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Fifty years of MSF desalination in Kuwait and sustainability issues

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ABSTRACT

Kuwait was the first country in the world to adopt desalting water as the main source of fresh water in the world. It was also the first to use the multi stage flash MSF desalting system in its present design in 1960. Many questions are raised about the sustainability of using seawater desalination as a main source of fresh water which is followed by most of the Arab Gulf countries. In other words, are the three conditions of sustainability satisfied? These conditions are: 1) The exploitation rate of ground water (the supplementary natural water source to the desalted water as potable water source) does not exceed the rate of their re-generation; 2) The consumption rate of non-renewable fossil fuel used in desalting does not exceed the developing rate of sustainable substitutes; 3) The pollutants emission (to air and sea) rates do not exceed the environment capacity to absorb, or render them harmless. In Kuwait, the replenishment rate of ground water is about 20 m^3/d while its extraction exceeds 550 m^3/d. The fuel oil resource is finite, and non-renewable. It represents the main income to the country. Its local consumption is continuously increasing to the extent that the total production can locally consumed within 40 years. For the time being, no alternative fuel energy source is seriously considered. Although the fossil fuels (as energy resource) required for desalting water cannot be completely sustainable, the efficient use of this fuel and desalted water can prolong the availability of these resources, making them more sustainable. The United Nations UN defined different environmentally sound technologies EST which decrease the environmental pollution, use the available resources efficiently to elongate its sustainability, and reclaim the waste as much as possible. This opens the way for new recovered resources and saves the environment. In trying to satisfy the staggering needs of desalted seawater in the Arab Gulf countries, some points were overlooked and now there is a need for re-consideration to make adoption of desalted water source more sustainable. These points include: over-utilization of ground water resources, over-consumption of energy needed to produce potable water, negative impact of desalting seawater on the environment, and looking for alternative source of water. This paper discusses these points and discusses possible solutions.

Keywords: Desalination; MSF; Sustainability; Kuwait

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1. Introduction

Desalting of seawater started by distillation processes, where seawater is partially evaporated, and the pure vapor is condensed to become pure water (distillate). Distillation was restricted historically for human consumption on ships, and isolated islands. The amount of heat used in evaporating (boiling) seawater was significant and costly. The heat energy and its cost were reduced by:

1. Emerging of the multi-effect (ME) and multi-stage flash (MSF) desalting systems, where each kg of heating steam (S) produces a number of kg of distilled water (D). The ratio of D/S is called the gain ratio, and is in the range of 6–10 in modern MSF units and 4–16 in modern ME units.
2. Combining of the ME and MSF desalting units with steam power plants (PP); where moderately low pressure steam, after being partially expanded in a turbine to produce work, is extracted to the ME or MSF units as heating steam. So, the cost of steam is then shared between both power production and water desalting processes.

Even with these advancements, large-scale thermal water desalination consumes too much energy to the extent that their application is limited only to extremely water-short areas and oil-rich Gulf Cooperation Countries (GCC) surrounding the Arabian Gulf.

In 1960, Kuwait installed the first ever built and largest (at that time) multi-stage flash (MSF) desalting units in the world of 2×0.5 million (M) imperial gallons (IG) per day (d) or (MIGD). One MIG is equal to 4,546 m^3. Today, the maximum capacity of an MSF unit reached 17 MIGD. Kuwait was the first country in the world to depend on seawater desalination for main potable water supply. Distilled water represented 92% of the total potable water in 2006. Kuwait water natural resources were very limited, and now almost vanished. Groundwater (GW) supplies are withdrawn faster than their replenishment, if any.

Installation of MSF units continued and its capacity became 423.1 MIGD (1.923 million cubic meters (Mm^3) per day (d) or Mm^3/d in 2008. In that year, the MSF distillate production was 120,638 MIG (548.42 Mm^3/y) or 330.5 MIGD (1.503 Mm^3/d) daily average. Kuwait's annual distilled water production increased from 156.37 m^3/y in 1985 to 548.42 Mm^3 in 2008. The annual potable water (distilled water mixed with small fraction of brackish GW) consumption increased from 36,904 MIG (168.43 Mm^3/y) in 1985 to 128,188 MIG (582.74 Mm^3/y) in 2008. The corresponding annual and daily per capita consumption increased from 95.3 m^3/y/person (daily 261 l/d/person) in 1985 to 169.3 m^3/y.p (462.8 l/d.p) in 2008. The per capita consumed brackish GW in 2008 was 38.7 m^3/y.p (106 l/d.p). Thus, the total consumed water per capita in 2008 was 208 m^3/y.p (570 l/d.p), among the highest in the world [1].

The GCC countries followed suit by building MSF units and adopting desalination as the main or partial, non-conventional water resource. MSF plants of capacity more than 100 MIGD (454.6×10^3 m^3/d) each commonly exist in GCC such as Kuwait, Saudi Arabia (SA), and United Arab Emirates (UAE).

Desalination was the main tool supporting the growth in every life aspect in the GCC, and resulting in urbanization of cities like Kuwait City, Dubai, Al Riyadh, Abu Dhabi, Jeddah, Doha, Manama, Muscat and other lively cities. Desalination satisfies about 60% of the area's potable water needs. More than 50% of the world total desalination capacity is located around the Arabian Gulf and the Red Sea. Almost all large desalination plants by distillation (like MSF) are combined with power plants (PP).

Currently, there is a strong trend towards large seawater reverse osmosis SWRO desalting plants due to its low consumed energy and continuous improvement in the RO process compared with the MSF. Operation of real large capacity SWRO plants (more than 100×10^3 m^3/d) started in the GCC by 108×10^3 m^3/d plant in Jubail, SA, and 128×10^3 m^3/d plant in Yanbu in SA in 1995. Today, SA completed the 212´103 m^3/d Shuquiaq SWRO plant [2]. More than 70% of the desalination plants installed since 2000, with capacities higher than 100×10^3 m^3/d are RO. With a total of 13,869 plants reported for 2008, the total contracted global desalination capacity is predominantly RO (59%) with thermal desalination (36%), reversed electro-dialysis EDR (4%), and others (1%) making up the balance. Spain is producing 2000×10^3 m^3/d using RO desalting system, and this is expected to increase to 2,642×10^3 m^3/d in the near future [3].

