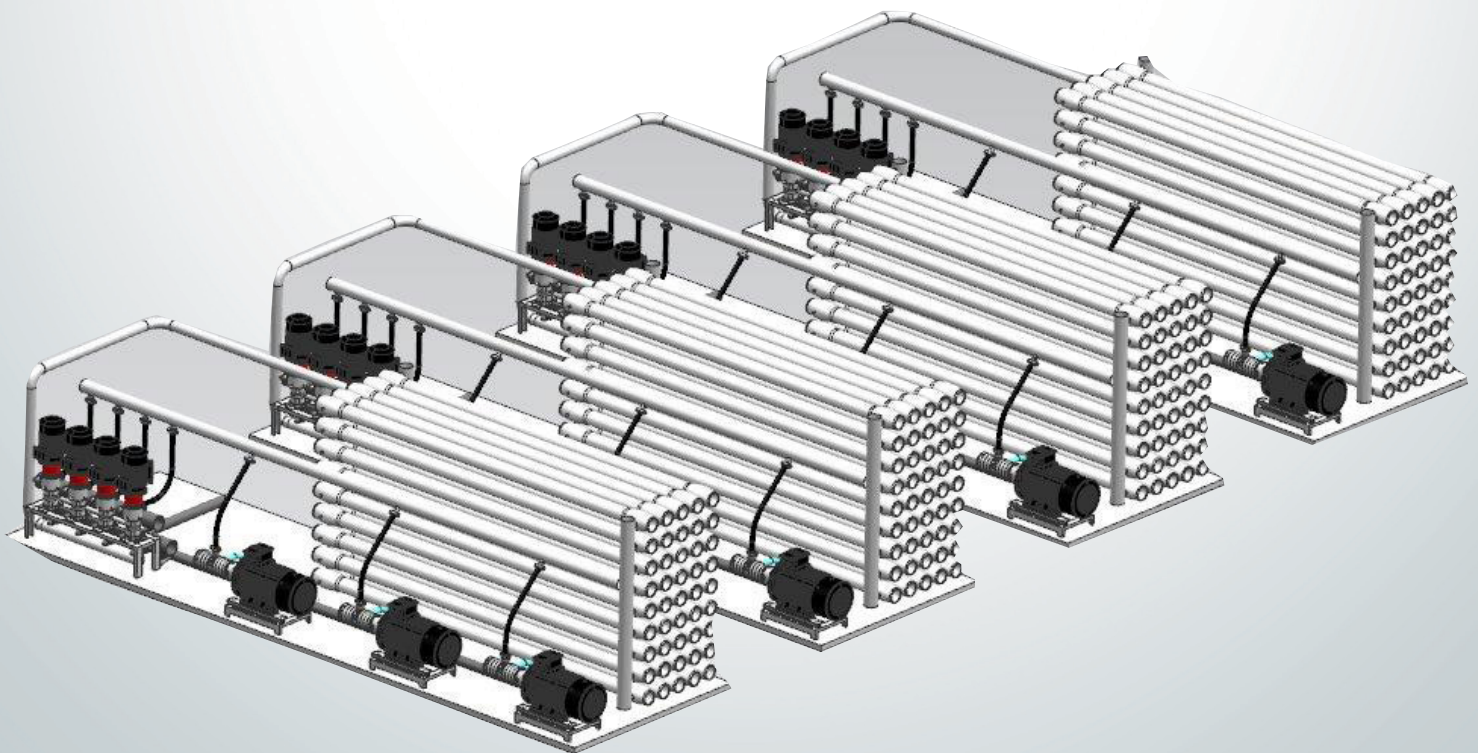


Design Guide

# Parallel coupled APP pumps and iSave® energy recovery devices



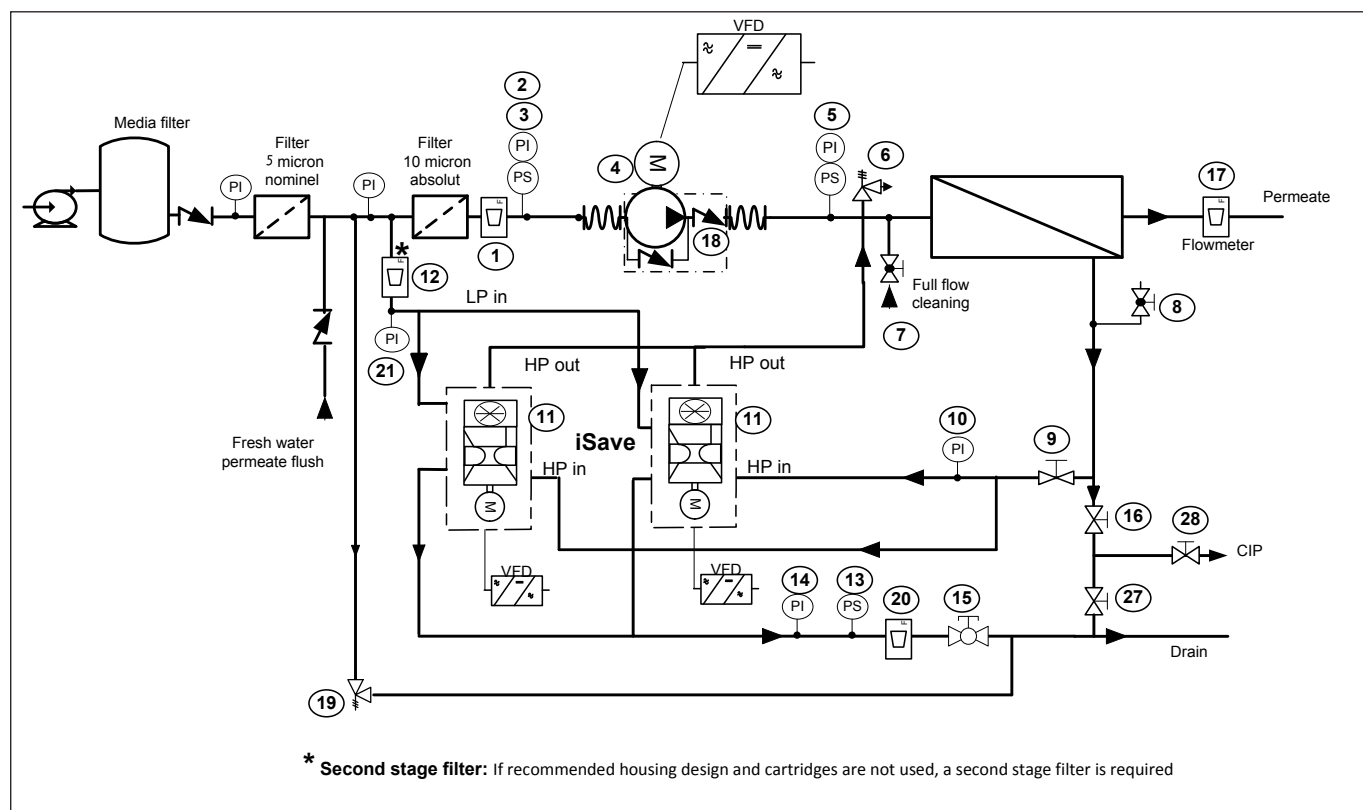
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## 2.1 P&ID explanation



The 10 micron, absolute **High-end** filtration, protect the pumps against debris. We strongly recommend that you always use precision depth filter cartridges rated 10µm abs.  $\beta_{10} \geq 5000$ .

The 5 micron nominal **High-end** filtration protect the iSaves® against debris. A true graded density, melt-blown depth filter cartridge rated at 5 µm is therefore recommended.

- Experience shows that a high amount of debris typically occur at initial start-up of the plant and after a change of filters.
- If recommended housing design and cartridges are not used, a second stage filter is required.

Flowmeter (2) in the inlet of common inlet manifold enable to monitor the total pump flow.

Flowmeter (12) in the common inlet of the iSaves® enable to balance the flow with the high pressure side.

Flowmeter (20) in the common brine outlet of the iSaves® enable to evaluate if the iSaves® have internal leak.

Transducer (3), in the common inlet manifold enable to monitor the inlet pressure. Pressure switch enable to evaluate a go/no go only for the inlet pressure Also see multiple-pump manifold design chapter 3.2.

Pressure switch (13) on common outlet of the iSaves® enable to monitor the outlet pressure.

HP non-return valve (18) protects pump against:

- HP back-flow at power cut-off.
- HP back-flow at sequence pump start.

