination process.

3.2 THREE BASIC APPROACHES TO DESALINATION

There are three basic approaches to separating water from salt. The first approach is to use thermal means to effect a phase change of the water (to vapor or solid), physically separate the new phase from the remaining salt solution, and then recover the thermal energy for reuse as the separated water reverts to liquid form. Distillation processes were the first desalination processes to be conducted on a large commercial scale and account for a large portion of the world's desalination capacity. In addition to the thermal component, distillation processes often include vacuum components to increase evaporation at lower temperatures. Although effective, freezing processes have failed to find a significant market.

The second approach to desalination is to physically separate the components, generally with a membrane, as they move in response to an externally applied gradient. The two major processes of this type are reverse osmosis (RO), and electrodialysis (ED). In RO, water passes through a membrane that is impermeable to the solute in response to a chemical potential gradient achieved through pressurization. In ED, ions in solution migrate through anion and cation selective membranes in response to an electric field. Both of these processes have been commercialized on a large scale. The flow through capacitor also uses an electric field to collect and separate dissolved ions from water.

Finally, there are chemical approaches to desalination. This category is more varied than the other two and includes processes such as ion exchange, liquid-liquid extraction, and gas hydrate or other precipitation schemes. Given the maturity of the distillation and membrane processes, novel approaches to desalination are almost by definition chemical processes or a hybrid combination of chemical and other processes. Generally, it is found that chemical approaches are too expensive to apply to the production of fresh water. Ion exchange is an exception in that it is used to soften water, and to manufacture high purity de-ionized water for specialty applications. However, even ion exchange is impractical for treating water with higher levels of dissolved solids.

CHAPTER – 4

MAJOR COMMERCIAL PROCESSES

4.1 DISTILLATION PROCESSES

4.1.1 MULTI-STAGE FLASH

Multi-stage flash (MSF) units are widely used in the Middle East (particularly in Saudi Arabia, the United Arab Emirates, and Kuwait) and they account for over 40% of the world's desalination capacity]. MSF is a distillation (thermal) process that involves evaporation and condensation of water. The evaporation and condensation steps are coupled in MSF so that the latent heat of evaporation is recovered for reuse by preheating the incoming water (Figure 4.1). To maximize water recovery, each stage of an MSF unit operates at a successively lower pressure. A key design feature of MSF systems is bulk liquid boiling. This alleviates problems with scale formation on heat transfer tubes. In the Persian Gulf region, large MSF units are often coupled with steam or gas turbine power plants for better utilization of the fuel energy. Steam produced at high temperature and pressure by the fuel is expanded through the turbine to produce electricity. The low to moderate temperature and pressure steam exiting the turbine is used to drive the desalination process. A performance ratio often applied to thermal desalination processes is the gained output ratio, defined as the mass of water product per mass of heating steam. A typical gained output ratio for MSF units is 8. A 20 stage plant has a typical heat requirement of 290 kJ/kg product.

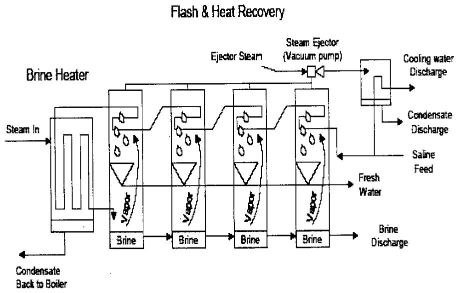


FIGURE 4.1: SCHEMATIC OF MULTI-STAGE FLASH DESALINATION PROCESS

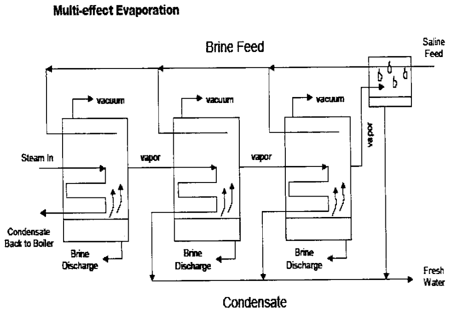


FIGURE 4.2: SCHEMATIC OF MULTI-EFFECT EVAPORATOR DESALINATION PROCESS (HORIZONTAL TUBE – PARALLEL FEED CONFIGURATION).

Multi-effect evaporation (MEE) is distillation process related to MSF (Figure 4.2). MEE was developed early on and plants were installed in the 1950s. However, due to problems with scaling on the heat transfer tubes, it lost favor and was replaced with MSF. MEE is still not widely used, but it has gained attention due to the better thermal performance compared to MSF. Newer plants are designed to limit problems with scaling. In MEE, vapor from each stage is condensed in the next successive stage thereby giving up its heat to drive more evaporation. To increase the performance, each stage is run at a successively lower pressure. This allows the plant to be configured for a high temperature (> 90 °C) or low temperature (< 90 °C) operation. The top boiling temperature in low temperature plant can be as low as 55 °C which helps reduce corrosion and scaling, and allows the use of low-grade waste heat. The MEE process can have several different configurations according to the type of heat transfer surface (vertical climbing film tube, rising film vertical tube, or horizontal tube falling film) and the direction of the brine flow relative to the vapor flow (forward, backward, or parallel feed).

MEE systems can be combined with heat input between stages from a variety of sources, e.g. by mechanical (MVC, Figure 4.3) or thermal vapor compression (TVC). Hybrid MEE-TVC systems may have thermal performance ratios (similar to the gain ratio, energy used to evaporate water in all the stages/ first stage energy input) approaching 17, while the combination of MEE with a lithium bromide/water absorption heat pump yielded a thermal performance ratio of 21.

4.1.2 VAPOR COMPRESSION (THERMAL AND MECHANICAL)

Vapor compression processes rely on reduced pressure operation to drive evaporation. The heat for the evaporation is supplied by the compression of the vapor, either with a mechanical compressor (mechanical vapor compression, MVC, Figure 4.3), or a steam ejector (thermal vapor compression, TVC). Vapor compression processes are particularly useful for small to medium installations. MVC units typically range in size up to about 3,000 m^3/day while TVC units may range in size to 20,000 m^3/day. MVC systems generally have only a single stage, while TVC systems have several stages. This difference arises from the fact that MVC systems have the same specific power consumption (power/unit water produced) regardless of the number of stages, while the thermal efficiency of TVC systems is increased by adding additional stages. Thus the main advantage of adding effects to an MVC system is simply increased capacity.

