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Comparison of multiple port and end port connections for pressure vessels

Nadav Shachaf*, Tobias Haarburger

BEL Group Ltd.
email: shachaf@bel-g.com

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Abstract

The design of reverse osmosis and nano filtration plants is essentially influenced not only by the module arrangement, but also by the arrangement of the pressure vessel connections.

Multifarious design possibilities can be considered as a result of many improvements introduced over the last few years.

The key attributes is the three purposes port arrangement, feed-, concentrate- and permeate connection while comparing multiple port versus end port design.

The following paper discusses the main factors for future plant design:

- Cost savings by reducing the complexity of stainless steel piping in multiple port design.
- The impact of the more compact design on total foot print required for the membrane plant,
- How can technical risks, especially corrosion, be considerably reduced, and
- The impact of the hydraulic design of the entire piping system and its influence on energy costs.

Keywords: Pressure vessel design; Multiple port versus end port; Capital costs; Corrosion

1. Cost saving by reducing stainless steel material

The essential considerations for the design of membrane desalination plants are capacity, operating pressure and the feed water quality, all measured against product water quality. Achieving that required product water quality requires a meticulous membrane plant design.

A precise hydraulic process calculation is at the core of the plant design and includes the pumping systems, piping and the membrane elements housing. It is not possible to operate a pressurised membrane plant, where the elements are simply submersed in a basin. The exact overflow of the membrane surface is the pre-requisition to avoid scaling and fouling. Therefore the ideal

*Corresponding author.

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design is to house the spiral wound membrane elements in pressure vessels.

As a consequence, each single vessel needs to have at least three connections: feed, concentrate and permeate stream. Concentrate and permeate are the split result of the feed stream, according to a calculated ratio. In general, each vessel can house one to eight elements, however the more common design consist of six elements, housed in an eight inch diameter vessel (203,20 mm).

The piping system has in connection with the approach-flow of the vessel, an essential influence of the hydraulic rates of the plant.

In general, pressure vessels can have an end port connection system, side port, or multiple port.

Beside the different hydraulic impacts which will be discussed later, cost effective design proves to be as important. Cutting on stainless steel material bears a significant influence on plant design bottom line.

The figures below illustrate how different multiple port and end port plants are.

The two plants have almost the same capacity, but the material and assembly costs are extremely different. An example design explains more details.

Here is a case study of a sea water application of a commercial plant with a capacity of 2000 m^3/d or 87.72 m^3/h.

Fig. 1. Multiple port design.

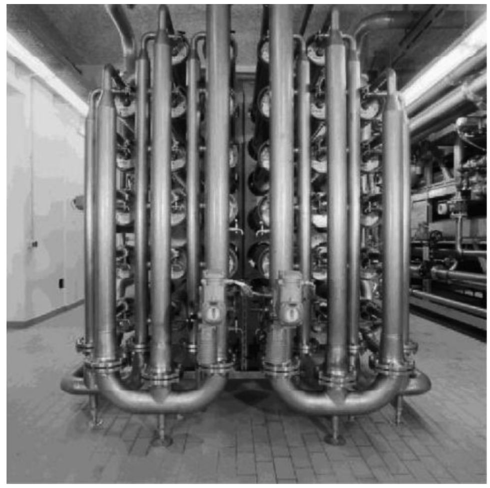

Fig. 2. End port design.

Turning sea water to potable water requires reduction of salinity from 40,000 to <500 ppm. The operating pressure is 68 bar, so the pressure vessel needs to be designed for 1000 psi.

For hydraulic reasons, this plant would be split into two racks and each rack would consist of 12 pressure vessel, containing 6 elements each.

Sea water plant would require super duplex stainless steel material to avoid corrosion.

Piping work is also very different — while the end port vessels design require a distribution manifold (consisting of a main pipe and connection pipes for each vessel) and at least a full working day of a welder and an assistant, the multiple port solution is much simpler, requires no welding, only Victaulic couplings that can be mounted on the vessels in a very short time.

In other words although the cost of the three types of pressure vessels is almost the same — stainless steel material that soared by 140% between 2002 and 2006, and labor costs make an enormous difference. As a rule of thumb it can be safely said that in multiple port systems stainless steel material cost is 50% cheaper than the material costs of an end port system.

