Description of different water intakes for SWRO plants

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Abstract

The two main seawater intake modes, i.e. indirect or direct intake, are described and compared, on the basis of technical-economical considerations, to help making the most appropriate choice, taking into account pumping flowrate capacity in each case. In addition, out of previous considerations, reasons of a different choice are listed regarding technical, financial and environmental considerations.

Then, different technologies are described for:

- indirect intakes : boreholes, radial drains, horizontal directional drains, infiltration trenches and basins …
- direct intakes : channel, pipes, use of common intake with power plants…

For each of them, advantages and disadvantages are listed, and main elements are given for design and sizing.

Influence on seawater quality depending on intake mode, and impact on sizing of SWRO units are described (choice of proper pre-treatment, impact on membrane stage…).

Main components of intakes are described particularly materials used.

Finally, impact of water intake on capital and operation cost for seawater desalination is described, related to energy, consumables, chemicals … to conclude that an investigation on all specificities (onshore and offshore) of possible intake sites should be made to choose the best one, inducing capital and operation costs optimization of the whole desalination plant.

I. INTRODUCTION

Heart of a reverse osmosis desalination plant is surely constituted by the membrane stage, associated with high pressure pumps and energy recovery device. However, the seawater intake is also important because:

- It's an important part of the SWRO plant capital cost;
- It influences the choice of pre-treatment to achieve required quality for membranes;
- It must deliver a permanent and reliable seawater volume for the desalination plant;
- It must respect environment, either onshore or offshore.

Location of a desalination plant will depend partly on technical-economical and ecological analysis of different seawater intakes, which requires a perfect knowledge of their design, sizing, and capacity to deliver the best feed water quality, avoiding possible natural or accidental pollution.

This paper is a useful overall view of different technologies available for intakes, to the attention of promoters and designers of SWRO plants for preliminary studies.

II. DIFFERENT SEAWATER INTAKE MODES

Different seawater intakes are described in figure 1.

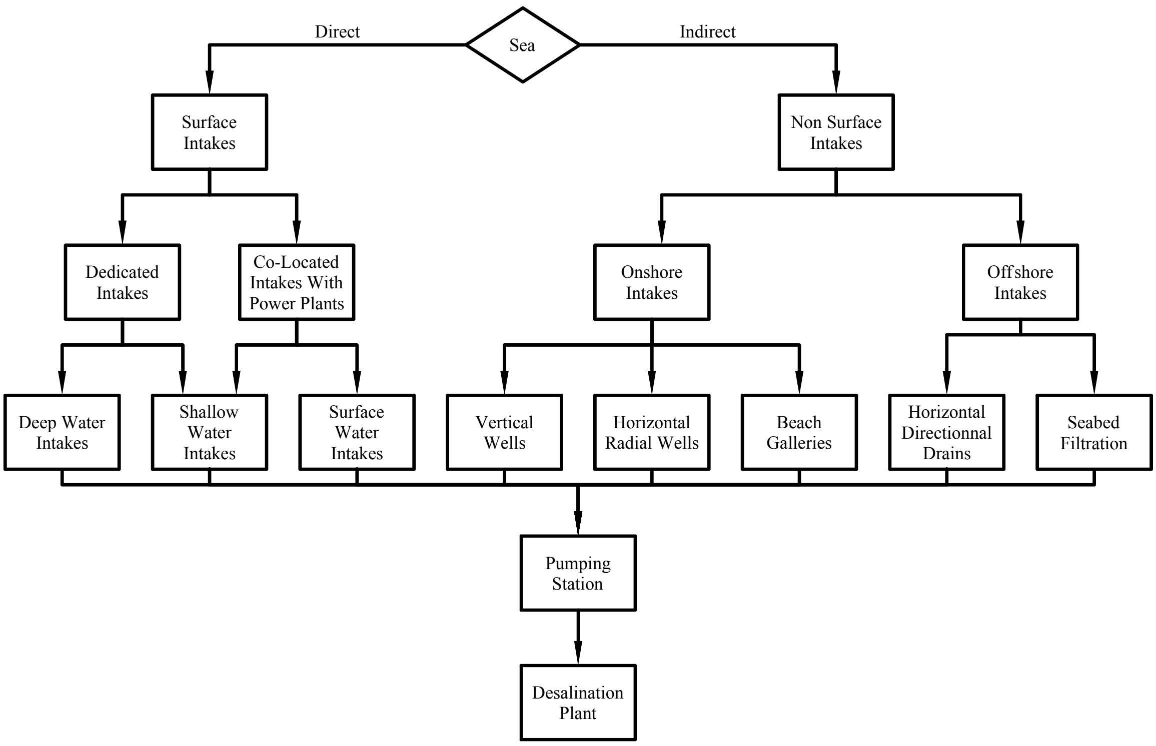

Figure 1 : Seawater Intake System Directory Structure

Classification defines eight different intakes, split in two main families:

- Surface water intakes (direct): seawater is taken directly at different depths;
- Non surface water intakes (indirect): seawater crosses through natural soil or sand bed before being pumped.