Despite the already available large desalination capacity in the GCC, massive increases are planned as the water demands are soaring. For example, SA is now producing about 3 Mm^3/d to satisfy 50% of its potable water needs by desalination, and this is expected to increase to 9 Mm^3/y within 20 years [4].

Kuwait and GCC were faced with limited to no natural water resources and desperate needs for large volumes of desalted water. They were pushed to build MSF units, the most reliable and the only large volume producing desalination system from the 1960 to almost 1990. In their rush to satisfy water demands, many issues were overlooked such as: high cost of desalted water production and its high consumed energy, its negative effect on environment, exploring other resources, rational water demand management, and so on. Governments' heavy subsidization of water and energy induces high consumptions of both water and energy; and distorts the choice towards desalting in favor of energy-inefficient methods. Hence, this paper addresses the following issues:

- Desalted water over-consumption,
- Desalted water energy consumption and cost,

- Negative impacts of desalting water on the environment and how to mitigate it,
- Exploring other water resources, and
- Use of sustainable desalination utilizing alternative energy.

2. History of developing MSF desalination units in Kuwait [5]

Kuwait relied on imported water from Shat Al-Arab in Iraq, for potable use from 1925 to 1950. Ten units of ME submerged tube evaporators of 100,000 imperial gallons per day (IGD) per unit were commissioned in 1953 by Westinghouse Company. Each unit has 3 effects. The same was repeated by Weirs (UK) in 1955. The 1957 was a turning point in the desalination industry when Westinghouse Company built the first four multi stage flash distillation unit. Each unit has four stages mounted vertically over each other, with brine heater mounted over them; and each unit has a capacity of 525,000 IGD. The feed water to the units was treated by 5 ppm polyphosphate dosing additives. The design of these unit was based on the ME principles, where the gain ratio (GR) is less but close to the number of effects. These units had GR of 3.7, with 4 stages. In 1960, the first MSF units, based on Professor Silver patent and design were commissioned after modifications by Kuwait engineers in Kuwait. These were two units, and each unit has 0.5 MIGD, and 19 stages.

In his remarkable paper about the introduction of the MSF in Kuwait, El Saie [5] stated that the fuel to the Shuwaikh power plant, enclosed the desalaniation plant was natural gas obtained at no charge from the oil field. This reflects that the consumed fuel energy was of no concern at these early times of desalination.

3. Desalted water over-consumption

Saving water (rather than adding more desalting plants or looking for another source) is the best next water source choice both economically and environmentally. The real water problem in Kuwait has resulted from the fact that it is an arid country with little or no nature water resources, while inhabitants are acting as if they have an unlimited cheap water source. They consume too much water with no incentive to conserve. From a consumer point of view, it is very cheap, and it is not even metered in many cases. Water demand management (reduction or prevention of further growth of final water needs) includes: appropriate water tariffs, improved public awareness, reliable metering, restrictions on wasteful activities, and control of leaky piping, should be developed and applied. The per capita consumed potable water in Kuwait in 2006, was 163 m^3/y.p (447 l/d.p) and that for total (potable and brackish) water was 211 m^3/y.p (580 l/d.p). The US consumed domestic water per capita reported in 2008 was 295 l/d.p, and the UAE had the highest, 500 l/d.p [6]. This indicates that Kuwait per capita potable water consumption is 51% higher than that in US. The main reason is the low water price in Kuwait because of high government subsidization. Since most potable water in US comes from natural sources, the Kuwait per capita consumed potable water of 447 l/d.p and total 580 l/d.p is an outrage knowing that this water is very expensive (at least 8 times the US water cost) and consumes lot of energy, which is damaging the environment. Subsidizing desalinated water should not be applied without imposing measures to conserve water and its use efficiently. When water subsidizing is necessary for social reasons, it should be limited to basic water needs and not for wasteful uses. While desalination is costly, conservation programs are simpler, more effective, and much less expensive than desalination, and without negative effects. The per capita consumed water in Kuwait is 2–3 times the basic needs per person, as shown by the next example from Australia [7].

In Brisbane, Australia, over 90% of its inhabitants did not get water meters until the l990s, and the majority of water users simply paid an access charge and not usage charge for their water. They had no way to know how much water they were using or wasting. No wonder per-capita consumption per day was around 700 l/d.p. This sitituation is similar to that in Kuwait now. Between l990 and l995, 218,000 new water meters were installed throughout Brisbane in order to charge users for the water amount they used. Water restrictions, introduced in June 2006, were imposed and include, besides other measures, banning any form of hosing. Brisbane Water Commission (June 2006) hands out egg-timers with a suction cap to be affixed to bathroom walls to encourage anyone to shower in under four minutes. By 2007, with restrictions and well-supported public campaign, consumption had fallen to 140 l/d/person, one of the lowest in the developed world. Such tactics have greatly reduced demand, and are being followed with interest around the world [7].

So, it is necessary to use current water supplies wisely through conservation; and it is time to put and apply strict water demand management.

4. Desalted water over-energy consumption and cost

Energy consumed by the MSF desalting system used in Kuwait is high and expensive. Lowering energy consumed by existing desalting systems and/or using energy efficient systems are essential to lowering the cost of desalted water and its negative impact on environment. The consumed energy by seawater reverse osmosis SWRO desalting system is in the range 3–4.5 kWh/m^3, although SA reported higher values of 5–7 kWh/m^3 [8]. The least reported SWRO energy consumption is 1.6 kWh/m^3 [9]. Recent data from SWRO in Qidfa and Zawrah, UAE was 3–3.5 kWh/m^3, by using energy recovery [10]. This is still higher than the minimum thermodynamic desalting consumed energy of 0.52 kWh/m^3 [11] to produce water of 300 mg/L from 35,000 mg/L seawater at 40% recovery. In Kuwait, the MSF equivalent consumed mechanical energy is 24.76 kWh/m^3 (20.76 counted for thermal energy, and 4 for pumping energy). This is very high (6–8 times higher) compared to the SWRO system. The significant effect of consumed energy on the cost of desalinated water is shown by a simple example.