HP relief valve (6) protects the system against pressure overload.

LP relief valve (19) protects the system against pressure overload. Especially when the system is applied to water hammering or if the valve (15) by accident is closed.

Valve (19) can only reduce pressure peaks from water hammering, in the pump inlet, if the valve is placed very close to inlet of the pumps.

Variable frequency drive (VFD) control has the purpose of:

- Controlling the pump or iSave® flow.
- Slowly ramp up and down the speed.
- Protect pump, iSave® and motor against overload.
- Monitoring changes in torque or Amps.

### 3. Manifold design

#### 3.1 Multiple-iSave® manifold design

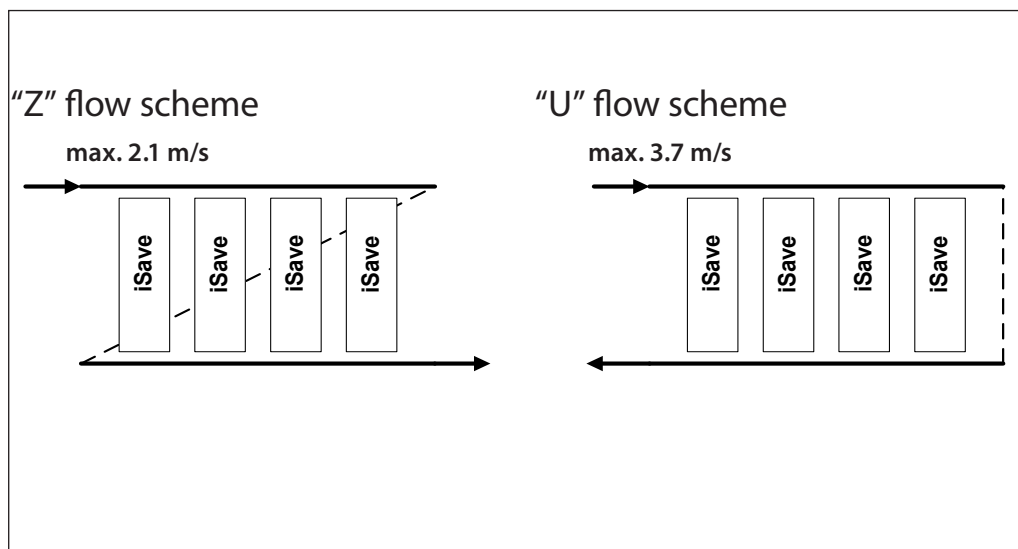
The purpose of the manifold is to distribute the flow to each iSave®.

- Without generating cavitation, erosion and air bubbles in the water.
- With minimum pressure drop.
- Assuring equal pressure into each iSave® inlet port.

Each iSave® has a HP circulation pump included in the design. This means:

- The flow through the HP side of the iSave® is controlled by the HP circulation pump. This means that equal pressure drop across each iSave® is not critical. The velocity in the HP manifolds may be as high as 5 m/s.

- The flow through the LP side of the iSave® is controlled by the pressure difference between  $LP_{feed}$  and  $LP_{out}$ . This means that the pressure drop across each iSave® is critical to assure equal flow distribution.
- With "Z" flow scheme, flow enters on one side of the array and leaves on the other.
- With "U" scheme, flow enters and leaves the array from the same side. Based on same diameter calculations, a "U" flow array always provides more even flow distribution among the iSave® units than a "Z" array.
- Market experience shows that inlet velocity is limited to less than 3.7 m/s for a "U" and less than 2.1 m/s for a "Z" flow scheme.



#### Manifold alignment and end load

Typical, manifold for multiple iSaves® are made in hard piping, using flexible couplings as connection to the iSave® discharge and inlet.

Experience in the market shows that precise welding of a steel manifold with multiple connections is difficult. The individual position of the manifold connections may exceed the flexibility of a single flexible coupling.

To reduce stress on the iSave® discharge and inlet it is preferred to use flexible hoses or a minimum of 2 flexible couplings combined on the same pipe connecting to each iSave® discharge and inlet.

- Do not use the iSave® discharge or inlet connectors as support for pipes. The pipes must have separate support.
- Do not force any misaligned pipes to connect to the iSave® discharge or inlet.

Follow instruction from flexible coupling supplier or see Design Guide 180R9367 Piping connections.