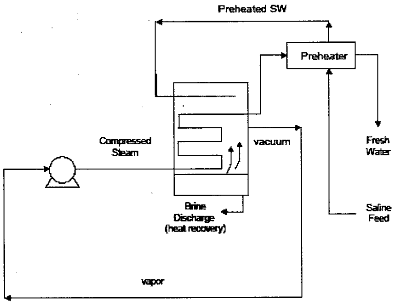


FIGURE 4.3: SCHEMATIC OF SINGLE STAGE MECHANICAL VAPOR COMPRESSION DESALINATION PROCESS

4.2 MEMBRANE PROCESSES

4.2.1 REVERSE OSMOSIS

Reverse osmosis (RO) is a membrane separation process that recovers water from a saline solution pressurized to a point greater than the osmotic pressure of the solution (Figure 4.4). The United States ranks second worldwide in desalination capacity, primarily relying on RO to treat brackish and surface water. In essence, the membrane filters out the salt ions from the pressurized solution, allowing only the water to pass. RO post-treatment includes removing dissolved gasses (CO_2), and stabilizing the pH via the addition of Ca or Na salts.

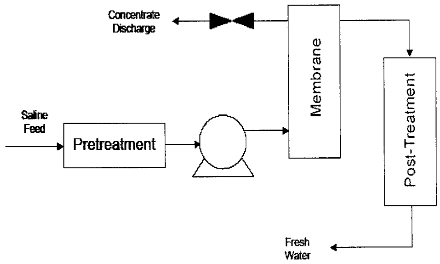


FIGURE 4.4: BLOCK DIAGRAM OF REVERSE OSMOSIS OPERATIONS – OPTIONAL PRESSURE RECOVERY DEVICES NOT DEPICTED.

Pressurizing the saline water accounts for most of the energy consumed by RO. Since the osmotic pressure, and hence the pressure required to perform the separation is directly related to the salt concentration, RO is often the method of choice for brackish water, where only low to intermediate pressures are required. The operating pressure for brackish water systems ranges from 15 – 25 bar and for seawater systems from 54 to 80 bar (the osmotic pressure of seawater is about 25 bar). Since the pressure required to recover additional water increases as the brine stream is concentrated, the water recovery rate of RO systems tends to be low. A typical recovery value for a seawater RO system is only 40%. Since most of energy losses for RO result from releasing the pressure of the concentrated brine, large scale RO systems are now equipped with devices to recover the mechanical compression energy from the discharged concentrated brine stream with claimed efficiencies of up to 95%. In these plants, the energy required for seawater desalination has now been reported to be as low as 9 kJ/kg product. This low value however is more typical of a system treating brackish water. RO membranes are sensitive to pH, oxidizers, a wide range of organics, algae, and bacteria and of course particulates and other foulants. Therefore, pretreatment of the feed water is an important consideration and can a significant impact on the cost of RO, especially since all the feed water, even the 60% that will eventually be discharged, must be pretreated before being passed to the membrane.

4.2.2 ELECTRODIALYSIS

Electrodialysis (ED) utilizes a direct current source and a number of flow channels separated by alternating anion and cation selective membranes to achieve the separation of water and dissolved salts (Figure 4.5). Since the driving force for the separation is an electric field, ED is only capable of removing ionic components from solution, unlike RO or distillation.

In the ED process, saline water is fed in parallel to each of the separate channels. Cations and anions then migrate in opposite directions in response to the applied voltage. Due to the charge selectivity of the membranes, the ion concentration increases and decreases in alternating channels of the apparatus. A single membrane stack may consist of hundreds of these alternating channels. Since the resistance in the stack changes from top to bottom, the separation is typically carried out is a series of small steps. This makes the process more economical and easier to control. Like RO, the energy required to separate the ions from solution increases with concentration, thus ED is generally limited to brackish waters containing only a few thousand ppm of dissolved solids.

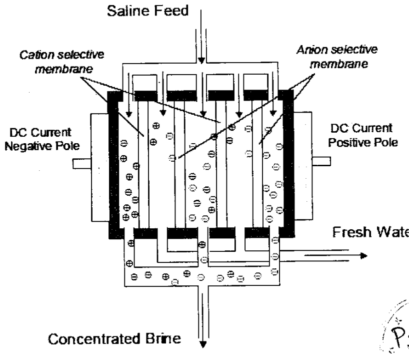


FIGURE 4.5: SCHEMATIC DIAGRAM OF ELECTRODIALYSIS DESALINATION PROCESS.

The membranes of ED units are subject to fouling, and thus some pretreatment of the feed water is usually necessary. Precipitation of scale can be facilitated in the ED process by changes on pH that occur near the membranes as a result of the transport of H^+ and OH^- ions. However, since there is not a flux of water through the membranes, ED can treat water with a higher level of suspended solids than RO. Also, since nonionic solids, e.g. silica, are not concentrated by the process, these components are of less concern. The electrodialysis reversal (EDR) process was developed to help eliminate membrane fouling. In the EDR process, the membrane polarity is reversed several times an hour. This has the effect of switching the brine channels to freshwater channels, and the freshwater channels to brine channels, and breaks up and flushes out deposits.

CHAPTER - 5

ENERGY REQUIREMENTS OF THE DESALINATION AND DESALINATION COSTS

5.1 ENERGY REQUIREMENTS OF THE DESALINATION

Energy consumption data for the major desalination processes has been compiled from a number of sources and is presented in Table 5.1. Although the most efficient process is not always the most cost effective design (Figure 3.2), this data allows the energy efficiency of different approaches to be compared. As a benchmark, recall that the theoretical minimum energy required to desalt seawater ranges from about 3-7 kJ/kg over the range of practical recoveries (Figure 3.1). Note that in Table 5.1, the energy requirements for the thermal processes (MSF, MEE, and VC) are virtually independent of salt concentration, while the energy requirements for the membrane processes are highly dependent on concentration. For this reason, separate data are provided for RO treatment of seawater and brackish water. ED can only be economically applied to brackish water and Table 5.1 reflects this fact.