The energy content of one equivalent barrel (bbl) of fuel oil is 6.1 giga Joule (GJ). When this energy is used to produce electric energy in an efficient steam PP of 0.36 efficiency (or 10,000 kJ/kWh heat rate), it gives $6.1\times10^6\times0.36/3600 = 610$ kWh. This is capable of producing 152.5 m^3 of desalted water by SWRO (of 4 kWh/m^3); or 24.64 m^3 by MSF unit combined with steam turbine (of 24.76 kWh/m^3 consumed equivalent energy). If the cost of one bbl of fuel oil is \$70/bbl, the fuel energy cost to produce one m^3 of desalted water is \$0.46/m^3 by the SWRO, and \$2.84/m^3 by the MSF. In case of SWRO, if fuel energy cost represents 35% of desalted water, 1 m^3 costs \$1.3/m^3. In the best case of MSF, if fuel energy cost represents 70% of total water cost, 1 m^3 of desalted water costs \$4/m^3. This means that the 550 Mm^3/y estimated production by MSF in Kuwait in 2007 costs \$2,200M. If this water amount was produced by SWRO, its cost would have been \$715M. In US the water cost from SWRO desalination plant is \$0.66–\$1.05/m^3. Typically, brackish water desalination will be half to two-thirds the cost of SWRO, and comparable with conservation and conventional surface water supplies of \$0.33/m^3–\$0.5/m^3 [3]. This calculation shows the very high cost of producing desalted water in Kuwait (almost 8 times the US average cost). This logically requires much more efficient use of water in Kuwait. Kuwaiti Ministry of Electricity and Water (MEW), the producer of desalted water, never shows its calculations of desalted water cost.

New desalination projects should aim to minimize energy consumption. The greenhouse gas (GHG) emissions generated by proposed projects must be quantified, and measures to avoid, minimize, or mitigate such emissions should be identified. To be more specific, it is time to stop installing the MSF and use SWRO with the best energy recovery system.

5. Impact of desalting water on environment

Seawater is not just water. It is a habitat containing an entire ecosystem of phytoplankton, fish and invertebrates [12]. Desalination has negative direct impacts on marine environment due to withdrawal of large volume of seawater and discharging large volume of highly concentrated brine; and at elevated temperatures in case of MSF and ME systems. Desalination also impacts adversely the environment, indirectly, due to combustion of fossil fuel used to generate the energy used by desalination. It is important to identify the effects of desalting plants on the environment, a subject rarely mentioned in Kuwait, and to indicate the ways to avoid or lessen those effects.

Seawater intake is an essential part of any desalting plant to supply reliable quality and quantity of feed seawater. Seawater intake to desalination plants can be either:

1. Surface intakes where water is collected from above the seabed,
2. Subsurface intakes where water is collected from drilled beach wells, infiltration galleries, or other locations beneath the seabed, and
3. Discharged cooling seawater from condenser of steam PP when SWRO desalination is co-located within steam PP.

A good intake can reduce the environmental impact on marine life, protects down-stream equipment, and reduces the cost of feed pretreatment [13].

5.1. Surface intake

All the MSF units in Kuwait, except those in Shuwaikh plant, are combined with steam PP forming cogeneration power desalting plant CPDP. Each CPDP has a common seawater intake of open surface type to supply cooling seawater for the condenser of the steam PP and for the heat rejection section of MSF units (Fig. 1) [14]. Seawater is pre-screened by using traveling screens (Fig. 2), with mechanical cleaning bars (Fig. 2) [12]. The screening chamber is usually located on or near shore and the intake pipe may be extended out hundreds of meters into the sea. The quality of this feed is good enough for the MSF system. Future SWRO desalting plants require much better feed quality than the MSF open surface intake, which may not be adequate, unless long pipes intake from deep seawater are used. Deep seawater far from shores is cleaner than open channel intake. The SWRO desalting plant in Yanbu, SA has long pipes intake from 15 m below seawater surface. All SWRO plants on Red Sea shores in SA use submerged pipe water intakes, and this is the dominant surface intake for the SWRO plants. In order to minimize the entrance of algal material in the open intake, the source water intake structure should be located at least 5 m under the seawater surface and design the intake so the water entrance velocity is less than 0.2 m/s. The low entrance velocity also minimizes entrainment of marine organisms with the collected source water. In US, the most crucial item that may stop a permit to build SWRO desalting plant is the approval of intake system in relation of its impact on marine environment. In Kuwait, the effect on the environment is not even considered.

Large marine organisms, such as adult fish, invertebrates, birds, and even mammals, are killed on the intake screen (by impingement). Impingement occurs when marine organisms are trapped against intake screens by the velocity and force of water flowing through them. The fate of impinged organisms depends on the intake

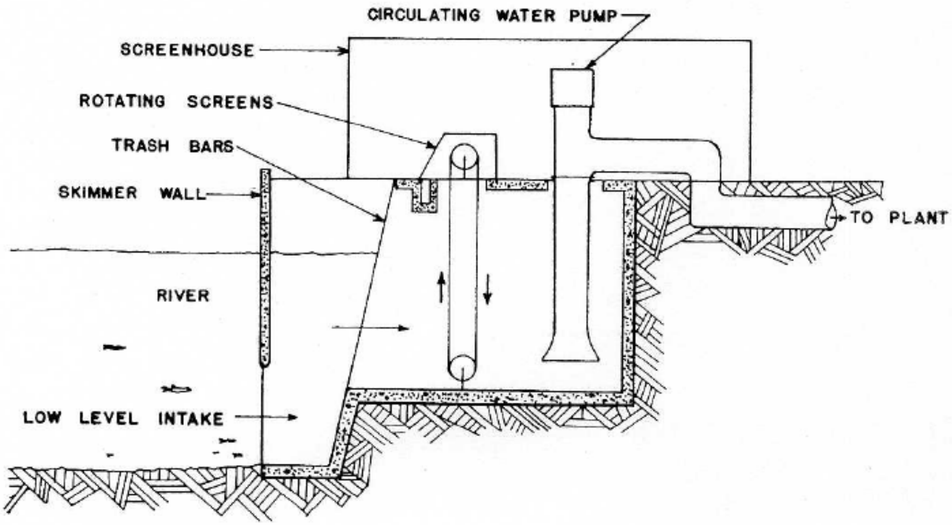

Fig. 1. Seawater intake from surface water for cogeneration power–desalting plant.

