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Efficiency optimization in SWRO plant: high efficiency & low maintenance pumps

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Abstract

Contractors and end users involved in desalination business are already asking for high efficiency pumps. In Sulzer we think that it is important for them to know how they can ask for the most efficient pump by means of learning about main basic principles (specific speed, suction specific speed and NPSH) of a centrifugal pump. These parameters have strong influence on the right pump selection, not only in order to increase pump efficiency, but also to be able to keep efficiencies values through pump life cycle, and decreasing maintenance periods. Additionally, comparison between two different plants concept: Separated feed lines or common pressure centre will be shown with different examples depending on plant size, indicating in every case the achievable efficiency. Askhelon SWRO Plant in Israel is the best example of the direct application of the above mentioned concepts in a real SWRO Plant, where high pressure RO feed pump efficiency of 88.5% has been reached on site.

Keywords: High efficiency Sulzer centrifugal pumps

1. Introduction

From the very beginning, main target in the Desalination Industry R&D has been to improve the SWRO plants efficiency in order to reduce the cost of the desalted water. These efforts have been mainly focused on the energy recovery devices (Francis and Pelton Turbines, Turbochargers, Isobaric Chambers) and the membrane elements, as they have been traditionally the areas where better improvements were achievable. Nowadays desalted water cost reductions are becoming slighter day by day, but they are still cost effective since SWRO plants sizes are also becoming bigger and small efficiency increases produce important OPEX saving. However these small efficiency increases can be obtained also by focusing in other plant elements as centrifugal pumps, more particularly their design and selection.

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It is clear that contractors involved in desalination business are already asking for high efficiency pumps, but we in Sulzer think that it is important for contractors to know how they can ask for that most efficient pump. The target of this presentation is to teach contractors about some basic principles (specific speed, suction specific speed and NPSH) of a centrifugal pump design that can affect to the right pump selection, not only in order to increase pump efficiency, but also to be able to keep efficiencies values through pump life cycle, decreasing maintenance periods too.

Additionally, comparison between two different plants concepts, separated feed lines or common pressure centre, will be shown with different examples depending on plant size, indicating in every case the achievable efficiency.

Askhelon SWRO Plant in Israel is the best example of the direct application of the above mentioned concepts in a real SWRO Plant. In this plant and thanks to the cooperation between Sulzer Pumps, IDE Technologies and Veolia Water, efficiencies of 88.5% are reached in the high pressure pumps.

2. Basic concepts

When a centrifugal pump is design, from the hydraulic point of view there are two main concepts which must be consider in order to reach the best design. These concepts are the specific speed and the suction specific speed. Those concepts will give us an idea about how a centrifugal pump will work. Definition, calculation and influences of these parameters will be shown.

Additionally to those parameters special attention must be paid on the NPSH (net positive suction head). Although this parameter is related to the suction specific speed, the comprehension of the NPSH concept will help us to design in a more efficient way the SWRO Plants and therefore it is worth to dedicate a special paragraph to it.

2.1. Specific speed

The specific speed of a pump impeller is a nondimensional parameter that gives an idea about the geometrical shape of the impeller. It combines the capacity (per impeller eye) the head that this impeller is able to give (capacity and head referred to the best efficiency point, BEP) and the speed the impeller will rotate at. This concept is defined as per following formula:

$$n_q = n \cdot \frac{\sqrt{Q}}{H^{3/4}}$$

This is important to remark that the specific speed will be always the same for every impeller with the same geometrical shape, independently of its size.

Impellers with lower specific speed values will have smaller capacities and will give higher head at the same speed, it means they will be thinner and will have larger impeller diameter. For example a typical radial flow, centrifugal pump will have specific speed values from 22 to 30. On the opposite side, with higher specific speed values, an impeller will give higher capacities and lower heads. For example, a propeller impeller has n_q values over 220.

The specific speed of an impeller has also strong influence in the performance curve slope: The lower the specific speed value is, the flatter the curve is. This is important to know because it gives us an idea about to control the pump.