TABLE 5.1. ENERGY USE FOR DESALINATION (KJ/KG FRESH WATER – DIVIDE BY 3.6 FOR KWHR/M^3)

MSF	MEE	VC	Seawater RO	Brackish RO	Brackish ED
299			61		
95			15-28		
230			27		
290		100-120*	23-30		4
216-288			18-22	11	
		25-43	11		
		29-39	15-28		
95-252*	107-132*	22-29			
		14-29			
		22-58			
		26			
		37-40			
	95-275*				
	152				
					0.4-1.8

The values for any given process in Table 5.1, show a fairly wide variation. This variation results from a number of factors including differences in the size and configuration of the units, technological advances, and the quality of the feed stream being treated. There are also variations in what is included in the energy calculation. In some cases, authors have declined to include thermal energy obtained from waste heat sources as part of the calculation, and instead only account for energy that is used in addition to this heat or that is diverted from the main process (usually electric power generation) as it is typically run. Using this type of accounting, MEE processes have reported to consume as little 20 kJ/kg. These calculations are instructive from a economic standpoint, and illustrate the advantages of integrating desalination with other processes. However, they are not helpful in comparing stand-alone desalination processes. Therefore, we have tried to avoid including these types of figures in the table.

Despite the variations, it is fair to say that Table 5.1 reveals that of the thermal processes, MSF consumes the most energy, despite its relative maturity (at least 50 years). MSF is followed by MEE (or hybrid MEE) systems and then vapor compression systems. None of the processes performs particularly well when compared to the theoretical minimum values. The energy consumption of MSF, by far the most widely used thermal process (see below), is still at least 30 times the theoretical minimum. RO is a newer technology (30 years) that with recent improvements in energy recovery is remarkably efficient, consuming only 3 to 10 times the theoretical minimum (using the conservative 3 kJ/kg number). This of course is an indication that RO is closer to being a thermodynamically reversible process than the distillation methods. It is important to consider however that RO consumes energy in the form of electricity. On the other hand, MSF uses heat (or fuel) more directly. The conversion of thermal energy to electrical energy is only about 35% efficient. Therefore, on a fuel basis, RO consumes 9-30 times the theoretical energy requirement.

5.2 DESALINATION COSTS

Reported Costs for Desalination Table 5.2 presents the costs compiled from the literature for water produced by each of the major desalination methods. Cost figures are inherently more variable and uncertain than energy consumption figures. A primary reason for this is that many costs, energy costs in particular, greatly vary over time, geography, and, for RO and ED, concentration. In addition, factors such as feed water quality determine the degree of pretreatment necessary, and thus the pretreatment costs. Also, the costs of transporting the water to the treatment or distribution site (e.g. from the ocean inland) will vary by location, as will the cost of disposing of the concentrated brine solution. Furthermore, factors such as low interest government financing or subsidies can significantly influence capital and other costs. The size of the plant is also a critical factor. To further complicate matters, it has been pointed out that there is no agreed on standard for computing and reporting water costs. Some authors have chosen to neglect capital costs; some have chosen to report all costs including delivery costs, and some report design costs that do not ultimately reflect actual operating expenses. These and other factors lead us to caution that the numbers in Table 5.2 should be used as rough guides in aggregate, or understood in their specific context. For the most part, these costs should be understood to be most applicable to reasonably populated and industrialized regions. Costs in less developed parts of the world will be greater. Due to geographical variation, government influence and social policies, water quality, custom, and other factors, the price consumers pay for water varies according to location, application, and quantity. Also, one should note that in many cases, the price consumers pay does not accurately reflect the actual cost of producing or delivering the water, and almost never reflects "opportunity costs". Therefore, it is difficult to provide a single meaningful benchmark for the current cost (or even the price) of freshwater provided from traditional sources. However, we note that in 1994, the price of water for domestic residential consumption averaged about \$0.53/m3 (\$2.00/1000 gal) with a high of about \$1.70/m3 and a low of less than \$0.20/m3.

TABLE 5.2. DESALINATION COSTS ($\$/M^3$ FRESH WATER – MULTIPLY BY 3.8 FOR \$/1000 GAL)

MSF	MEE	VC	Seawater RO	Brackish RO	Brackish ED
1.10-1.50	0.46-85	0.87-0.92	0.45-0.92	0.20-0.35	
0.80	0.45		0.72-0.93		
0.89	0.27-0.56		0.68		
0.70-0.75			0.45-0.85	0.25-0.60	
			1.54	0.35	
			1.50	0.37-0.70	0.58
1.31-5.36			1.54-6.56		
1.86	1.49				
	1.35		1.06		
			1.25		
1.22					
				0.18-0.56	
		0.46			
			1.18		
	1.17				
		0.99-1.21			
			0.55-0.80	0.25-0.28	
			0.59-1.62		
			1.38-1.51		
			0.55-0.63		
			0.70-0.80		
				0.27*	
			0.52		

Table 5.2 clearly illustrates that RO has a significant economic advantage for treating brackish waters. Price quotes for ED are not readily available, an indication of small market share relative to RO. For desalination of seawater, RO clearly has an economic advantage over MSF. The situation is not as clear cut for RO and MEE. The widespread acceptance and application of RO (see below) lends greater credibility to cost estimates for this process, and it appears to be generally accepted that seawater RO can be carried out in the U.S. for somewhere in the range of \$0.50/m^3. In contrast, although gaining new acceptance, MEE plants are uncommon, show great variation in design,

and are relatively unproven on large scales. Thus, claims that MEE is cost competitive with RO are viewed by some with skepticism. Recent improvements in energy recovery for RO are likely to further fuel this skepticism. Yet, the economics of low temperature MEE systems that are integrated with other processes to utilize waste heat are probably favorable.

As a final note to this section, water produced by desalination is often blended with water from other freshwater sources before distribution. This seems to be particularly true in the United States. This has two notable impacts. First, the specifications for the desalination process may be relaxed. That is, product water from the desalination process will be diluted with water from other sources and therefore a less perfect separation may be acceptable. This of course is mainly a factor for the membrane processes. The second impact is on the overall cost of water delivered to the consumer. While the cost of water produced by desalination may be higher than the cost of more traditional sources, the price the consumer must pay is only increased incrementally in proportion to the contribution of desalinated water to the overall supply. Hence, the overall price the consumer must pay is impacted in a lesser way.

CHAPTER - 6

DESIGN AND FABRICATION OF VACUUM DESALINATION SYSTEM

6.1 DETAILS OF VACUUM DESALINATION SYSTEM

The vacuum desalination system was designed to operate according to the following table. The table 6.1 shows the boiling range of water with respect to the vacuum range.