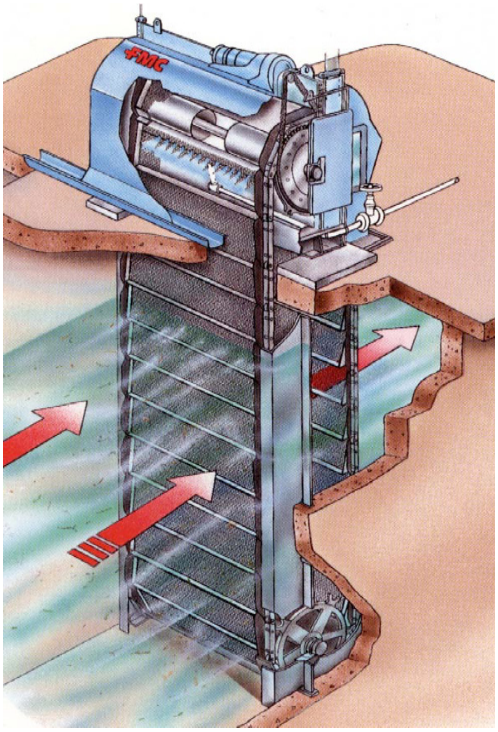

Fig. 2. Vertical intake seawater screens [12].

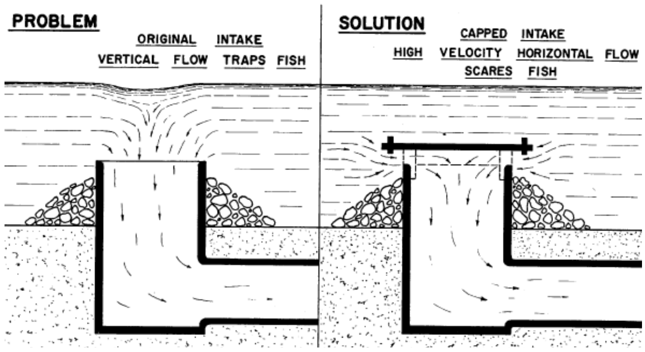

Fig. 3. Vertical cap convert vertical flow into horizontal flow at the intake entrance to reduce fish entrainment.

designs and marine life species, age, and water conditions. Small enough organisms pass through the intake screens, such as plankton, eggs, larvae, and small fish, and are killed during processing of seawater (entrainment). The impinged and entrained organisms are then disposed of in the marine environment. Decomposition of these organisms can reduce the oxygen content of the water near the discharge point, creating additional stress on the marine environment. The impingement and entrainment impacts are mitigatigated by [15].

1. Physical barriers, which physically block fish passage shown in Figs. 2–4;
2. Collection systems, which actively collect fish for return to safe release location (Fig. 5);
3. Diversion systems, which divert fish to bypasses for return to a safe release location, and
4. Behavioral barriers, which alter or take advantage of natural behavior patterns to attract or repel fish, by certain lights or sound.

Physical barriers impingement mitigation can be done by creating horizontal or vertical velocity gradient from the open sea to the face of the intake. This gives marine organisms time to swim away from the intake. A cover, called velocity cap, placed over the vertical terminal of an offshore intake pipe is used to convert vertical flow into horizontal flow at the intake entrance to reduce fish

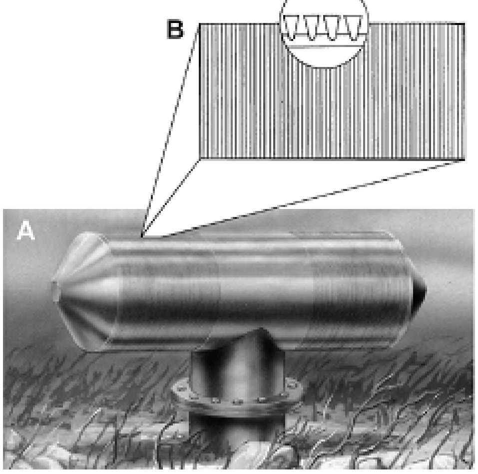

Fig. 4. Passive screen called wedge wire screens, which utilize slotted screens constructed of trapezoidal-shaped "wedge-wire [15].

entrainment (Fig. 4). It was noted at two California power stations [13], that fish avoids rapid changes in horizontal flow and velocity cap intakes can provide 80–90% reduction in fish impingement.

The impingement at intake can be lowered by specially designed screens limiting the intake flow velocity to values of weak natural ocean flows (<5 cm/s). An example is a passive screen called wedge wire screens, which utilize slotted screens constructed of trapezoidal-shaped "wedge-wire" as shown in Fig. 4 [15]. These screens have the potential to reduce both entrainment and impingement at water intakes by:

a) Sufficiently small screen slot size to physically block passage of the smallest life stage to be protected (typically 0.5–1.0 mm for egg and larval life stages); and
b) Low through-slot velocity (on the order of 0.5–1.0 ft/s).

Cylindrical screens are usually oriented on a horizontal axis with screens sized to maintain a velocity of less than 15 cm/s to minimize debris and marine life impingement. Passive screens are best-suited for areas where an ambient cross-flow current is present, and air backwash system is usually recommended to clear screens if debris accumulations do occur.

A Ristroph screen is a modification of a conventional traveling water screen in which screen panels are fitted with fish buckets that collect fish and lift them out of the water where they are gently sluiced away prior to debris removal with a high pressure spray (Fig. 5). Ristroph screens may be effective for improving the survival of impinged marine life, but they do not affect entrained organisms.