The most remarkable influence of the specific speed is probably on the impeller efficiency. It is known from the experience that the efficiency of an impeller will increase together with specific speed up to a certain value, where the maximum efficiency is reached. From this point, higher n_q values will lead us to slightly lower efficiencies. This n_q top value is around 34: Close to it the most efficient impellers are found. Obviously the efficiency of the impeller depends also on its capacity: For capacities from 500 to 2500 m^3/h, the optimum efficiency that can be obtained can vary between 82 and 88%. Those values must be the target when designing high pressure pumps in RO plant, although they can not always be reached due to constructive reasons.

It must be noted that for the same n_q value, an impeller will be generally more efficient when it is fitted in a volute pump than in a diffuser pump, as in the volute pump there is no diffuser generating the correspondent head losses.

2.2. Suction specific speed

This parameter expresses the suction capability of a centrifugal impeller, and it defines the relationship between the capacity per impeller eye, the NPSHR (at 3% head losses), both at the BEP, and the rotating speed. It depends on the impeller geometrical shape and the impeller eye width. This nondimensional parameter is defined by the following formula:

$$N_{SS} = n \cdot \frac{\sqrt{Q}}{(\text{NPSHR}_{3\%})^{3/4}}$$

The suction specific speed is entirely necessary to select the right pump in order to guarantee the NPSHA requirements.

According to the good engineering practice, the suction specific speed for water application must be limited to a maximum of 9500 (US units), 185 (SI unit). The use of higher values will lead us to more hydraulically compromised impeller eye geometric shape, with higher risk of bubbles formation.

On the other hand, the suction specific speed will indicate us how the NPSHR curve will be. For N_{SS} values below 9500, the NPSHR curve will be relatively flat with favourable values for lower and higher capacities. However, for higher N_{SS} values than 9500, the NPSHR at the best efficiency point will be lower, but will dramatically increase for lower and higher capacities.

2.3. NPSH: its importance for optimum pump selection and life cycle cost operation

Prior to define what the NPSH is, some explanations must be given regarding the cavitation phenomenon. This phenomenon occurs when the pressure of a liquid falls below its vapour pressure, vapour bubbles form inside the liquid. When for any reason the pressure increases again, bubbles get collapsed suddenly, producing its implosion.

When cavitation occurs close to a wall with a high velocity (jet impact) the wall gets attacked by erosion and chemical attack, producing really important damages. In a centrifugal pump, this phenomenon can occur at the impeller inlet and along the impeller vane under certain conditions, due to local pressure reductions and strong increase of the fluid velocity.

In a centrifugal pump, cavitation can be prevented by controlling the bubbles formation at the impeller inlet, just avoiding suction pressure falling below liquid pressure vapour, it means:

$$\text{NPSHA} \geq \text{NPSHR}$$

NPSH (net positive suction head) is defined as the difference between total absolute pressure in the pump suction flange and the vapour pressure of the pumped liquid, expressed in meters.

NPSHA (available) is defined as the suction absolute pressure in meters expected in the pump suction due to the installation conditions.

NPSHR (required) is the minimum suction pressure in meters required to avoid cavitation in the impeller. Based on that, different NPSHR values can be defined as follows:

- Onset of cavitation: The first bubbles appear (noise) and material started to be attacked. Bubbles zone covers an increasing length of impeller vane.
- NPSHR 0% head drop. Head starts to drop.

- NPSHR for 40,000 h of impeller efficient life (Sulzer NPSHR recommended).
- NPSHR 3% head drop. Widely used cavitation criterion because it is the only one that can measure on a test bed.
- NPSHR total: Full cavitation at a certain suction head. Delivery head falls very steeply.

In order to have an efficient pump life cycle, obtaining a strong operation and maintenance saving with no production availability losses, Sulzer defines the recommended NPSHR in order to reach up to 40,000 h impeller life with no significant material erosion that can produce head and efficiency losses, vibrations and noise, as the $NPSHR_{3\%}$ multiplied by a safety factor that can vary between 1.5 and 2 depending on the capacity.

$$\mathrm{NPSHR}_{40{,}000\ \mathrm{h}} = F \times \mathrm{NPSHR}_{3\%} \quad F \approx 1.5/2$$

3. SWRO plant design: separated feed lines vs. common pressure centre: reachable efficiencies and examples

Traditionally the RO plants have been designed considering separated feed lines; it means one high pressure pump feeding on membrane rack of certain daily production. By increasing the number of trains the total daily production is obtained. However, it is known that pump efficiency depends strongly on its capacity: The highest the capacity is, the highest its efficiency is. Therefore, and since the RO plants are becoming bigger, in some cases it can be interesting, from the power consumption point of view, to have what is called pressure centre; it means that reduced number of high pressure pumps would be feeding a common manifold that would distribute the flow to the membrane racks. In that way, there would be less number of pumps than membrane racks but pumps' efficiency will be high as their capacity would be higher. An example of this pressure centre design can be found in the Askhelon SWRO Plant (330,000 m^3/day) in Israel.