TABLE 6.1: OPERATING RANGES AND MEASURING RANGES OF VACUUM.

		Measuring ranges					Boiling ranges in °C			
			mbar¹)		Torr²)		H_2O	Hg	$C_2H_5 \cdot OH$	CH_3OH
Normal vacuum	Rough vacuum		1013		760		100	357	78,3	64,7
			1000		750		99,6	356,2	78	64,2
			800		600		93,5	344	71	56,5
			600		450		85,5	329	61,5	48
			400		300		75	309	54	40,5
			200		150		60,1	278	45	32
		↑	100	↑	75		45,7	251	29,5	16,5
			80		60		41	242	24	11
			60		45		36,4	232	17	5,5
			50		37,5		32,5	225	14	3
			40		30	Evaporation	29	218	11,5	0
			30		22,5		24	208	8	−3,5
	Intermediate vacuum		23,4		17,53		20	201	5	−6
		Millibar range	20	Torr range	15		17,2	196	3,5	8
			15		12		14	190	−1	−11,5
			12		9		9,7	181	−4	−15,5
			10		7,5		7	176	−9	−19,6
			8		6	↑	3,8	170	−12,5	−24
			6,11		4,58		0	162,5	−15,6	−25
Fine vacuum range			6		4,5	↓	−0,2 ³)	162	−17	−20,5
			4		3		−5	152	−21,5	−32
		↓	2	↓	1,5		−13	135,5	−28	−38
			1		0,75		−20,3	119	−38,5	−47,5
		↑	1000	↑	750					
			800		600		−22,7	115,5	−42	−50,5
			600		450		−25,4	110	−45,5	−53
			400		300	Sublimation	−29,3	102	−48,5	−56,5
		Microbar	200		150		−36	89	−53	−61
			100	Millitorr	75		−42	77,5	−60	−67,5
			80		60		−43,7	73,5	−63	−70
			40		30		−50	63	−68	−74,5
			10		7,5		−60,5	42,5	−75	−83
			8		6		−62	39,8	−77	−85
		↓	4	↓	3		−67	31	−81	−88,5
			1		0,75					
High vacuum range		↑	1000	↑	750		−76,3	14,4	−87	−94
			800		600		−77,8	12	−88,5	−95
			400		300		−82	5	−91,5	−98
		Nanobar	100	Microtorr	75		−90	−9	−94	−100
			80		60		−91,5	−11		
			40		30		−96	−17		
			10		7,5		−101,5	−29		
			8	↓	6		−103	−31		
		↓	4		3		−106	−36		
			1		0,75		−112	−42		
Ultra vacuum range		↑	1000	↑	750					
			800		600		−113			
			400		300		−116			
			100	Nanotorr	75		−121,5			
		Picobar	80		60		−122			
			40		30		−124,5			
			10		7,5		−129,5			
			8	↓	6		−130			
		↓	4		3		−132,5			
			1	Picotorr	0,75		−137	−100		
			1000		750					
			800		600		−137,5			
			400		300		−139,5			
			100		75		−143,5			

¹) 10^2 N/m²

²) mm Hg

³) above ice

The vacuum desalination system consists of vacuum pump to create vacuum for appropriate ranges, vacuum chamber for the process and the condenser to collect the pure water. The vacuum chamber should with stand very low pressure under desired conditions.

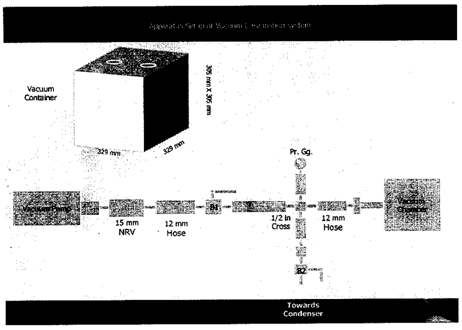


FIGURE 6.1: APPARATUS SETUP OF THE VACUUM DESALINATION SYSTEM

6.2 PRINCIPLE OF OPERATION

Fig.6.1 gives a schematic layout of the vacuum desalination system. The vacuum desalination system consists of a vacuum pump, vacuum container, condenser and appropriate valves. The system's principle of operation is that by reducing the pressure in a vacuum chamber using a vacuum pump the impure water inside the vacuum chamber will be converted to low temperature steam accordingly. Then by condensing the low temperature steam pure water can be obtained by using appropriate equipments and devices. Initially B1 is open and B2 is closed for operation.

After the creation of vacuum inside the chamber the B1 is closed to maintain the vacuum inside the vacuum chamber and to avoid the oil returning from the vacuum pump. The low temperature steam from the lower part of the vacuum chamber is collected with the help of condenser and then condensed.

6.3 DETAILS OF VACUUM PUMP

The vacuum pump required for producing the required vacuum in the desalination system. The specification of used vacuum pump is shown below.

Make: M/S Toshniwal – High Vacuum pump
Capacity: 150 lt/min Oil required: 2.2 lt
Motor HP: 1/3 Voltage: 220 / AC
Motor Specification: 1/3 HP, 230 V, 1 Φ, 50 Hz, 250 W, 3 A, 1440 rpm.

6.4 DETAILS OF VACUUM CHAMBER

I. Vacuum Chamber-1

Initially the vacuum chamber was designed for one cubic foot capacity. With this vacuum chamber around 28 liters of water could be poured. But for the process certain air column should be there inside the chamber to create and maintain the vacuum. The vacuum chamber-1 was constructed using aluminium plates of thickness 6mm and glass plates of thickness 12mm.The vacuum chamber-1 details and various gauges placed are shown below.

1. 1 cu. ft. capacity
2. Fabricated with Industrial adhesive LOCKTITE 352 & LOCKTITE 595.
3. Side dimensions:

i.	Glass plates	2	305 mm X 305 mm
ii.	Aluminium	2	305 mm X 323 mm
iii.	Glass + Aluminium	2	329 mm X 329 mm

Glass plate of 329mm X 329mm was placed at the bottom of the chamber and aluminium plate of 329mm X 329mm was placed at the top with vacuum gauge and temperature measuring devices. The vacuum chamber was coupled with the vacuum pump and the condenser with appropriate valves and other equipments.