Recent analyses have noted that marine life impingement and entrainment associated with intake designs

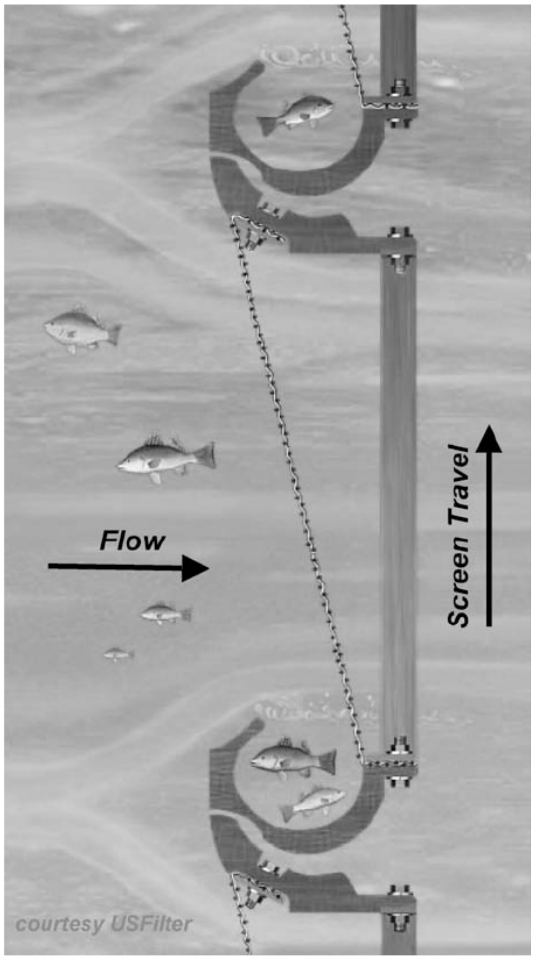

Fig. 5. Ristroph screen, a modification of a conventional traveling water screen [13].

are great, hard to quantify and may represent the most significant direct adverse environmental impact of seawater desalination [13].

The intake designs are highly site specific, and can cost up to 20% of the capital cost of the entire facility. It is possible that intake-related issues may ultimately determine the feasibility and performance of the desalination plant itself [16].

An example of behavioral barriers is an acoustic fish detection system shown in Fig. 6 to repel fish by certain sound.

5.2. *Subsurface intakes*

Surface intakes can be vertical, slant and horizontal beach wells, and infiltration gallery, or seabed filtration system. Beach-wells are drilled onshore at varying depth below the sea floor. The design and construction of sea-wells are similar to those of artesian wells of same dimension. Central part of the well double casing is per-

Fig. 6. A typical transducer used in acoustic fish deflection system with 300 mm diameter active area (black disk) [17].

forated with large number of slots of about 0.3–0.5 mm for the interior casing as compared to about 0.7 mm for the exterior one. The depth of the well is determined by the soil geology, soil permeability and the quality of water desired from the well. Water quality tends to vary from one subsoil stratum to another.

Vertical intake beach wells drilled vertically into a coaster aquifer wells are the most used for SWRO intake systems (Figs 5a and 5b). They can be an economical alternative to open sea intakes for desalination plants with capacities less than 20,000 m^3/d (4.5 MIGD). It delivers clean water that may greatly reduce additional pretreatment requirements.

Vertical intakes are typically cheaper to construct than horizontal wells. Examples of beach wells employed to supply feed to a relatively large number of SWRO plants are: all SWRO plants in Malta, capacity 31 MGD with well depth of about 50–60 m, SWRO plants in Canary Islands as well as in UAE, and Caribbean Islands, and the Island of Lanzarote, Canary Islands [17]. One US gallon is equal to 3.785 l.

Directional drilling now allows for drilling of sea wells of horizontal position, which has the advantage of increasing flow from the wells. A new porous polyethylene well pipe, available since 1995, is reported to require no additional external media packing for long-term operation as that required with conventional sea wells. Polyethylene pipe porous structure acts as both well screen and packing media. This product can make horizontal drilling of wells under the seafloor feasible and economical for the first time [19]. Horizontal wells have number of horizontal collection arms that extended into the coastal aquifer from central vertical collection shaft in which the source water is collected. The water is pumped from the vertical shaft to the desalination plant intake to the pretreatment system.

Slant wells are subsurface intake wells drilled at an angle and extended under the seafloor to maximize the collection of seawater and the beneficial effect of the filtration of the collected water through the sea floor sediment [20].

The subsurface infiltration gallery intake system consists of submerged slow sand media filtration system located at the bottom of the sea in the near-shore surf zone, which is connected to a series of intake wells located in the shore.

Subsurface intake is better environmentally than open sea intakes as it eliminates the impingement and entrainment of marine organisms. The intake wells use sand or other geologic structure as a natural filter; and lower the chemical requirements in the feed pre-treatment. It separates open seawater from the point of intake. It can be used if geologic conditions beneath a surface water are relatively impermeable or of sufficient thickness and depth to support water extraction. Natural filtration separates most of the marine organisms from the water intake.

5.3. Discharge outfalls

Brine discharge from desalting plants to sea contains total dissolved solids TDS up to 70,000 ppm. Salinity and temperature of the reject stream are the most prominent parameters negatively affecting the environment. This brine, besides its high salt concentrations, contains chemicals used in pretreatment of the feed seawater to the plant. Chemical constituents of plant discharges include [22]:

1. *Chlorine* (sodium hypochlorite NaOCl or free chlorine). Chlorination is one of the most widely used techniques to control biofouling resulting from cooling seawater to power plants and desalination systems. Seawater is usually chlorinated with typical chlorine doses of 0.5–1.5 ppm. Seawater contains about 65 ppm of bromide and during chlorination bromine is formed by the oxidation of bromide, leading to the formation of organobromine compounds. As a result, trihalomethanes (THM) in chlorinated seawater mainly consist of bromoform ($CHBr_3$) and di-bromo-chloro-methane ($CHBr_2Cl$). Bromoform has a slow and progressive formation, being the final product in the oxidation of organic substances. Accordingly, majority of monitoring studies have focused on these two compounds. The resultant residual oxidant in the coolant water is generally in the range 0.1–0.2 ppm. Though the organo-chlorinated by-products represent a small fraction of the added chlorine, they are relatively more persistent than residual chlorine, and thus pose a potential hazard to marine life because of their possible mutagenicity.