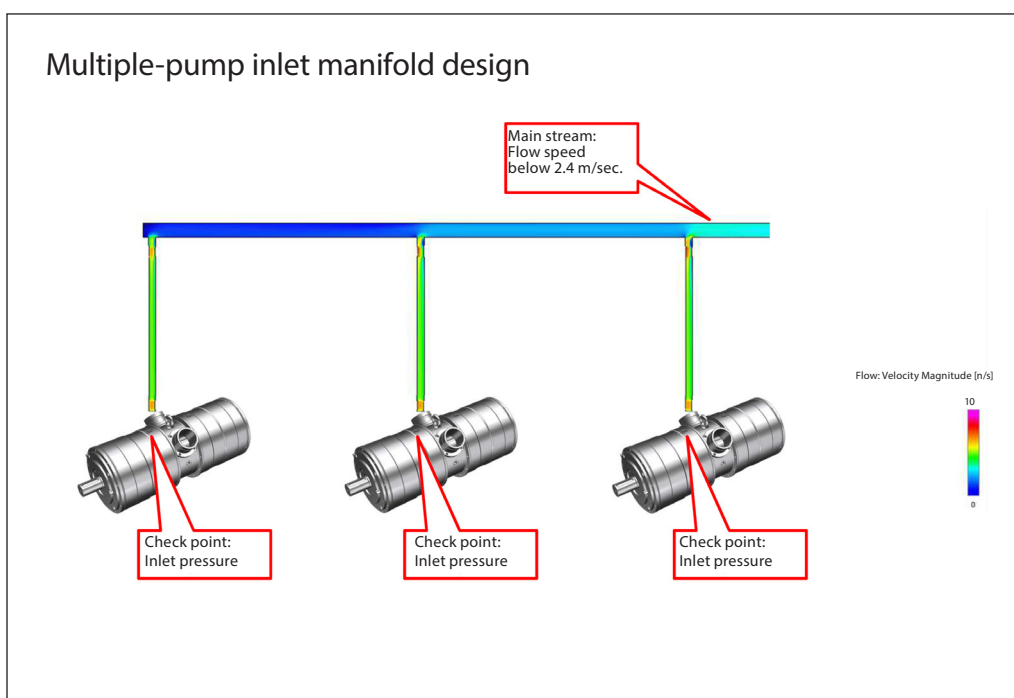
### 3.2 Multiple-pump inlet manifold design

The purpose of the manifold is to distribute the flow to each pump.

- Without generating cavitation, erosion and air bubbles in the water.
- With minimum pressure drop.
- Assuring equal pressure into each pump inlet port.

Here you see a few guidelines to assure a proper manifold design.

- The Hydraulic Institute publishes ANSI/HI 9.8 - 1998 Pump Intake Design, which provides information and design recommendations for suction piping. "The ideal flow entering the pump inlet should be, steady, and free from swirl and entrained air."
- The suction piping should be designed such that it is simple with gentle transitions in changing pipe sizes. Transitions resulting in flow deceleration at pump shall not be used.
- The maximum recommended velocity in the suction piping is 2.4 m/sec. Velocities may be increased at the pump suction flange by the use of a gradual reducer.
- To avoid preswirl in the pump inlet: A straight length of pipe of an equivalent length of five times the pump inlet (5D) or a hose should be installed before any filling into the pump.
- If inlet pressure transmitter is not positioned close to the pump inlet the transmitter pressure setting must assure correct pressure at the individual pump inlet.



#### 4. Starting multiple pumps and iSaves® in parallel

##### 4.1 Starting multiple iSaves®

There are in principal two ways to start the iSaves®.

- Slowly ramp up all the iSaves® at the same time
- Slowly ramp up one by one.

Starting sequence – one by one:

1. Start the LP feed pump.
2. Bleed air from high pressure piping (8).
3. When inlet pressure (3) is OK:
  - a. Start iSave® #1.
  - b. After 5 seconds start iSave® #2.
  - c. In a sequence of 5 seconds start the remaining iSaves®.

Comments:

- (#) refer to P&ID on page 3.
- Ramp up time on iSaves® is set between 3 to 15 sec. according to IOM.
- By starting up the iSaves® in above sequence, the total starting current from the grid is reduced to a minimum.
- The VFD has to be able to deliver constant torque.
- Also see IOM for iSaves®.