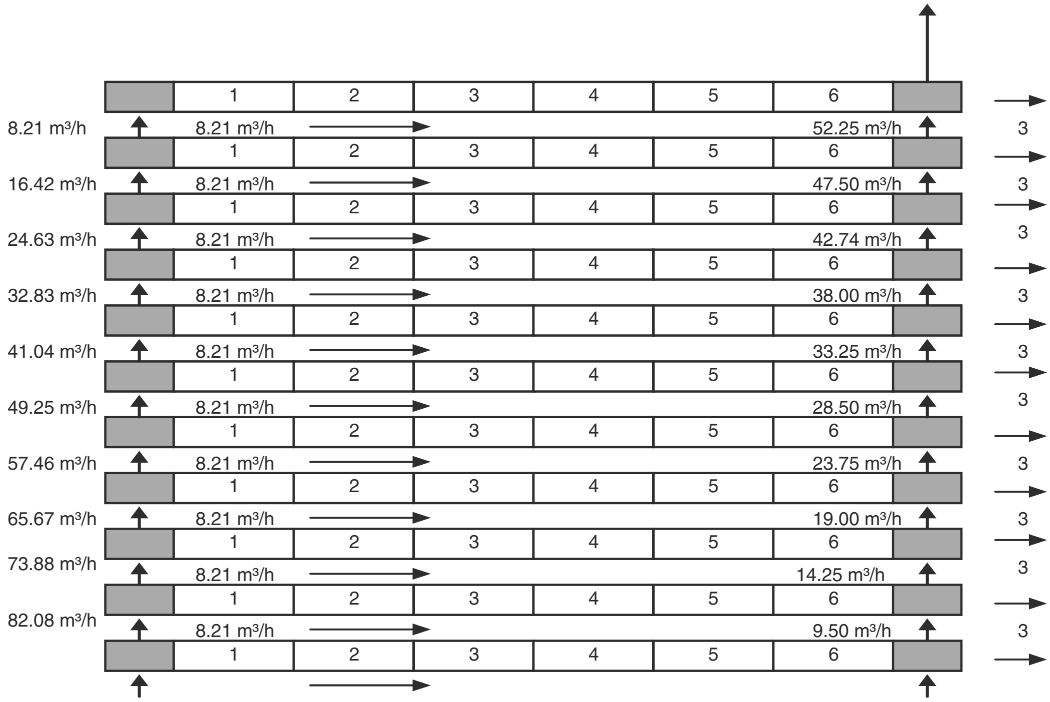

Fig. 3. Hydraulic in a multiple port.

The side port design that still requires a distribution pipe is lying somewhere in between.

To illustrate the above in details:

Indirect construction costs such as procurement and quality control should also be added to the material and labour costs.

	Stream	Material	Vessel costs	Piping, resp. port material material costs	Labour costs	Total costs
24 end port vessel – 8″ 1.000 psi	feed + concentrate (2 × 1.5″)	DIN 1.4539/ AISI 904L/ super duplex	€27.240.00	€27.720.00	€1.760,00	€56.720.00
24 side port vessel – 8″ 1.000 psi	side port connection (2 × 2″)	DIN 1.4539/ AISI 904L/ super duplex	€26.064.00	€21.690.00	€880.00	€48.634.00
24 multi port vessel – 8″ 1.000 psi	multi port connection (4 × 3″)	DIN 1.4539/ AISI 904L/ super duplex	€27.367.20	€14.460.00		€41.827.20

Fig. 4. Cost comparison between end port-, side port-, multiple port design.

Welding is a critical issue that may justify a separate article but here we should only mention that poor welding quality creates major problems and delays in start-up phase.

Maintenance work also bears great influence on cost and efficiency:

In an end port design, especially in larger plants, accessing the membrane elements is time consuming and labour intensive process involving the removal of the manifold. The interruption of the water production is longer and the risk of leakages after the re-assembly in operating plants is much higher.

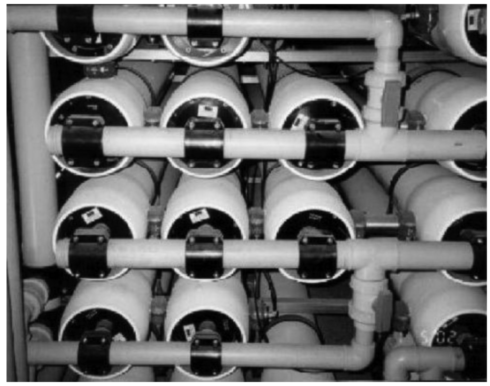

Fig. 5. Compact multiple port design.