II. Vacuum chamber-2 [Conical Vacuum Defreshner (CVD)].

The vacuum chamber-2 was a readymade Conical Vacuum Defreshner with a seperate way for suction and the measuring devices could be placed comfortably with the help of Rubber cock.This Conical Vacuum Defreshner was made up of strong glass and it could with stand very low pressure without leakage problem and maintaining the vacuum for long period of time.

1. 1000 ml capacity
2. Indian made BOROSIL.

6.5 DETAILS OF APPARATUS DIMENSIONS

Equipment	Number	Range
• Pressure Gauge	1	0 - 5 bar
• Vacuum Gauge	1	0 - 760 mm Hg
• Digital Thermometer	1	-10 – 200 °C
• Ball Valve	2	½ in
• Non Return Valve	1	15 mm
• Cross	1	½ in
• Reducer	10	½ in
• Nipples	4	½ in

The above equipments with specified dimensions are used for the experiment. The condenser used here is also another Conical Vacuum Defreshner of 1000ml capacity.

CHAPTER – 7

EXPERIMENTAL STUDY OF VACUUM DESALINATION SYSTEM AND DISCUSSION

The Vacuum Desalination System fabricated for one cubic foot with glass plates and aluminium plates could withstand the pressure only up to 310 mm of Hg. There was a severe leakage problem occurred and up to certain limit the problem was solved but we couldn't reach the required pressure for the experimental study of the system.

The Conical Vacuum Defreshner specially made for vacuum usage was used as a vacuum chamber. With this vacuum chamber the experiments were done successfully and readings were taken to plot the graphs. This vacuum chamber can with stand ultra vacuum ranges, but the vacuum pump used in the experiment could create vacuum only up to 50 mm of Hg. With this vacuum pump the experiments were done and the following are the readings taken and the graphs were plotted respectively.

7.1 EXPERIMENT WITH HOT WATER

Quantity: 500ml	Room Temperature: 30°C.
Time Duration: 20 minutes.	Date: 08-02-06.

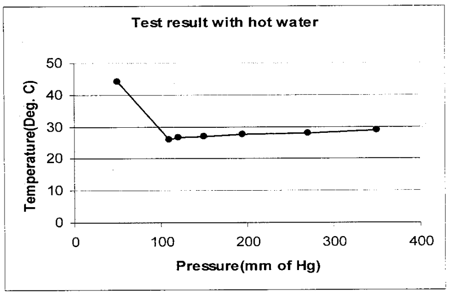
Initially the impure hot water about 45°C was poured inside the vacuum chamber. The ball valve B1 and B2 was closed and the temperature and pressure was noted. Then the ball valve B1 was opened and the vacuum pump was operated. The vacuum chamber pressure was attained about 50 mm of Hg with a fraction of seconds and the impure water inside the vacuum chamber got boiled vigorously and some quantity of water entered into the vacuum pump. The vacuum pump operation was stopped and the pressure and temperature inside the vacuum chamber was noted for further study.

TABLE 7.1: EXPERIMENT WITH HOT WATER.

Pressure(mm of Hg)	Temperature(°C)
50	44
110	26
120	26.5
150	27
195	27.5
270	28
350	29

The experiment with the hot water shows that pressure inside the vacuum chamber increases with respect to the temperature initially and the low temperature steam obtained as a result and the obtained low temperature steam condensed inside the vacuum chamber itself. So the low temperature steam to be recovered at the condenser end of the vacuum desalination system.

The graph 7.1 shows that the temperature inside the vacuum chamber got decreased with respect to decrease in the pressure. Between these changes the impure water inside the vacuum chamber undergone a phase change and due to the condensation again the temperature raised.



GRAPH 7.1: TEST RESULT WITH HOT WATER.

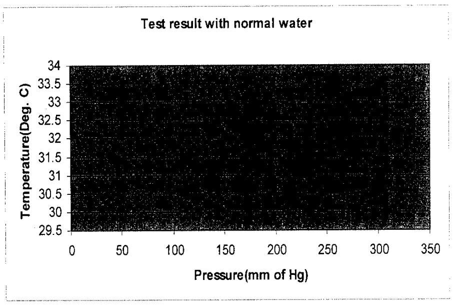
7.2 EXPERIMENT WITH NORMAL WATER

Quantity: 500ml	Room Temperature: 30.2°C.
Time Duration: 20minutes.	Date: 07-02-06.

The impure water about 500ml was poured inside the vacuum chamber and the vacuum pump was operated. Initially the ball valve B1 was opened and B2 was closed. The vacuum created only up to 110 mm of Hg due to some leakage problems we can't attain even 50 mm of Hg. This experiment was done to know about the Withstanding capacity of the vacuum chamber and to know about the leakage occurring due to the couplings and any other way to disturb the vacuum maintaining inside the vacuum chamber and throughout the vacuum desalination system.

TABLE 7.2: EXPERIMENT WITH NORMAL WATER.

Pressure(mm of Hg)	Temperature(°C)
110	33.5
130	33
145	32.5
160	32
180	31.5
220	31
245	30.5
310	30



GRAPH 7.2: TEST RESULT WITH NORMAL WATER.

The graph 7.2 shows that with decrease in pressure inside the vacuum chamber up to certain extent the temperature raises and then decreased according to increase in pressure inside the vacuum chamber.

7.3 EXPERIMENT WITH WATER QUANTITY OF 250ML

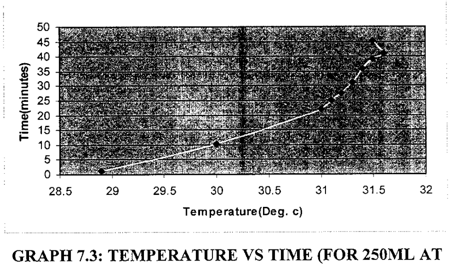
Quantity: 250ml	Room Temperature: 31.2°C.
Inlet water temperature: 30.3°C.	Chamber temperature: 31.2°C.
Water out temperature: 26.8°C.	Chamber maximum temperature: 31.8°C.
Time duration: 45 minutes.	Date: 22-03-06.

The impure water about 250ml was poured inside the vacuum chamber and the vacuum pump was operated. Initially the ball valve B1 was opened and B2 was closed. The vacuum created up to 50 mm of Hg. This experiment was done to know about the boiling range of the given impure water at ambient temperature. From this experiment only we analyzed that the vacuum pump mentioned in the fabrication part can create vacuum only up to 50 mm of Hg.