In the first case, water is taken directly and in the second case, water is naturally filtered.

III. PRELIMINARY STUDIES

In order to choose the most appropriate technology, all specific characteristics of a considered intake location should be listed, resulting in a global comparison of advantages and disadvantages in all respects.

Regarding only the intake mode, following data should be collected:

Onshore:

- Geology and hydrogeology
- Interactions between seawater aquifer and coastal aquifer
- Shore topography
- Environmental specific requirements
- Urban, agricultural or industrial activities

Offshore:

- Seabed profile
- Seabed nature
- Tide type
- Bathymetry
- Currents
- Winds
- Maritime activities
- Wastewater disposal (from towns, industries …)
- Rivers influence
- Protected fauna and flora species.

IV. SEAWATER VOLUMES CALCULATION

First of all, seawater needs have to be defined. They will depend on:

- Conversion factor, which varies in the range 35 to 60%;
- Water intake mode, i.e. indirect or direct: the first mode requires few treatments to achieve the required turbidity and SDI for membranes feed water, whereas the second mode may require more intensive treatments (classical like coagulation, flocculation, clarification or flotation, filtration or membrane treatments like micro or ultrafiltration). All those pre-treatment create water losses for sludge discharge or wash water. Water losses may vary from 2% for a classical filtration, to 10% for ultrafiltration.

Two different raw water volumes will be consequently calculated with the following relation:

$$Q_{sw} = Q_{wtp} \frac{x100}{Y \cdot l \cdot d} \qquad (1)$$

With:

Q_{sw}	:	daily seawater capacity ($m^3 \cdot d^{-1}$)
Q_{wtp}	:	daily fresh water production ($m^3 \cdot d^{-1}$)
Y	:	recovery ratio (%) = (freshwater flowrate x 100) : feed water flowrate
l	:	pretreatment water losses compared to seawater flowrate (%)
d	:	other losses in water pipes and network (%)

In a first approach, following values can be taken:

Y	:	40% (most common value)
l	:	2% for indirect intakes 10% for direct intakes
d	:	2%

V. DIRECT INTAKES

5.1 Deep, shallow and surface water intakes

The seawater depth generally taken is:

- 0 (*) to 15 m for shallow intakes;
- 20 to 35 m for deep intakes.

(*) surface water taken by a channel, used for power plants, thermal desalination plants, or hybrid plants, which need large flowrates.

Intake depth is of high importance in regard to water quality because the deeper the intake, the higher sun rays are absorbed, limiting photosynthesis and consequently algaes quantity (figure 2). In deep intakes, there are less suspended solids too.

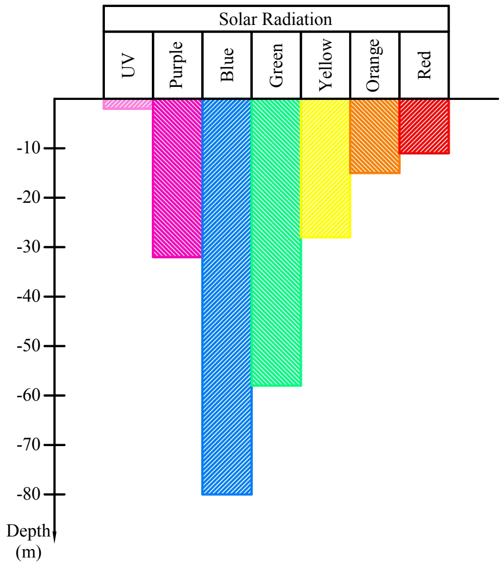

Figure 2 : Solar Radiation Absorption vs depth

The disadvantage of deep intakes is that seawater temperature decreases with depth, which increases membranes surface (increasing capital cost) or requires higher feed pressure (increasing operation cost). On the other side, a constant temperature over the year facilitates SWRO plant design and operation (figure 3).

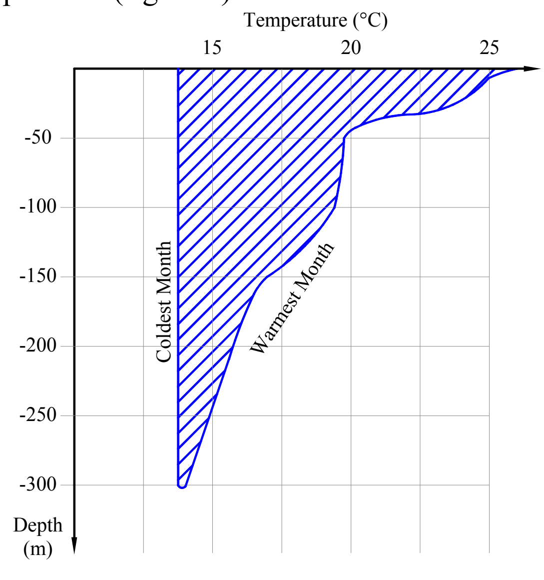

Figure 3 : vertical profile temperature of the occidental Mediterranean Sea

Deep water intakes can be economically foreseen only if the required depth is close to the shoreline (less than 50 m). That's why most of seawater intakes are at shallow depth, despite the following disadvantages:

- Turbulence maintaining solids in suspension;

- Algal bloom risk at warm seasons;
- Important variation of seawater temperature;
- Important presence of microorganisms and nutrients (high total organic carbon content).
- Risks of accidental pollutions and mixing with concentrate reject.