Starting sequence - All iSaves® at the same time:

1. Start the LP feed pump.
2. Bleed air from high pressure piping (8).
3. When inlet pressure (3) is OK:
  - Start all iSaves® at the same time.

Comments:

- Ramp up time on iSaves® is set between 3 to 15 sec. according to IOM.
- The VFD has to be able to deliver constant torque.
- Also see IOM for iSaves®.

##### 4.2 Starting multiple pumps

###### 4.2.1 Considerations to be taken

Multiple APP pumps in parallel in a SWRO are commonly used.

There are some considerations to be taken:

- Starting torque on each pump when starting one by one.
- Acceptable current-draw from the grid by starting multiple pumps up at the same time.
- Acceptable pressure build-up on RO-membranes.<sup>1)</sup>

There are in principal five ways to start the pumps:

- Ramp up one by one to full speed.
- Two-step ramp up.
- Ramp up all the pumps at the same time.
- Direct On Line (DOL) start.
- Combined ramp up and DOL start.

<sup>1)</sup> The guideline from membrane manufacture:

- LG NanoH2O: Have no guideline.
- DOW chemical: Pressure rise should be about 1 bar/sec.

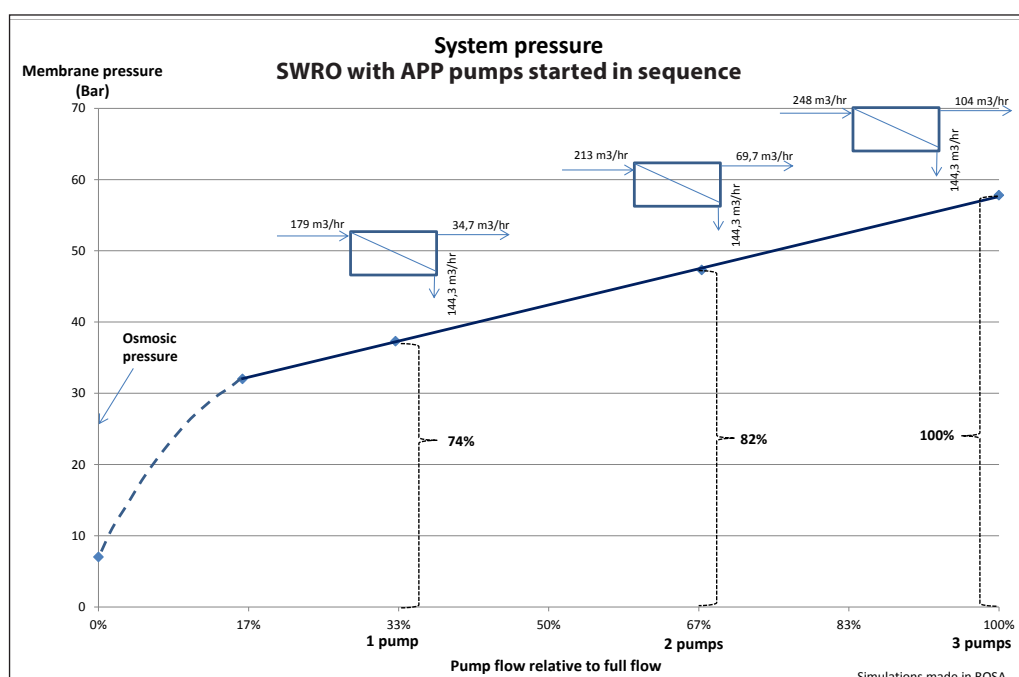
Notice:

- All APP pumps can be started DOL up against zero discharge pressure.
- The most APP pumps can be started DOL up against max. allowable operating pressure.
- Consult Danfoss about starting DOL up against pressure.
- To control flow at least one APP pump should be equipped with VFD control.

#### 4.2.2 Pressure build-up on the RO membranes

Example: Assuming 3 pumps in parallel are started up to full speed one by one.

- First pump generates about 74% of the final pressure of 58 bar but only 1/3 of the final flow.
- Second pump adds another 10 bar.
- The final pump adds another 10 bar.