The vacuum about 50 mm of Hg was created and maintained within fraction of second's time. By that maintenance of vacuum inside the vacuum chamber the temperature inside the vacuum chamber decreases up to 28.9°C with respect to time 1.05 minutes and then raised gradually with constant pressure of 50 mm of Hg due to enthalpy of evaporation and condensation processes. The table 3 shows the temperature with respect to time at constant pressure 50mm of Hg and the graph 7.3 drawn with respect to the table 7.3.

TABLE 7.3: EXPERIMENT WITH WATER QUANTITY OF 250ML AT CONSTANT PRESSURE (50MM OF HG).

Temperature(°C)	Time(minutes)
28.9	1.08
30	10.33
31	22.05
31.1	25.15
31.2	27.47
31.3	30.92
31.4	35.7
31.5	39.06
31.6	41.03
31.5	45.16

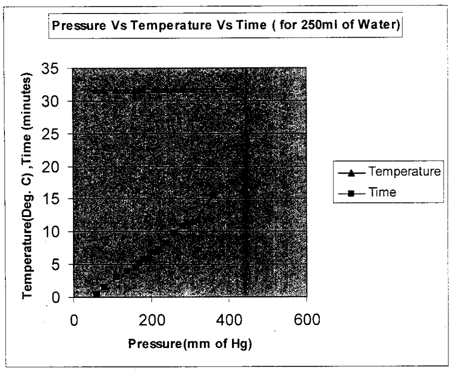


GRAPH 7.3: TEMPERATURE VS TIME (FOR 250ML AT 50MM OF HG).

The table 7.4 shows the various ranges of pressure, temperature with respect to time and the graph 7.4 was plotted with the readings shown in the table 7.4. The readings were taken only up to a limited time of 18 minutes. Up to that time the temperature and the corresponding pressure were noted for the study of the system. The temperature could be noted up to ambient temperature but it is not needed and the vacuum chamber will take more time to reach the ambient temperature.

TABLE 7.4: EXPERIMENT WITH WATER QUANTITY OF 250ML AT VARIOUS PRESSURE RANGES.

Pressure(mm of Hg)	Temperature(°C)	Time(minutes)
60	31.6	0.45
80	31.7	1.58
110	31.7	3.03
140	31.7	3.92
160	31.7	4.42
170	31.8	5.17
180	31.8	5.8
210	31.8	6.83
220	31.8	7.28
240	31.8	8.2
260	31.8	9.67
280	31.8	10.8
310	31.8	11.48
360	31.8	15.48
410	31.8	17.55



GRAPH7.4: PRESSURE VS TEMPERATURE VS TIME (FOR 250ML OF WATER).

After the end of the experiment the impure water inside the vacuum chamber was measured for temperature. The temperature of the impure water inside the vacuum chamber was 26.8°C. The maximum temperature obtained with this experiment without external heat was 31.8°C.

7.4 EXPERIMENT WITH WATER QUANTITY OF 500ML

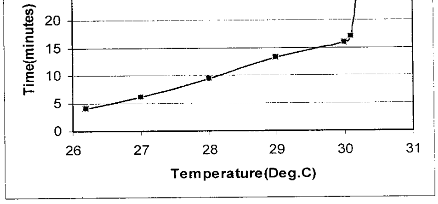
Quantity: 500ml	Room Temperature: 31.2°C.
Inlet water temperature: 29.5°C.	Container temperature: 30.9°C.
Water out temperature: 24.0°C.	Container maximum temperature: 31.8°C.
Time duration: 25 minutes.	Date: 23-03-06.

The impure water about 500ml was poured inside the vacuum chamber and the vacuum pump was operated. Initially the ball valve B1 was opened and B2 was closed. The vacuum created up to 50 mm of Hg. This experiment was done to know about the boiling range of the given impure water at ambient temperature with the volume of 500ml.

The vacuum about 50 mm of Hg was created and maintained within fraction of second's time. By that maintenance of vacuum inside the vacuum chamber the temperature inside the vacuum chamber decreases up to 26.2°C with respect to time 4 minutes and then raised gradually with constant pressure of 50 mm of Hg due to enthalpy of evaporation and condensation processes. The table 7.5 shows the temperature with respect to time at constant pressure 50mm of Hg and the graph 7.5 drawn with respect to the table 7.5.

TABLE 7.5: EXPERIMENT WITH WATER QUANTITY OF 500ML AT CONSTANT PRESSURE (50MM OF HG).

Temperature(°C)	Time(minutes)
26.2	4.05
27	6.055
28	9.5
29	13.35
30	16.01
30.1	16.98
30.2	24.95

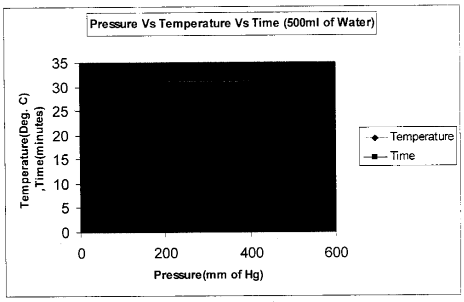


GRAPH 7.5: TEST RESULT (FOR 500ML AT 50MM OF HG).

The table 7.6 shows the various ranges of pressure, temperature with respect to time and the graph 7.6 was plotted with the readings shown in the table 7.6. The readings were taken only up to a limited time of 17 minutes. Up to that time the temperature and the corresponding pressure were noted for the study of the system. The temperature could be noted up to ambient temperature but it is not needed and the vacuum chamber will take more time to reach the ambient temperature. The water temperature of the vacuum desalination system after the process obtained was 24°C.

TABLE 7.6: EXPERIMENT WITH WATER QUANTITY OF 500ML AT VARIOUS PRESSURE RANGES.

Pressure(mm of Hg)	Temperature(°C)	Time(minutes)
60	30.4	0.45
80	30.5	1
110	30.6	1.83
130	30.7	2.34
160	30.8	3.67
180	30.9	5.03
220	31	7.32
320	31.1	12.45
410	31.2	16.63



GRAPH 7.6: PRESSURE VS TEMPERATURE VS TIME (FOR 500ML OF WATER).