5.2 Co-located intakes with Electrical Power Plants

More and more, important SWRO plants are located near power plants, which require large quantities of cooling water.

Two solutions can be foreseen:

- An independent feed water intake
- Power plant infrastructures utilization.

In the second case, water can be taken before cooling (cold water) or after to benefit from water temperature rise (5 to 15°C approx.)

Independent devices are more flexible for plants operation, which may be specific, like chlorination for example: shock chlorination is preferred for SWRO plants, whereas continuous chlorination is necessary for cooling water.

Common devices enable to:

- Reduce capital cost for water intake;
- Use cooling seawater screening device to reduce needs for RO pre-treatment;
- Increase or stabilize RO feed water temperature, using water after cooling, which enables to reduce membranes surface, like for cold water or water with large temperature variations over a year (see figure 3).

However, the use of water after cooling device should be made carefully after checking:

- Cooling water chemical conditioning;
- Type of cleaning chemicals;
- Pollution risks by metal corrosion residues;

and after making an economical balance, taking into account dechlorination chemicals needed for instance.

If direct use of cooling water is risky, a heat exchanger can be used. A simple solution could be the convey of a part of the RO feedwater into the discharge channel of cooling system by means of an immersed pipe as illustrated in figure 4.

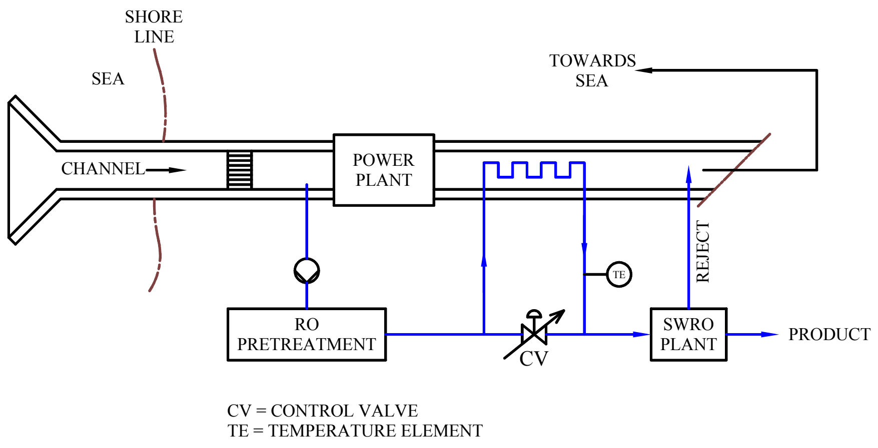

Figure 4 : seawater heating by immersed heat exchanger in discharge channel

VI. INDIRECT INTAKES

6.1 Subsurface onshore intakes

Small and medium SWRO plants are generally fed by beach wells or infiltration galleries.

A good water quality is obtained (turbidity $\leq$0,5 NFU, SDI $\leq$ 2, low quantity of micro organisms and nutrients). This kind of intakes is moreover protected from accidental pollution like tankers cleaning out for instance.

Onshore wells can be fitted with vertical drains (figure 5) or with radial laterals (figure 6), which capacity varies with soil permeability. Soils can be made of sand, gravel, rocks more or less cracked (karstic soil). Sand and/or gravel soils are the most permeable.

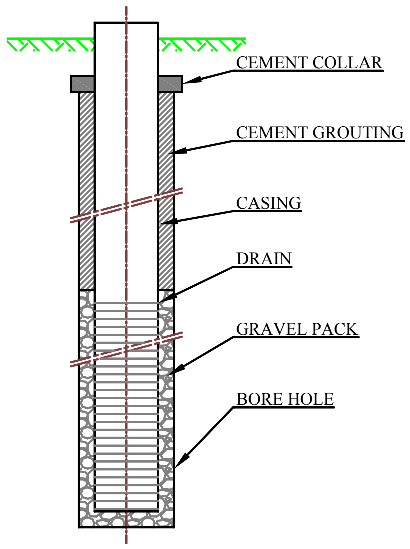

Figure 5 : Beach well with vertical drain

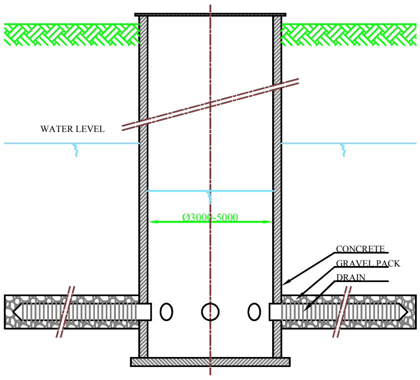

Figure 6 : Beach well with radial laterals

Vertical drains diameter never exceed 16". Most of the time, diameter is 10". In a sandy soil, maximum capacity is about 170 $m^3 \cdot h^{-1}$ (4000 $m^3 \cdot d^{-1}$ approx.).
To increase capacity, wells with radial laterals can be foreseen, to reach 500 $m^3 \cdot h^{-1}$ and more per unit.