#### 4.2.3 Starting sequence - One by one to full speed:

1. Start the LP feed pump.
2. Bleed air from all high pressure piping (8).
3. Start the iSave®.
4. When inlet pressure (3) is OK:
  - Start pump #1.
  - After 10 seconds start pump #2.
  - In a sequence of 10 seconds start the remaining pumps.

#### Comments:

- (#) refer to P&ID on page 3.
- Ramp up time on HP pumps is set between 10 to 60 sec. or according to the membrane manufacturers recommendations.
- The VFD has to be able to deliver constant torque. The VFD may set limitations on how fast you can ramp up the pumps.
- Starting torque and current draw from the motor must be calculated in order to make correct VFD limit settings.
- Also see IOM for APP pumps.

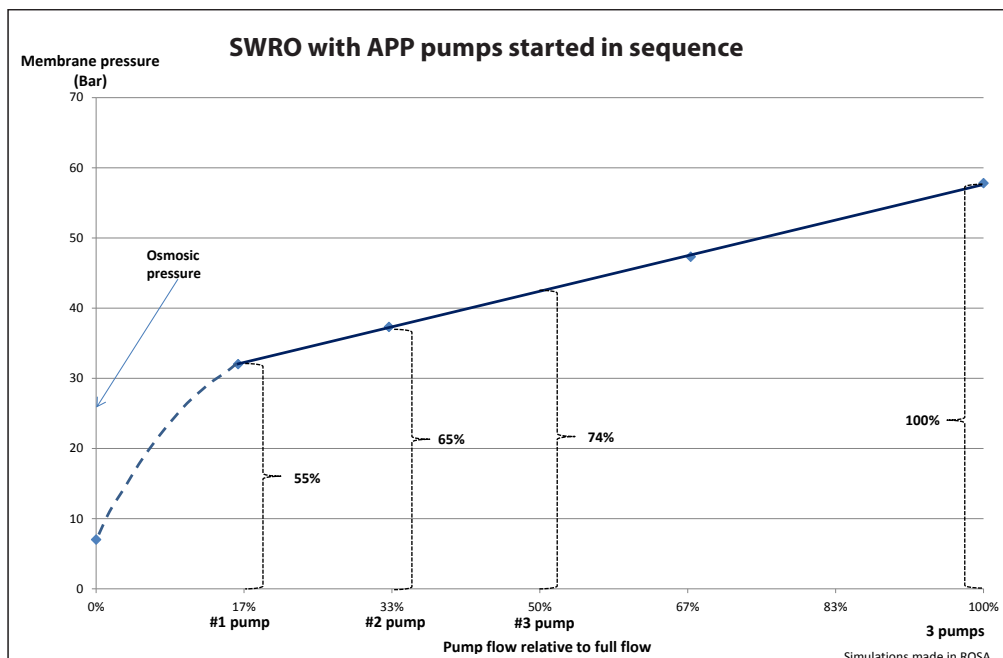


#### 4.2.4 Starting sequence - Two step ramp up

Example: Assuming 3 pumps in parallel started up to minimum speed one by one.

- First pump generates 55% of the final pressure of 58 bar - but only 17% of the final flow.

- Second pump adds another 6 bar.
- The final pump adds another 6 bar.
- Finally all 3 pumps are ramped up to full speed.



Starting sequence:

1. Start the LP feed pump.
2. Bleed air from all high pressure piping (8).
3. Start the iSave®.
4. When inlet pressure (3) is OK:
  - Start pump #1 and ramp up to 700 rpm.
  - Start pump #2 and ramp up to 700 rpm.
  - Start pump #3 and ramp up to 700 rpm.
  - Ramp up all three pumps to final speed.

- By starting up the pumps in the above sequence the total starting current from the grid is reduced to a minimum.
- The VFD has to be able to deliver constant torque. The VFD may set limitations on how fast you can ramp up the pumps.
- Starting torque and current draw from the motor must be calculated in order to make correct VFD limit settings.
- Also see IOM for APP pumps.

Comments

- (#) refer to P&ID on page 3.
- Ramp up time on HP pumps is set between 10 to 60 sec. or according to the membrane manufacturers recommendations.

#### 4.2.5 Starting sequence - All pumps at the same time

1. Start the LP feed pump.
2. Bleed air from high pressure piping (8).
3. Start the iSave®.
4. When the inlet pressure (3) is OK:
  - Start all pumps at the same time.