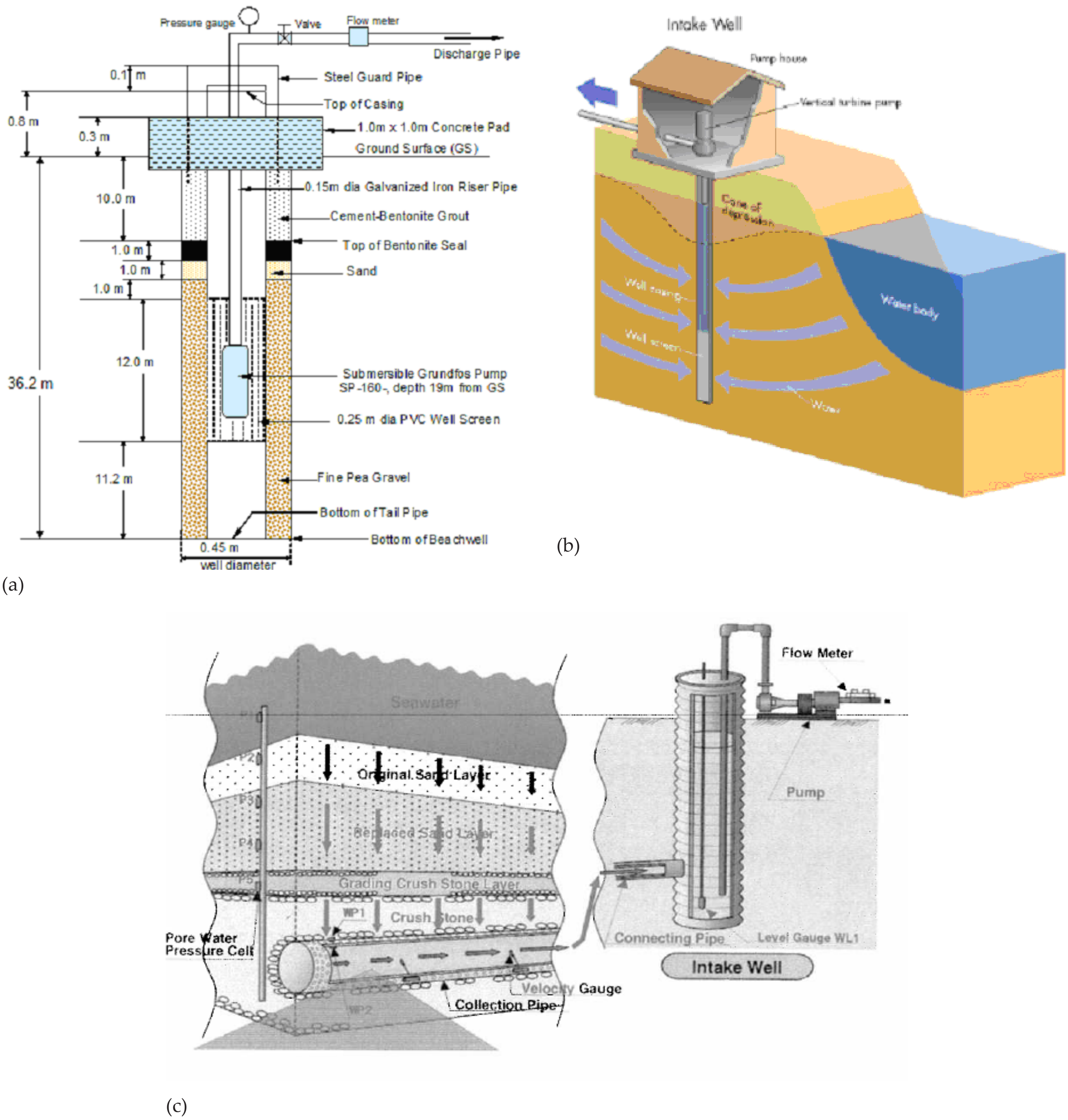

Fig. 7. Beach wells construction schematic diagram, SWDRI pilot plant [18].

The combined outfall from the condenser and desalination seawater was discharged on the shore through an outfall structure.

The minimal amount of residual chlorine in the brine discharge can be controlled by adding a de-chlorinator (e.g. sodium meta-bisulfite) to the brine before it is discharged. The chlorine and its by-products create carcinogenic effect of greatest environmental and public health concerns.

2. *Surfactants* (ferric chloride $FeCl_3$ or aluminum chloride $AlCl_3$): Addition of surfactants into the seawater feed helps to prevent scale formation, and improves the performance of the heat transfer tubes. Their effect on the environment is not well known.

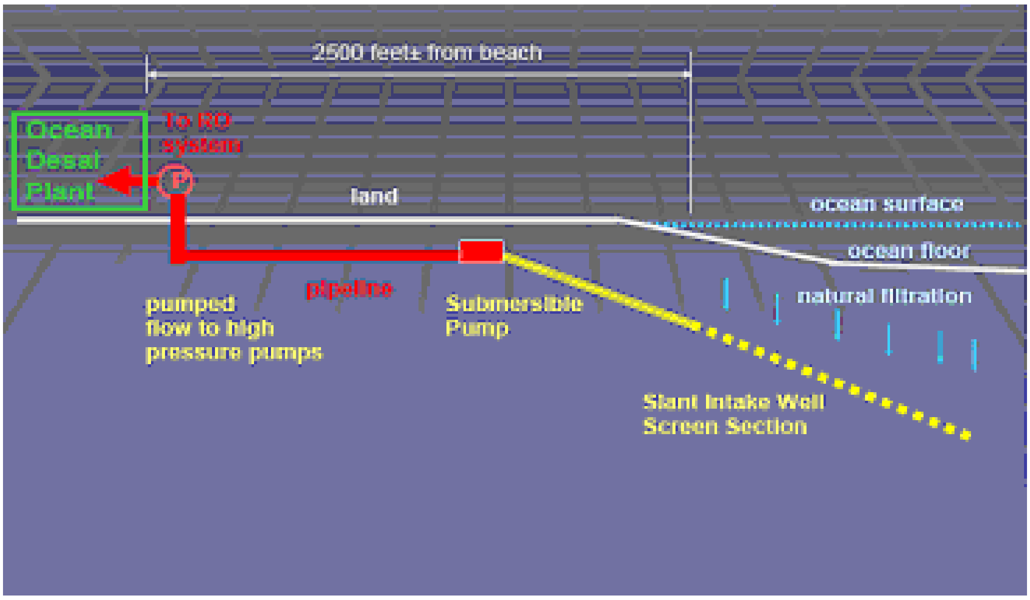

Fig. 8. Slant well intake of feed seawater system [21].