The more the pumping flowrate, the more the aquifer is drawn, especially if soil transmissivity is low, obliging to increase distance between two wells.

Multiplication of wells number induces longer shore development which may have several effects:

- Land availability;
- Visual impact;
- Environmental impact during wells erection;
- Protection against vandalism;
- Road access construction;
- Length of collecting pipes.

If aquifer is not deep and has low thickness, infiltration galleries, in a parallel direction to shore line, leading to a pump sump can be foreseen (figure 7). Length of drains is about 15 m on both sides of the pumping sump.

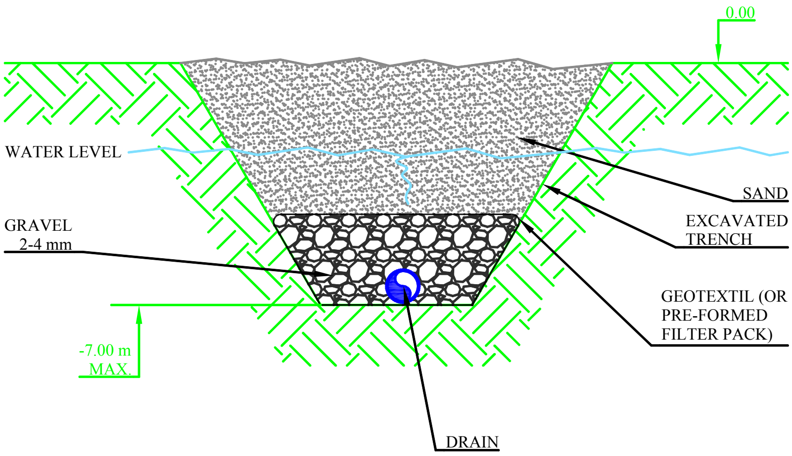

Figure 7 : Infiltration galleries section

For all indirect intakes, it's important to take water in seawater aquifer and not in fresh water aquifer, or brackish water laying over the seawater (due to the difference of density), because fresh or brackish water aquifer may:

- Be influenced by surface water (rainy periods) that can pollute it (turbidity, organic matter, iron …);
- Present variable salinities, which complicates SWRO plant operation;
- Increase seawater intrusion in land aquifer, which degrades its quality for agricultural use for instance.

Wells must be located quite far from the shore line to avoid structures erosion by the sea (waves effect).

Finally, in opposition to direct intakes, indirect intakes water productivity may decrease over time due to clogging by chemical precipitation and microorganism development. In that case, periodical chemical regeneration and construction of stand-by wells must be realized, which has of course an impact on capital and operating costs.

6.2 Subsurface offshore intakes

Intake by horizontal directional drains

It consists in directional drillings set in geological structure under sea bed, fitted then with HDPE drains (figure 8).

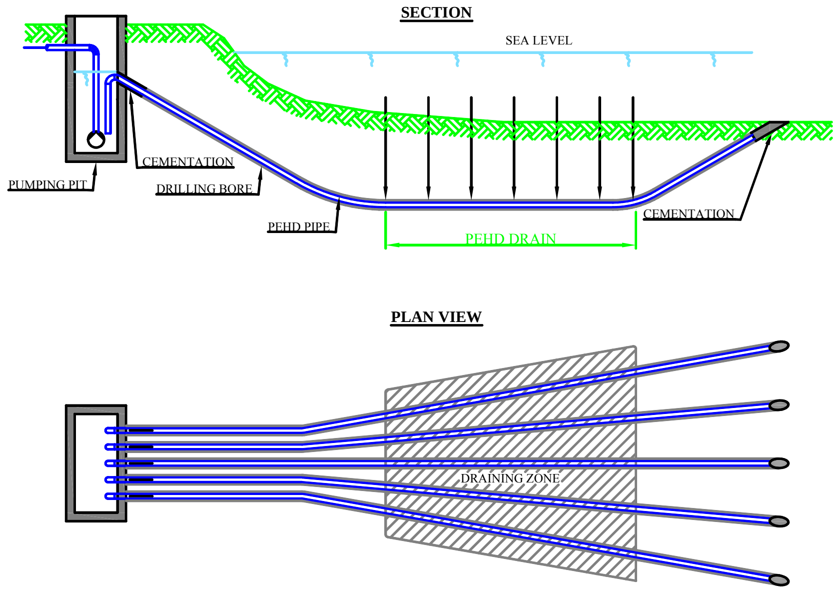

Figure 8 : intake by horizontal directional drain

As for beach well intakes, water quality is good (filtrated). Moreover, this system has following advantages:

- No impact on seawater bed, all works being made from the coast, unlike direct intakes. Poseidonia fields (protected specie in Mediterranean Sea) can be then protected;
- Low overall dimensions for onshore development, inducing low visual impact;
- No impact of fresh water aquifer that may modify seawater salinity and add pollution;
- Constant recharge of seawater aquifer.