7.5 EXPERIMENT WITH WATER QUANTITY OF 750ML

Quantity: 750ml	Room Temperature: 31.9°C.
Inlet water temperature: 30.1°C.	Container temperature: 31.9°C.
Water out temperature: 26.4°C.	Container maximum temperature: 32.5°C.
Time duration: 30 minutes.	Date: 23-03-06.

The impure water about 750ml was poured inside the vacuum chamber and the vacuum pump was operated. Initially the ball valve B1 was opened and B2 was closed. The vacuum created up to 50 mm of Hg. This experiment was done to know about the boiling range of the given impure water at ambient temperature with the volume of 750ml.

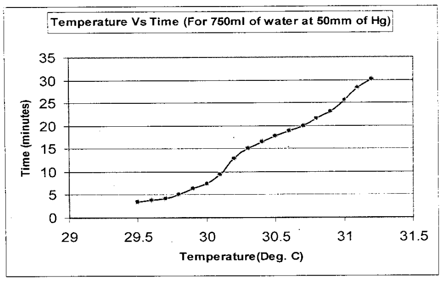
The vacuum about 50 mm of Hg was created and maintained within fraction of second's time. By that maintenance of vacuum inside the vacuum chamber the temperature inside the vacuum chamber decreases up to 29.6°C with respect to time 3.5 minutes and then raised gradually with constant pressure of 50 mm of Hg due to enthalpy of evaporation and condensation processes. The table 7.7 shows the temperature with respect to time at constant pressure 50mm of Hg and the graph 7.7 drawn with respect to the table 7.7. The air column inside the vacuum chamber was the main aspect for the creation and maintenance of vacuum during the processes.

The ambient temperature in the room insists in some condition in increasing the temperature and maintaining the low pressure inside the vacuum chamber.

TABLE 7.7: EXPERIMENT WITH WATER QUANTITY OF 750ML AT CONSTANT PRESSURE (50MM OF HG).

Temperature(°C)	Time(minutes)
29.5	3.5
29.6	3.75
29.7	4.2
29.8	5
29.9	6.28
30	7.5
30.1	9.52
30.2	12.9
30.3	14.98
30.4	16.47
30.5	17.8
30.6	18.87
30.7	20.02
30.8	21.53
30.9	23.08
31	25.5
31.1	28.32
31.2	30.08

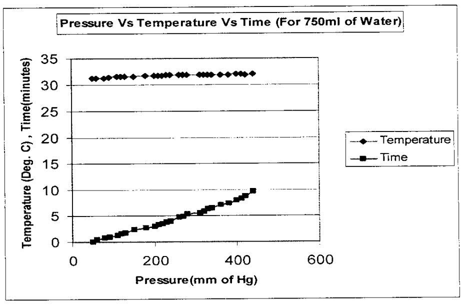
The graph 7.8 shows that the pressure inside the vacuum chamber got increased in very short time nearly around 10 minutes. This was due the ambient temperature and the air column inside the vacuum chamber. The main problem occurs was that to maintain the vacuum inside the vacuum chamber during the operation.



GRAPH 7.7: TEMPERATURE VS TIME (FOR 750ML OF WATER AT 50MM OF HG).

TABLE 7.8. EXPERIMENT WITH WATER QUANTITY OF 500ML AT VARIOUS PRESSURE RANGES.

Pressure(mm of Hg)	Temperature(°C)	Time(minutes)
50	31.2	0
60	31.3	0.42
80	31.3	0.75
90	31.4	0.93
110	31.5	1.28
120	31.5	1.53
130	31.5	1.67
150	31.6	2.37
180	31.7	2.65
200	31.7	3.02
210	31.7	3.33
220	31.7	3.52
230	31.8	3.72
240	31.8	3.93
260	31.8	4.73
270	31.8	4.88
280	31.9	5.27
310	31.9	5.55
320	31.9	5.83
330	31.9	6.3
340	31.9	6.5
360	31.9	7.03
380	31.9	7.4
400	32	8.07
410	32	8.32
420	31.9	8.75
440	32	9.68



GRAPH 7.8: PRESSURE VS TEMPERATURE VS TIME (FOR 750ML OF WATER).

Some of the experimental photos are shown in Figure 7.9 to 7.11.

FIGURE 7.9 EXPERIMENTAL PHOTO 1

FIGURE 7.10 EXPERIMENTAL PHOTO 2

FIGURE 7.11 EXPERIMENTAL PHOTO 3

The above experimental photos were taken while the readings were taken. The vacuum pump used was 150lts/min range.

7.6 PURE WATER FROM VARIOUS VOLUME OF IMPURE WATER

The impure water about 100ml was poured inside the vacuum chamber and heated with the help of acetone fuel and kerosene fuel externally up to 45°C. Then the vacuum pump was operated suddenly. Due to sudden creation of vacuum up to 50mm of Hg the impure water inside the vacuum chamber under goes a phase change and some amount of water vapor was collected in the condenser end and some amount stayed in the tube structure itself. The water vapor obtained due to the process was collected and measured.

From 100ml of impure water about 10-15 ml of pure water was obtained. Initially the ball valve B1 was opened and B2 was closed. After the vacuum created up to 50 mm of Hg inside the vacuum chamber the B2 was opened for the collection of water vapor from the vacuum chamber. The water vapor will follow the least resistance path for the flow.

The air column inside the vacuum chamber was the main aspect for the creation and maintenance of vacuum during the processes. The ambient temperature in the room insists in some condition in increasing the temperature and maintaining the low pressure inside the vacuum chamber.

Then the process was continued with 150ml and the procedure followed as in the process of 100ml operation. The impure water about 150ml was poured inside the vacuum chamber and heated with the help of acetone fuel and kerosene fuel externally up to 45°C. Then the vacuum pump was operated suddenly. Due to sudden creation of vacuum up to 50mm of Hg the impure water inside the vacuum chamber under goes a phase change and some amount of water vapor was collected in the condenser end and some amount stayed in the tube structure itself. The water vapor obtained due to the process was collected and measured.

From 150ml of impure water about 15-20 ml of pure water was obtained. Initially the ball valve B1 was opened and B2 was closed. After the vacuum created up to 50 mm of Hg inside the vacuum chamber the B2 was opened for the collection of water vapor from the vacuum chamber. The water vapor will follow the least resistance path for the flow.