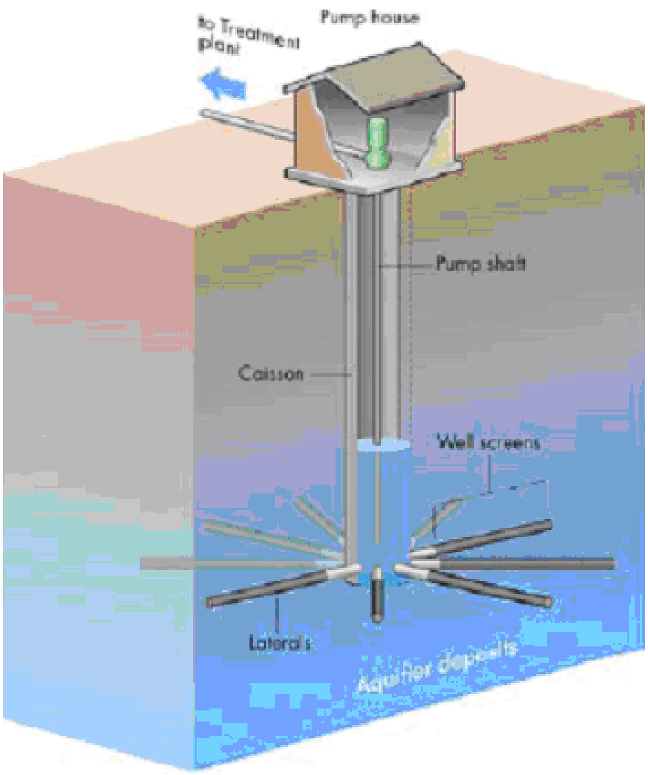

Fig. 9. Horizontal well intake of feed seawater system [20].

3. *Scale inhibitors*: Anti-scalant additives are usually aqueous alkaline solutions of synthetic dispersants and scale-inhibiting agents designed to control formation of insoluble salts in the distillation process. The most widely used anti-scalants are the polymaleic acid and poly-phosphonate-based ones. Although the dosing rate of anti-scalants (and antifoams mentioned below) is low, the overall consumption is huge. Information is lacking about the degradation of anti-scalants and their effect on the marine environment.
4. *Antifoams*: These are organic (basically acylated polyglycols, fatty acids and fatty acid esters) or silicon-based compounds (composition normally not revealed by manufacturers) used to suppress seawater foaming. These chemicals are certified to be non-toxic. However, no data are available on their fate in the marine environment or whether they have potentially harmful degradation products.
5. *Oxygen scavengers*: Hydrazine is mostly used in boilers and may cause long-term damage to the environment. Hypo-chlorites are used in parts other than boilers to deplete oxygen in order to minimize corrosion. Sodium sulfite is also used, and has the potential of increasing the sulfate level in water, with no foreseen harm.
6. *Acids and alkalis*: Sulfuric acid is added to feed water in order to convert the less soluble calcium carbonate and magnesium hydroxide to more soluble calcium and magnesium sulfate salts. Sodium hydroxide is added to seawater feed to adjust the pH to approximately 8.0. Both sulfuric acid and sodium hydroxide impose insignificant shift in the ionic composition of the brine discharge, and are not envisioned to have an environmental impact.

The belief is that the effect of chemical additives is more benign to the environment than changes in temperature and salinity. The marine environment adjacent to desalination plants naturally exerts a profound influence on the operation and maintenance of these plants. The effects of the marine environment on desalination plants employing an open intake system (e.g. Jubail plants) are recognized primarily as biofouling of: intake structures, membranes, pumps, water lines, water boxes, heat exchangers, and others. Bio-fouling also triggers corrosion of materials which could be costly.

Appropriate technology is required to ensure proper dispersion of the brine for minimization of its effects on the marine environment, and includes:

a) Discharging the brines by a long pipe far into the sea,
b) Direct discharge of the brines at the coastline,
c) Discharging the brines via the outlet of the power station's cooling water,
d) Directing the brines to a salt production plant.

The brine high salinity creates denser brine plumes than seawater. This effluent (i.e. discharge) is generally 33% saltier than the water originally drawn into the plant. Its greater density causes this effluent to sink and, in some cases form stable pool on the seafloor that resists mixing. Decrease in oxygen and associated changes then kill marine animals and plants. Also, increased salinity affects some marine animals and plants.

In Kuwait, the MSF desalting units are located within steam PP, and brine water is mixed with cooling seawater returning from the PP condenser to sea. This dilutes the brine and lowers the salt concentration to less than 1.1 the intake salinity.

A key challenge for dedicated sea outfalls is to minimize the size of the zone in which the salinity is elevated, before adequate mixing with ambient waters. In some cases, this can be achieved by reliance on the mixing capacity of the tidal (surf) zone. However, this approach may lead to high salt concentrations along the shoreline. In other cases, where the discharge occurs beyond the tidal zone and in low energy environments, it may be necessary to install diffusers to accelerate and facilitate mixing.

It is required to set guidelines to be followed for new power and desalting plants projects concerning the major environmental issues associated with the project. Potential options to address those issues, including facility sitting, facility operations (e.g., intake impacts (entrainment / impingement), discharge impacts, greenhouse impacts, etc should be should be identified and evaluated early to insure that the guide lines are followed before approving the projects by Kuwait protection agency. Intake and discharge characteristics: such as type (e.g., beach well or open water intake), location, volumes, salinity levels and other critical water quality parameters in the vicinity of intakes and outfalls should be addressed in the reviewing and approval processes.

Environmental impacts resulting from desalination plants should be avoided or minimized through (1) appropriate siting, (2) choosing an intake which is suitable (beneath coastal sediments and in open, well-circulated, marine waters), and (3) treating rejected brine properly to save marine species.