Maximum diameter of drains is 700 mm, with a maximum length of 600 m .The quantity of drains depends on soil porosity. Geological studies may be realized to define porosity and pilot drilling may be achieved to confirm the results.

Seawater velocity in the ground must not exceed 2.5 $mm \cdot s^{-1}$ and velocity in drains must be around 0.6 $m \cdot s^{-1}$. Consequently a 700 mm diameter pipe can have a maximum flowrate of 230 $l \cdot s^{-1}$ approx.

Seabed filtration intake

Infiltration intakes located offshore are constituted of drains installed in trenches or excavations covered by sand. Their design is similar to onshore infiltration galleries (figure 7). Drains are placed in a perpendicular direction to the coast and limited to an header which goes to a pumping sump.

Infiltration trenches or basins are adapted to low depth seawater, with minimum submersion of 2 m. Works are achieved during low tide, and require classical machines for trenches erection (excavators) unlike directional drains which require specific machines and specialized companies.

Because of low submersion, trenches support dynamic efforts (currents, waves …) that may cause erosion and drains undermining. Trenches or excavations can be covered by concrete slabs or rip-rap, to avoid damages, collection of seawater being then mainly made by the trench sides and bottom.

Drains diameter varies from 6" (ND150) to 12" (ND300). Due to low water level, velocity in drains should not exceed 0.5 $m\cdot s^{-1}$.

Total surface of drainage area should be chosen so that velocity calculated hereafter is in the range 0.1 to 0.4 $m.h^{-1}$ (as slow sand filtration used for surface water treatment) :

$$V(m\cdot h^{-1}) = \frac{\text{total flowrate of drainage area } (m^3\cdot h^{-1})}{\text{total surface of drainage area } (m^2)} \quad (2)$$

An average velocity of 0.2 $m\cdot h^{-1}$ can be taken in a preliminary approach. At this value, suspended solids retained on the surface of sand are regularly evacuated by seawater currents if their velocity is 0.02 $m\cdot s^{-1}$ minimum.

VII. DIRECT INTAKES AND BEACH WELLS SIZING

For small and medium SWRO plant capacities (≤ 20 000 $m^3\cdot d^{-1}$), direct intakes and beach wells are most of the time chosen. Hereafter are some general indications for a rough sizing.

7.1 Direct intakes

These intakes include mainly a pipe between seawater collecting point at the desired depth and the pumping sump. Pipe material is most of the time HDPE, with diameters up to 1600 mm and unitary length up to 600 m, limiting the quantity of coupling and consequently the risk of leakages, and facilitating pipe laying.

Long pipes can be delivered on site by flotation with a towboat.

Pipes either lay on seabed or are hided into seabed. They must be fixed properly (as HDPE density is less than 1), generally with concrete staples. The pipes diameter is calculated on the basis of a velocity around 0.6 $m\cdot s^{-1}$.

At collecting point, pipe is fitted with a strainer to avoid suction of waste and fishes (figure 9).

Strainer is made of a triangular wire as shown in figure 10 to avoid clogging. Slots width is generally 3 mm. Total surface is calculated to obtain a velocity of 0.135 $m\cdot s^{-1}$ in slots, to minimize:

- Waste intrusion that could clog the pipe;
- Impact on flora and fauna owing to the fact that the influence zone of the suction around the strainer is weak.

Water distribution should be optimized to reach a constant velocities all along the strainer. Figure 11 shows distribution if no specific measures are taken, whereas figure 12 shows a strainer with good distribution.

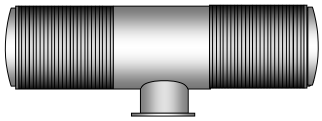

Figure 9 : Strainer (Johnson screens)

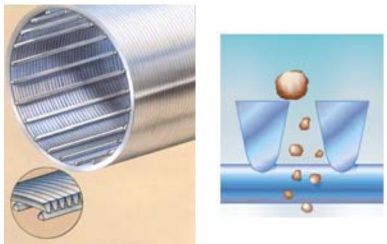

Figure 10 : Triangular slots (Johnson screens)

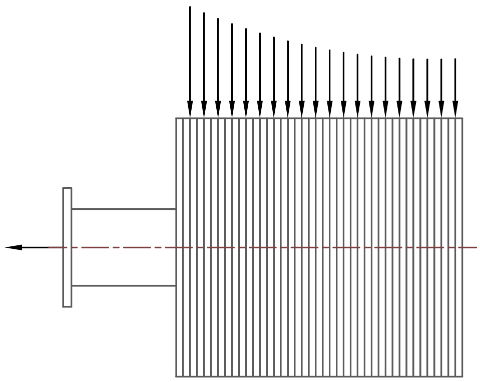

Figure 11 : intake strainer without flow modifier

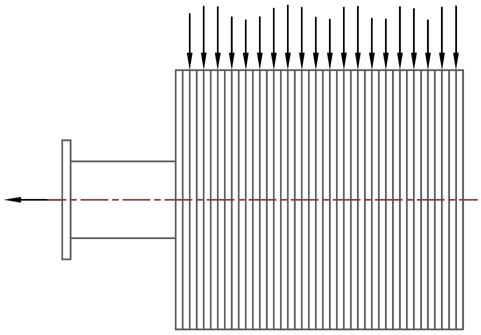

Figure 12 : intake strainer with flow modifier

Flow distribution can be achieved:

- With perforated pipe inside and all along the strainer as shown in figure 13 where disadvantages of the system are indicated;
- With two concentric pipes (figure 14). In this case head losses are ten times less important than those of a perforated pipe.