Then the process continued with the impure water volume of 200ml and heated up to a temperature about 45°C and the vacuum about 50mm of Hg was created inside the vacuum chamber. But due to vigorous boiling of water some amount of water entered into the vacuum pump. These are the experimental study of the vacuum desalination system designed as mentioned. The capacity of the vacuum chamber used in the vacuum desalination system was smaller one. Due to the leakage problems occurred in the vacuum chamber-1 this vacuum defreshner was used as the vacuum chamber. So that only about 150ml of impure water can be desalinated from this vacuum desalination system.

7.7 ENERGY UTILIZED FOR PURE WATER RECOVERY

The total energy used for pure water recovery from the designed vacuum desalination system was the combination of electrical energy and the heat energy.

Input energy = Electrical Energy + Heat Energy.
Output = Water yielded from the system.

Energy used for 100ml of impure water:
Electrical energy = 0.2 Kwhr.
Fuel used = 10ml of kerosene.
One Kwhr (unit) = 4 Rupees.
One liter kerosene = 20 Rupees.
The total energy input cost = [(0.2 X 4) + (0.01 X 20)] = 0.8 + 0.2.
= 1 Rupee.
The pure water collected = 10-15ml.
Therefore to collect 10-15ml from the designed vacuum desalination system about one rupee was spent as an energy input.

Energy used for 150ml of impure water:
Electrical energy = 0.2 Kwhr.
Fuel used = 15ml of kerosene.
One Kwhr (unit) = 4 Rupees.
One liter kerosene = 20 Rupees.
The total energy input cost = [(0.2 X 4) + (0.15 X 20)] = 0.8+0.3.
= 1.1 Rupees.
The pure water collected = 15-20ml.

Therefore to collect 15-20ml from the designed vacuum desalination system about 1.1 rupees was spent as an energy input.

Initially acetone fuel was used for the external heat purpose but the cost of the fuel was nearly 250 rupees and above with the tax. So we shifted to kerosene fuel.

7.8 PROBLEMS FACED IN THE PROJECT WORK

Step 1: Vacuum Chamber (VC) could withstand a vacuum of 400 mm Hg only.
The problem: Leakage in Vacuum chamber.
Remedy: Reapplied adhesive.

The VC could now withstand a pressure of 350 mm Hg. Leakage was found again and adhesive was applied again.

Step 2: CVD was used as vacuum chamber. The tests were done without B1. An NRV was placed between Vacuum Pump and VC and tested. The VC could withstand a vacuum of 110 mm Hg but suddenly the pressure returned to atmospheric pressure. Inside the VC water could be boiled at atmospheric temperature when the vacuum was maintained but VC temperature decreased according to decrease in pressure.
Problem: Leakage was found between VP and NRV.
Remedy: Adhesive was applied.

Step 3: The tests were repeated. The vacuum was created up to 60 mm Hg and maintained for 3 – 5 minutes.
Problem: After 5 minutes the oil from VP returned to VC.
Remedy: Used a ball valve between NRV and VC.

Step 4: After placing Ball valve (B1) the tests were continued and vacuum was created and maintained up to 60 mm Hg in VC and B1 was closed. No oil returned from VP to VC.

Step 5: Hot water at about 50 °C was poured into the VC and tests were continued. The water boiled vigorously and came down increasing the vacuum. The result was the VC temperature got reduced to 14.5 °C at 50 mm Hg.

Step 6: At room temperature water was poured inside the VC and all the valves were closed. The water was heated with a spirit lamp fueled by acetone. The temperature raise was up to 45 °C and then the VP was operated. At 42 °C, the steam was obtained and condensed inside the VC itself.

1. Problem: The condensed steam couldn't be measured as it was condensing inside the container itself. This vacuum pump could be operated only until 50 mm of Hg. So with this I could boil water at 42°C.
2. Remedy: with the help of condenser and the sudden flash the pure water was recovered from the system.

7.9 DISCUSSIONS OF RESULTS

The pure water recovered from the designed vacuum desalination system was at yield ratio of 10-15%. By decreasing the vacuum chamber pressure we can yield at higher rate comparatively. The temperature inside the vacuum chamber also should be high to yield more water from the system. The vacuum chamber used in the vacuum desalination system for experiment was a capacity of 1liter; if the vacuum chamber capacity was high the yield will be more due to air column inside the vacuum chamber would be high. The input energy cost for experiment was differs with the source of heat for increasing the temperature of the water inside the vacuum chamber internally or externally. If the source of heat was free then the energy cost will be very low comparatively. The steam at ambient temperature was not obtained due to vacuum pump with range of 50mm of Hg. With this vacuum pump we could evaporate the water only up to 45°C.

7.10 LIMITATION OF THE PROJECT

The main limitation of the project was the initial cost of the system was very high. The vacuum pump of the vacuum desalination systems cost was very high according to the vacuum range. Then the maintenance of vacuum, inside the vacuum chamber was very high task to perform. The leakage problem was the main drawback of every vacuum desalination system. As the vacuum desalination system designed for the process was with a batch operation the process to be done precisely. Every time the vacuum chamber is cleaned to prevent the scaling problems. The vacuum chamber size in my project was small comparatively. These are the limitation of my project.

CHAPTER – 8

CONCLUSION

The vacuum desalination system has been designed and implemented to produce steam at ambient temperature from impure water and practically the experiment was conducted to produce fresh water. Vacuum pump is used to create the vacuum inside the vacuum desalination system. The yield increases with a decrease in chamber pressure and condenser temperature. Also the yield increases with an increase in vacuum chamber temperature. High range vacuum pump should be used for further experiments. The vacuum chamber fabricated for one cubic foot to be used without any leakage problems and to yield more.

The pure water recovered from the designed vacuum desalination system was at yield ratio of 10-15%. By decreasing the vacuum chamber pressure we can yield at higher rate comparatively. The temperature inside the vacuum chamber should be high to yield more water from the system. The vacuum chamber used in the vacuum desalination system for experiment was a capacity of 1liter; if the vacuum chamber capacity was high the yield will be more due to air column inside the vacuum chamber would be high. The input energy cost for experiment was differs with the source of heat for increasing the temperature of the water inside the vacuum chamber internally or externally. If the source of heat was free then the energy cost will be very low comparatively. The steam at ambient temperature was not obtained due to vacuum pump with range of 50mm of Hg. With this vacuum pump we could evaporate the water only up to 45°C.

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