6. Evaluating other water resources

Because of the expensive desalination and very limited supply of natural ground water GW in Kuwait, the next best water resource is saving water, as mentioned before. Another viable alternative water source is the reclaimed wastewater effluents (treated wastewater TWW). The TWW became an accepted water source worldwide for a wide variety of applications, including: landscape and agricultural irrigation, power plants cooling, industrial processing, car washing, flushing toilets and urinals, construction, streets and walkways wash-down, backfill consolidation, cooling and air conditioning, commercial laundry, mixing concrete, fire fighting (installed fire control systems and fire hydrants), and indirect potable reuse as infiltrated aquifer recharge.

Potable water with highest purity and most rigorously treated should be used only for drinking (only 10% of total personal use), cooking, and personal washing where water comes with direct contact with people (about 25% of total use). The remaining 75% of personal water use is for non-potable purposes such as laundries, flush toilets, wash clothes, and water gardening.

This implies that not all water used in a household or urban area needs necessarily to be potable quality. An example in this regard is toilet flushing, for which lower grade water can readily be used. Urban reuse of TWW is the most effective way to reduce potable water consumption and the environmental dangers posed by the disposal of large quantities of insufficiently treated wastewater. Dual reticulation water system supplying potable water and TWW (for non-potable use) to buildings are widely used in Australia, [23,24]. Bulk of wastewater in Kuwait is discharged into sewerage system managed by Ministry of Public Work MPW and arises from domestic consumption. Wastewater in Kuwait is mainly collected in three catchments areas of three main treatment plants, with total capacity of 535,000 m^3/d, (336,000 m^3/d in Sulaibya; 65,000 m^3/d in Jahra; and 134,000 m^3/d in Riqq).

While non-potable reuse options is technically acceptable, concerns about possible health risks were frequently raised by the public because of the quality of reuse water. The public health concern is the major issue in any type of reuse of wastewater, be it for irrigation or non-irrigation utilization, especially long-term impact of reuse practices.

Concerning TWW in Kuwait, the average fresh water consumption in 2006 was 1.424 Mm^3/d, and about 52.5% of this became wastewater. The projected fresh water use and wastewater generation is given in Table 1 [25].

Bulk of wastewater in Kuwait is discharged into sewerage system managed by Ministry of Public Work

Table 1
Projected wastewater generation from domestic and commercial sources [25]

Year	Projected net water use from MEW freshwater source (mill m^3/d)	Estimate of wastewater generation (mill m^3/d)
2005*	1.06	0.55
2010	2	1.0
2020	3	1.6
2030	4.3	2.3

(MPW) and arises from domestic consumption. Wastewater in Kuwait is mainly collected in three catchment areas of three main treatment plants, with total capacity of 535,000 m^3/d, (336,000 m^3/d in Sulaibya; 65,000 m^3/d in Jahra; and 134,000 m^3/d in Riqq).

The Sulaibiya wastewater treatment plant, commissioned in June 2004, treats about 336,000 m^3/d municipal wastewater. It provides most advanced treatment beyond tertiary level (to potable water quality but there is no plans for its direct use as potable water). Its cost of $\$0.6/m^3$ is much cheaper than desalinated water. More similar treatment plant should be installed to treat the expected increase in wastewater. The intent was to supply its effluent water for non-potable uses served now by brackish water, and through the brackish water distribution facilities, called secondary piping system. Dual triculation piping system (one for potable, and one for non-potable supply, and one for waste water) is used in Kuwait since 3 decades. The output of Sulaibya plants with potable water quality should be piped to houses in the secondary piping system, besides the municipal system supplies treated drinking water. The TWW can be used on gardens and toilet flushing. The major purpose of such systems is to reduce the overall cost of providing water by using cheaper treated water for irrigation and preserving higher quality water for drinking.

7. Utilizing sustainable alternative energy to operate desalting plants

Since desalination is an energy intensive process, huge amounts of fossil fuel (fuel oil and natural gases) are combusted to supply the energy needs for desalting. As a result, millions of tons of air polluted gases (sulfur dioxide SO_2, nitrogen oxide NO, carbon monoxide and green house gases such as CO_2, methane CH_4, and NO are emitted to atmosphere). Petroleum oil has finite reserve, price fluctuation, insecure supply, and better usage than burning in steam generators of power plants (PP). These are enough reasons to free desalting seawater from its dependence on this fuel oil. Alternative energy such as wind, solar, geothermal, and nuclear energy can be better substitutes the oil and natural gas fuels.

Presently, nuclear energy is the only economically viable large scale alternative to fossil fuel to operate CPDP. Recent studies, e.g. [26], suggested using nuclear light water-pressurized water reactors LW PWR to produce electric power to operate SWRO. A nuclear power plant NPP using LW PWR reactor and of 600 MWe power output can produce 3.6 Mm^3/d SWRO plant.

The use of NPP of 600 MWe capacity can prevent emission of huge amount of green house gases GHG. If this plant is operated at 90% capacity factor, the annual produced electricity by this plant reaches 4,730 GWh. This amount of electricity can be generated by the most efficient conventional PP using combined gas/steam turbine cycle GSCC of 46% efficiency, but with a lot of CO_2 emission. The annual fuel heat required by the GTCC of 46% efficiency operating with 90% capacity factor is equal to M 37 GJ (million GJ). If fuel oil of 40 MJ/kg is used to provide this heat, the amount of fuel required per year is 0.9255 million tons of fuel. By assuming the carbon content is 90%, then the amount carbon to be burned is 0.833 million ton, and the CO_2 emitted is 3.05 million ton.

8. Conclusion

Seawater reverse osmosis SWRO desalination system is much more efficient, energy wise, and less bad impact on the environment than the multi-stage flash MSF, and the multi-effect ME desalting systems even if the MSF and ME are operated in combination with power plants.

A good feed water intake to desalting system, using subsurface intakes (vertical, slant and horizontal beach wells, and infiltration gallery, or seabed filtration) can significantly reduce the environmental impact on marine life, protects down-stream equipment, and reduces the cost of feed pretreatment, when compared with open sea intake. The fossil fuel (oil) used in Kuwait's cogeneration power desalting plant as energy source is finite, expensive, polluting to the environment, not sustainable, and has much better use than being combusted in furnaces or gas turbines. Alternative (renewable and nuclear energy) should be considered for sustainable seawater desalination. Other water resources, specially reclaimed wastewater should be pursued. However, the best and most sustainable water resource is efficient use of water.

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