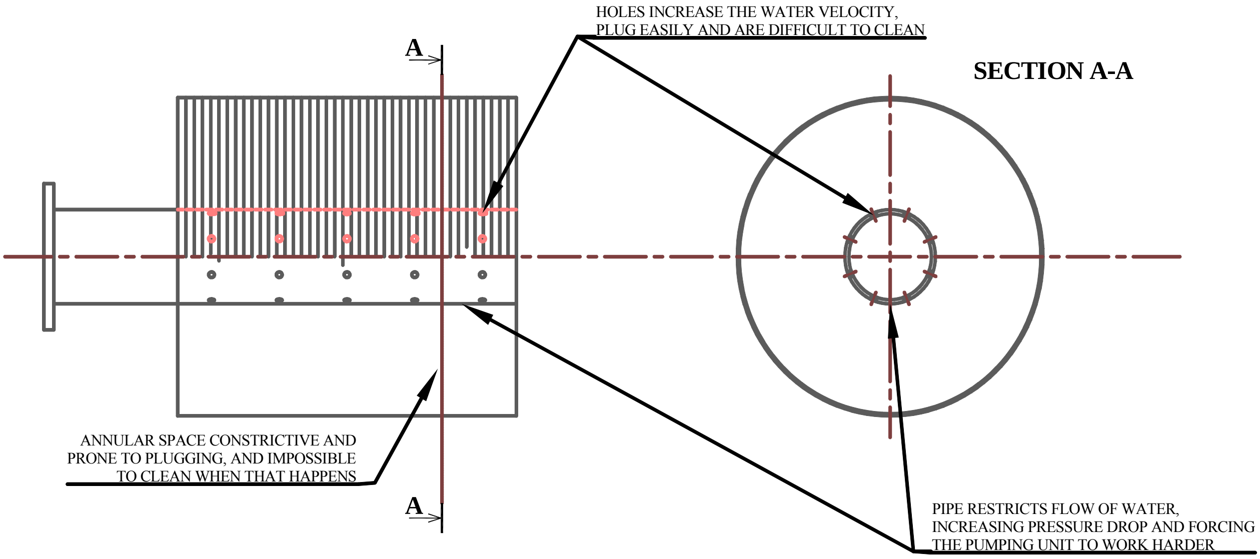

Figure 13 : Intake strainer with restricted flow modifier pipe

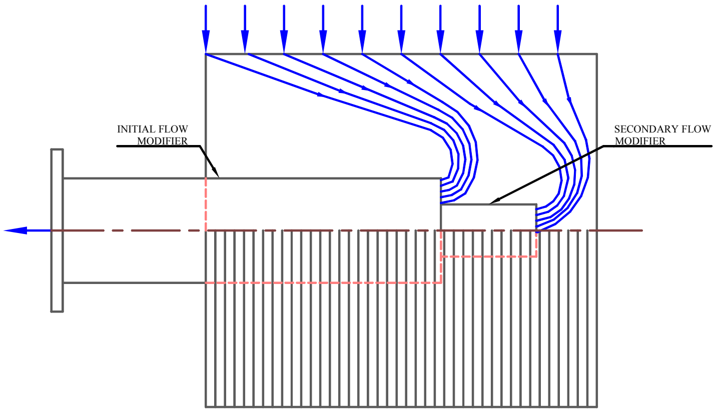

Figure 14 : Intake strainer with flow modifier (Johnson screens)

To avoid biofouling (accumulation of shells and algae on strainer surface), materials such as copper-nickel alloy CuNi 90/10 can be used.

Triangular slots strainers can reach a maximum flowrate of 4000 $m^3 \cdot h^{-1}$ about.

Intake screens can be fixed with rigid pipe at the desired level from seabed (4 m generally), or suspended to a submerged buoy fastened by chains (figure 15).