Comments:

- (#) refer to P&ID on page 3.
- Ramp up time is set between 10 to 60 sec. according to the membrane manufacturers recommendations.
- By starting up the pumps in the above sequence the starting current per motor is reduced to a minimum but the total current draw from the grid is the maximum.
- The VFD has to be able to deliver constant torque. The VFD may set limitations on how fast you can ramp up the pumps.

#### 4.2.6 Starting sequence - Direct On Line (DOL) start

Starting all the pumps DOL one by one in sequence will provide the pressure on the membranes described in 4.2.2.

1. Start the LP feed pump.
2. Bleed air from high-pressure piping (8).
3. Start the iSave®.
4. When the inlet pressure (3) is OK:
  - Start the pumps one by one in sequence.

Comments:

- (#) refer to P&ID on page 3.
- By starting up the pumps in above sequence the starting current per motor is maximum and current draw from the grid is the maximum.

#### 4.2.7 Starting sequence – Combined ramp up and DOL start

To be able to control the total flow to the membranes, at least one pump must have VFD control on the electric motor.

To assure a soft pressure build up on the membranes and minimum power draw on the pumps starting DOL, the starting sequence should be:

1. Start the LP feed pump.
2. Bleed air from all high pressure piping (8).
3. Start the iSave®.
4. When inlet pressure (3) is OK:
  - Start pump #1 and ramp up to 700 rpm.
  - Start pump #2 DOL.
  - Start pump #3 DOL.
  - Ramp up pump #1 to final speed.

Comments:

- (#) refer to P&ID on page 3.
- Ramp up time on HP pumps is set between 10 to 60 sec. or according to the membrane manufacturer's recommendations.
- The VFD has to be able to deliver constant torque. The VFD may set limitations on how fast you can ramp up the pumps.
- Starting torque and current draw from the motor must be calculated in order to make correct VFD limit settings.
- Also see IOM for APP pumps.

#### 4.2.8 Stopping sequence

The main focus when stopping APP pumps in parallel is to prevent water-hammering in the inlet of the pumps.  
It is recommended to slowly ramp down the pumps. Either one by one or all at the same time.

Be aware of, if the pump is controlled by a soft starter, ramping down the speed cannot be done gently. The soft starter is ramping down the power to the motor and not the rpm.  
As the APP pump needs constant torque the pump will stop immediately when the power input becomes too low and potentially generates water hammer.

## 5. Water hammering

Water hammer is a pressure surge or wave caused when a fluid in motion is forced to stop or change direction suddenly. A water hammer commonly occurs when a valve closes suddenly at an end of a pipeline system or a pump stops promptly, and a pressure wave propagates in the pipe and potentially damage the pumps or iSaves®.

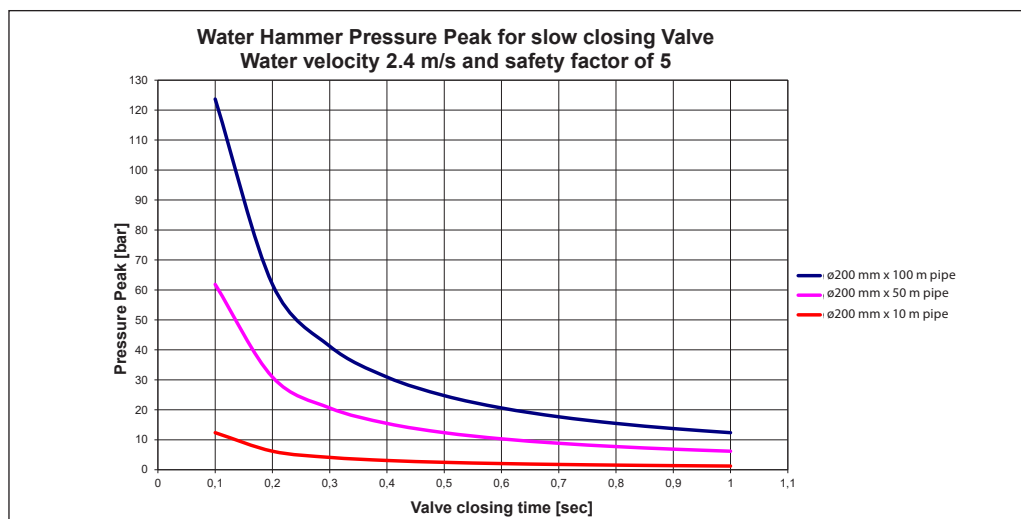
This pressure wave can cause major problems, ranging from noise and vibrations to pipe/equipment collapse.