2. The advantages of compact design

In containerized desalination plants as well as in long established industrial plants, each available centimetre of space do count.

Two staged plants, as well as sea water desalination plants which have a lower recovery rate of less than 40%, are connected to a piping system, which are constrained the limited available space. End port design consumes much larger space than multiple ports design. Other disadvantages mentioned above have stronger impact the smaller the available space is — restricted access and manoeuvrability effecting longer down time and extended maintenance and repair work.

Some clients like the armed forces, request ergonomic friendly solutions, which limit the available space even more. Multiple port vessels do not require the single connection, vessel per vessel from the front and end side.

The limited space of a 40 ft container, which is 12 m long and 2.43 m wide and high, makes it always difficult, to install other system components, like dosing stations, pumps, controls, prefilters etc. To design a 10 m^3/h plant so it will fit into a 40 ft container is a true challenge.

The complex the piping system is the more it is exposed to transportation damage. Less pipes is not only cheaper it is simply better.

The use of multiple port vessels is definitely the best solution for containerized and other space restricted membrane plants.

3. Avoiding of corrosion

Reduced pipe work is about material and labour cost, space and time consumption and also about exposure to corrosion.

In theory, it is possible to build a desalination plant with limited, or even corrosion free plants but material cost and available practical solutions do not justify the effort.

The more common high pressure application of 70 bar needs stainless steel pipes.

Regardless whether for pitting corrosion or crevice corrosion protection, the stainless steel material has to be at least of AISI 904L or compatible grade, in case of a salinity higher than 10,000 ppm or pinholes will appear in matter of days.

The entire RO rack will face no corrosion risk, in case of using multiple ports as the vessels connection configuration creates a built in manifold.

The stainless steel port itself is just fit into the vessel and sealed with a simple rubber seal. No welding, no pre-formed parts.

Non metallic vessel ports are already available on the market limited at this stage to 20 bar operating pressure applications but at this pressure stage, the piping system is usually of non metallic/ composite as well.

4. Impact on hydraulic design

By connecting several vessels in a multiple port design, we create a feed area inside the vessel between the feed port and the opposite side port which is connected and feeds the stream to the following vessel. Inside this feed area we also have the end cap device, so it is left for us to examine the impact of that design on the pressure of the whole system.

The pressure loss caused by the ports themselves can be easily calculated.

The earlier discussed design case study is the basis for the following pressure loss calculation:

24 vessels are fed by 1960 m^3/h in a one stage system. For this calculation, two times twelve vessels are connected, which would result in a rather high building, but to maximise the back-pressure, it is a useful assumption.

The port diameter can be changed and reduced twice — from four inch to three and finally from three to two inch during the process flow. Since it is a sea water application which requires ports made of super duplex stainless steel material we have limited the diameter for cost reduction purposes.

The piping of this configuration consists of a feed and concentrate manifold and a single piping stream for each vessel on both ends, feed and concentrate.

The pressure loss calculation shows that in total 1.44 bar (which correspond to 6.88 kW/h) have to be balanced, which has indeed a significant cost impact.

The same calculation done for multiple port vessels design shows a loss of only 0.6 kW/h.

The pressure loss by the end cap is minor and can be ignored — although considered as a grit however the majority of the flow pass the device around, so the impact is limited. Furthermore, due to the conical design, the free space around the end cap has at least the same diameter as the port and in addition, the grit structure of the holding part of the end cap allows water to flow through.

The pressure drop is reduced by each vessel, because of the entire stream is reduced by each vessel until the final feed of 8.21 m^3/h on the last vessel in the line.

This calculation depends directly on the port size and the given hydraulic parameters and may vary from application to application.

The more advanced design approach is of 4 inch ports but the port diameter selection is a question, which has to be discussed by considering other parameters as well.

5. Conclusions

(a) The design of multiple port vessels cuts 50% of the stainless steel piping costs while keeping vessels costs at the same price level (may slightly change from supplier to supplier).

(b) Multiple port solutions needs smaller foot print and space, especially in containerized solutions.

(c) Maintenance and repair works are faster and re-start step is safer and shorter as no piping dismantling and re-assembling work is required.

(d) By leaving out the manifold on the rack, the corrosion impact is extensively reduced.

(e) By using a multiple port design, the pressure loss, created by manifold and piping is at least three times higher in case of an end port vessel system. Multiple ports design can save up to ten times on energy cost.

(f) Operators should consider operating expense as well as capital expense.