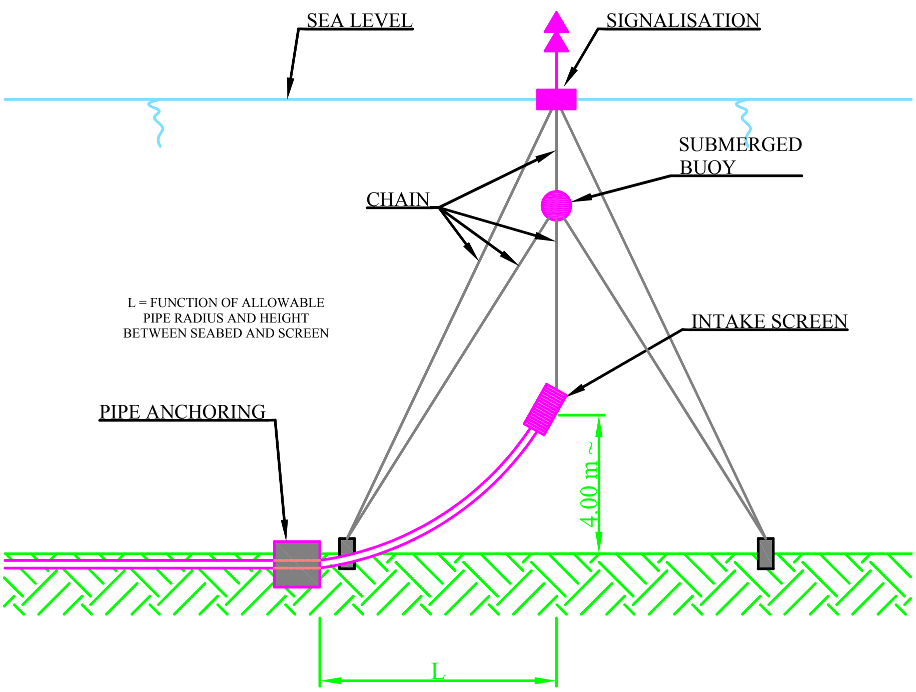

Figure 15 : Intake screen installation

If clogging risks are important, backwash of strainer by compressed air can be foreseen.

7.2 Beach wells

Maximum flowrate calculation

Beach well flowrate can be calculated with following simplified formula:

$$Q = \frac{T \cdot \Delta s}{4.4} \qquad (3)$$

Q : well flowrate ($m^3 \cdot d^{-1}$)
T : transmissivity = k.b ($m^2 \cdot d^{-1}$)
k = permeability ($m \cdot d^{-1}$)
b = aquifer thickness (m)
Δs : acceptable aquifer draw down (m)

Permeability k is given in table 1 for different soils material.

Material	**k ($m.d^{-1}$)**
Clay	10^{-5} to 10^{-7}
Silt	10^{-1}
Fine sand	10^{-1} to 10
Coarse sand	10 to 2.10^{2}
Gravel	10 to 10^{3} or more

Table 1 : Permeability for different soil materials

Only a detailed hydrogeological analysis can give the real values to take for a specific site.

For a first approach, following values can be taken into consideration:

k = 80 $m \cdot d^{-1}$ (coarse sand)
b = 10 m
Δs = 5 m.

On this basis, maximum daily flowrate is 4000 $m^3 \cdot d^{-1}$ (170 $m^3 \cdot h^{-1}$) per well. With a rising velocity of 1 $m \cdot s^{-1}$ in borehole pipe, diameter should be10" (250 mm).

Borehole drain characteristics

Lateral velocity through ***drain*** must be between 35 and 100 $m \cdot h^{-1}$. Length is given by following formula:

$$L = \frac{Q \cdot (\pi \cdot D \cdot V_1)^{-1} \cdot 100}{X} \qquad (4)$$

L	:	total ***drain*** length (m)
Q	:	pumping flowrate ($m^3 \cdot h^{-1}$)
D	:	strainer diameter (m)
V_l	:	lateral water velocity ($m \cdot h^{-1}$)
X	:	mesh void (%)

With previous flowrate of 170 $m^3 \cdot h^{-1}$, a 250 mm strainer diameter with a 40 % mesh void,, strainer length should be 8 m about with a 100 $m \cdot h^{-1}$ lateral velocity.

VIII. TECHNICAL-ECONOMICAL CONSIDERATIONS

Depending on intake mode, seawater intake facilities represent 5 to 20 % of the SWRO plant total capital cost: 5% in case of common facilities with power plant, and 20% for multiple beach wells.

A limit must be defined for beach well use, considering technical and economical aspects regarding a specific site. Figure 16 defines average economical limit for beach wells, which is around a global flowrate of 1700 $m^3 \cdot h^{-1}$, the table hereafter giving corresponding SWRO production capacity for different recovery ratio, taking into account water losses for pre-treatment:

Recovery (%)	SWRO plant capacity ($m^3 \cdot d^{-1}$)
35	14 000
40	16 000
45	18 000
50	20 000
55	22 000
60	24 000

Table 2 : Desalination plant capacity for 1 700 m3·h^{-1} seawater intake flowrate

For instance, for 4000 $m^3 \cdot d^{-1}$ per well, 25% security factor, and for 40 800 $m^3 \cdot d^{-1}$, 13 wells are required.