It is not the author's intention to recommend which designed is the right one. This decision shall be taken by the plant designer, who will take into consideration different factors (CAPEX, OPEX, production availability, etc.) in order to make the right choice. The final decision shall be taken case by case, as every RO plant is different, based on the advantages and disadvantages that both plant conceptions can have in every case.

The author's intention is just to show a comparison from the efficiency point of view of both systems, introducing the advantages and disadvantages that can be found in every case.

To show such comparison, two different plant sizes will be considered, 60,000 and 100,000 m^3/day and in every case three plant designs will be considered, as per following table:

Plant size (daily production)	Separated feed lines/no. of trains		Pressure centre/ no. of HP pumps
60,000 m^3/day	6 trains	4 trains	3 pumps
100,000 m^3/day	8 trains	5 trains	2 pumps

In this six cases, it will be shown the efficiency that can be obtained in the so called core pumps, i.e. high pressure RO pumps and low pressure booster pumps. This comparison will be done based on the following suppositions:

- 50 Hz country
- Approx. 45% recovery ratio
- Isobaric chambers as energy recovery device

The obtained results in the mentioned six cases, as per following figures:

Plant size: 60,000 m^3/day

Plant design/ no. of pumps	Capacity	HP pump/ no. of stages	Reachable efficiency	
			HP pump	LP booster pump
6 separated trains	500 m^3/h	6 stages	82%	82%
4 separated trains	750 m^3/h	5 stages	85%	86%
3 HP pumps in pressure centre	1000 m^3/h	4 stages	86%	87%

Plant size: 100,000 m^3/day

Plant design/ no. of pumps	Capacity	HP pump/ no. of stages	Reachable efficiency	
			HP pump	LP booster pump
8 separated trains	625 m^3/h	5 stages	85%	85.5%
5 separated trains	1000 m^3/h	4 stages	86%	87%
2 HP pumps in pressure centre	2500 m^3/h	2 stages	88.5%	88%

Looking at the above figures, we can observe following conclusions:

- By reducing the number of pumps, higher efficiencies are obtained, it means lower OPEX.
- By reducing the number of pumps, their capacity becomes higher. It means that LP booster pump design will change form end suction, Overhung pump to double suction, between bearing pumps.
- By reducing the number of pumps, the motor sizes will increase. It can affect strongly on the CAPEX, as maybe medium voltage can be required. It can affects also to the LP booster pump VFD design (low voltage vs. medium voltage).
- By increasing the pump capacity, high pressure pump design will change from ring section type to axial split volute casing pump type.
- By increasing the capacity, number of stages of the high pressure pump will decrease from six to two stages. It means less rotating parts and less maintenance.
- By increasing the pump capacity, the high pressure pumps and the corresponding motors may require force oil lubrication (lube oil system), and the start procedure becomes more complicated.
- By reducing the number of pumps, the plant flexibility decreases.

4. Pump selection criteria to reach the highest efficiency: flow and pressure distribution between HP and LP booster pumps

The purpose off the plant designer must be to find the core pumps running as closest as possible to the best efficiency point. As core pumps are considered in this case those ones running continuously with the biggest portion of total absorbed power, the LP booster pump and the high pressure RO feed pump.

The first point that must be considered is the use of frequency converter, normally in the LP booster pumps, although in the last year some contractors are considering the high pressure pump with VFD. The VFD will be used to adjust the pressure at the inlet RO membrane, depending on the different RO plant conditions: temperature variations, different pressure losses variations due to clean/dirty filters and membrane inlet pressure variations due to new/old membrane conditions. Based on that, it is possible to play with the distribution of the total pressure that the membrane requires in order to reach the highest efficiency pumps.