One estimate that the total seawater volume draw off by a bank of beach wells is in a range of 10 000 to 15 000 $m^3 \cdot d^{-1}$ per kilometre of coast. Hence, for a 40 800 $m^3 \cdot d^{-1}$ pumping capacity the beach wells hold 2.8 to 4.0 kilometers of coast (corresponding distance between two beach wells : 230 to 300 m). This induces:

- Land availability problems and environmental impact (visual, ecological during erection of plant and operation);
- 3 to 4 kms of access road;
- 13 technical rooms and electro-mechanical equipments associated;
- Long hydraulic and electrical networks;

- Suggestion for protection against the vandalism.

when a surface intake needs only one development on coast for the pumping station including only 3 or 4 pumps, with one stand-by, for the same flowrate (1 700 $m^3 \cdot d^{-1}$)

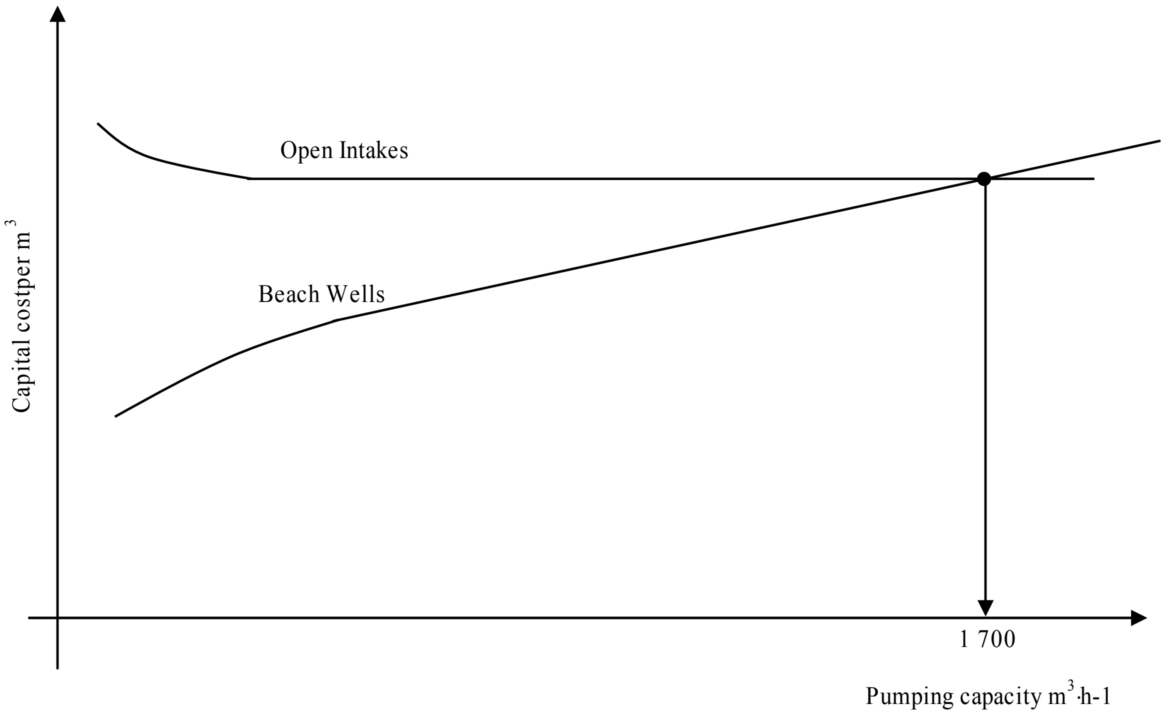

Figure 16 : Comparative capital cost per m^3 for direct intakes and beach wells

IX. CASE STORIES

Table 3 gives some examples of representatives intake systems which have been presented in this paper, implemented all around the world

SWRO Plant	Country	Intake System	SW Intake Capacity ($m^3 \cdot h^{-1}$)	Specifications
Fukuoka Kyushu	Japan	Infiltration	4 290	Infiltration through sand layer SW intake area : 20 000 m²
Ashkelon	Israël	Open Surface	36 000	Suction is carried by three pipes – Diameter : 1,6 m – Length : 1 000 each
Laayoun - OCP	Morocco	Beach Wells	48 000	16 beach wells - 14"
Tampa Bay	USA	Cooling System	6 960	Co-location with power generation station – SWRO is directly connected with the cooling water discharge
San Pedro Del Pinatar	Spain	Drainage	7 200	Horizontal directed-drilled drains bellow the sea bed – 20 drains – Diameter : 450 mm

Fujairah	Emirate of Abu Dhabi	Open surface	20 000	Hybrid plant fed via three pipes, one is dedicated to the RO plant – Length : 380 m each – Position : 6 m above sea bed, 10 m below surface
Perth	Australia	Open Surface	15 120	Suction is carried by pipe – Diameter : 2,3 m – Length : 300 m – Screen location : 5,5 m below mean sea level
Palma de Mallorca	Spain	Beach Wells	3 730	16 beach wells
Pemex Salina Cruz Refinery	Mexico	Radial Collectors Beach Wells	1 875	3 beach wells

Table 3 : Examples of various intake systems

X. CONCLUSIONS

The choice of the seawater intake facilities for SWRO plants presents a great importance, because its impact is far to be negligible on:

- SWRO plant location;
- Pre-treatment process;
- Capital cost;
- Operation cost;
- Maritime and coastal environment;
- Seawater feed reliability.

Therefore, it is necessary to call out the specialists of the various fields (oceanology, coastal works, geology, hydrology, desalination, ecology, finance) to ensure the success for the whole desalination project.

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