One it has been decided the energy recovery system that will be used and the recovery ratio of the plant based on the information from membrane manufacturers, the pump selection procedure would be as follows:

(1) *Flow distribution* (number of trains): This will depend on the following:
   (i) Water production availability (plant flexibility) the end user required.
   (ii) Selected configuration: separated feed lines or common pressure centre.
   (iii) Membrane elements cleaning needs.
   (iv) Investment cost and availability of VFD for the LP booster pumps.

(2) *$NPSHR_{40,000\,h}$ calculation:* For the selected capacity and considering a suction specific speed N_{SS} of 9500 (US units), using the corresponding formulas it can be calculated the $NPSHR_{3\%}$ and therefore, the $NPSH_{40,000\,h}$.

$$\mathrm{NPSHR}_{3\%} = \left(n \frac{\sqrt{Q}}{N_{\mathrm{ss}}} \right)^{4/3}$$

$$\mathrm{NPSHR}_{40{,}000\ \mathrm{h}} = F \times \mathrm{NPSH}_{3\%} \quad F \approx 1.5/2$$

That $NPSH_{40,000\,h}$ will tell us what is the minimum continuous suction pressure shall be guaranteed in the high pressure pump.

(3) By adding to this minimum suction pressure the filters and piping losses in old/dirty conditions we get the minimum discharge pressure the LP booster pump shall deliver.

The maximum discharge pressure of the LP booster pump is obtained by adding the variations of the requested feed pressure at the membrane inlet due to clean/dirty membrane conditions and due to sea water temperature and salinity.

(4) All remaining pressure up to the requested feed pressure will be given by the high pressure pump.

(5) Based on requested flow and the total requested pressure, a pump with a specific speed of $n_q = 34$ must be searched, with the proper number of stages according to the requested flow. In that way we get the differential pressure that the selected HP pump can deliver.

(6) If that differential pressure is higher than requested, then a certain impeller cut is requested. If it is lower than requested, new adjustments shall be done.

It might also happen that calculated LP booster pump pressure range goes over the maximum design pressure of the polyethylene piping or filters.

If this happen, new pump selection procedure shall be repeated with the indicated limits:

(a) Maximum design pressure of piping and filters.
(b) Minimum differential pressure of the HP pump.

In general terms (obviously depending on the different RO plant parameters (temperature, salinity, filters and membrane characteristics) we can consider as an indication for a 50 Hz country the following values regarding the high pressure pump selection:

Capacity	HPP efficiency	High pressure pump	
		No. of stages	Discharge flange
500–550 m^3/h	82%	6	6"
650–750 m^3/h	85%	5	8"
950–1050 m^3/h	86%	4	10"
1200–1300 m^3/h	86.5%	3	12"
1600–1700 m^3/h	87%	2–3	12"
2200–2400 m^3/h	88%	2	14"

5. Sulzer Askhelon experience

The above explained pump selection criteria was used the first time in Askhelon SWRO Plant located in Israel, built up by a consortium formed by IDE Technologies and Veolia Water. Daily production in Askhelon SWRO Plant is 330,000 m/day, which makes it the biggest SWRO plant ever constructed. The plant was designed with common pressure centre in order to improve the plant efficiency.

In that plant, Sulzer pumps supplied, among others, the high pressure pumps, multistage, axial split, volute casing pump, model MSD 14 × 14 × 19 with two stages, with a guaranteed efficiency of 88%. In fact, efficiencies of 88.5–90% have been measured on site. It allows the operator to produce water at a cost of 0.53 US$/m^3, including CAPEX and OPEX.

Pumps supplied by Sulzer in Askhelon SWRO Plant:

Item	Pump type	Q (m^3/h)	H (m)
Sea water intake pump	BS 600-1s/001 (5 units)	8650	25.8
LP Booster I pump	SMN 402-620 (8 units)	2270	53.8
LP Booster II pump	ZPP 52-600 (6 units)	4600	54.7
High pressure pump — 1st pass	14 × 14 × 19 MSD-D/2 (8 units)	2270	625
2nd pass pumps	SMN 302-640 (8 units)	2200	110
3rd pass pumps	SMN 253-720 (4 units)	1255	126
3rd pass booster pumps	ZE 150-3315 (4 units)	332	102
4th pass pumps	SMN 253-720 (4 units)	1130	60.4