Water hammering will typically result in very high pressure peaks in the inlet of the pump and, hence also inside the pump.

These pressure peaks can be very high and may cause damage to the pump. Below is an **example** on water hammering in piping system. The pressure peak will be added on the existing static inlet pressure in the piping and will typically exceed the pump inlet pressure limitations.

If multiple trains are connected to a common feed line, any change in a train may interact on feed flow and feed pressure in another train – causing water hammering. The pressure peaks may also exceed the maximum operating pressure of the LP feed pump.

It is the OEM's responsibility to design the RO-system in such a way that the maximum permissible inlet pressure at the pump is not exceeded.



## 6. Sizing of electric motors and VFD

### 6.1 Sizing of electric motors and VFD for APP pump and iSave®

The APP pump and iSave® are positive displacement machines:

- The torque is proportional to the difference between inlet pressure and discharge pressure. This means that e.g. doubling the differential pressure requires double torque.
- At same differential pressure, the pump or iSave® requires same torque over the whole range of rpm - **CONSTANT TORQUE**.
- If the pump or iSave® starts against an existing pressure, the pump torque applies immediately as the pump starts to rotate and correspond to the existing differential pressure.

- The APP pump and iSave® have water lubricated bearings. These bearings generate a stick-slip torque at startup.
- To size the electric motor and VFD the starting torque generated by both stick-slip and discharge pressure must be taking into calculations - See next page.
- Both the electric motor and VFD must have sufficient power to start the Pump or iSave®. See IOM for APP pump and iSave®.
- **VFD needs to be able to deliver COSTANT TORQUE and power enough to start the pump or iSave®.**
- It is recommended that both the electric motor and VFD have a minimum 10% over-capacity on the ongoing operation torque.

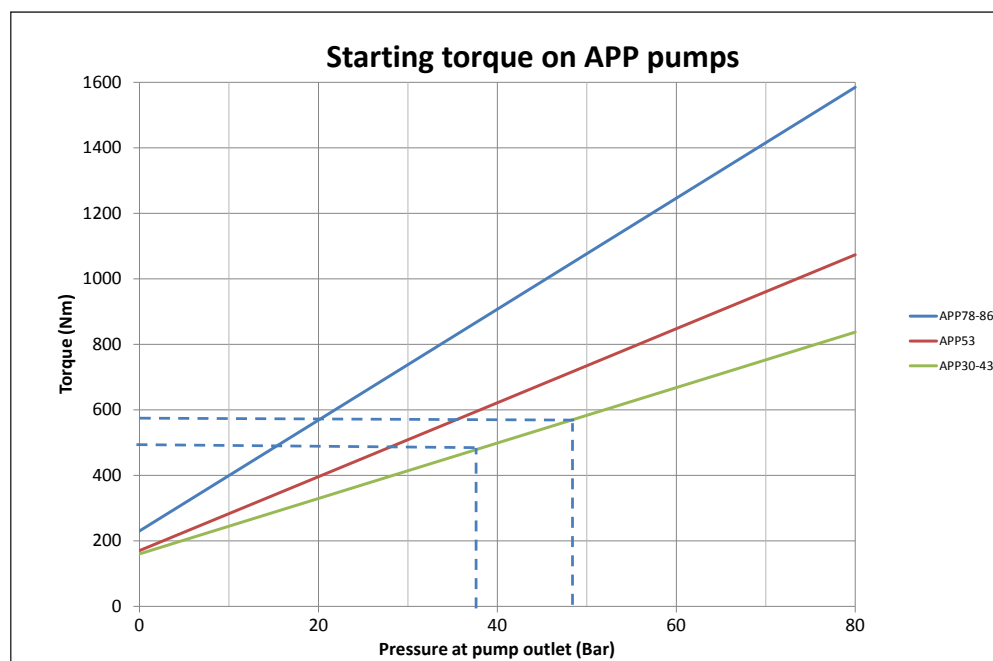
### 6.2 Maximum starting torque for iSave®



### 6.3 Starting torque for APP pumps

Example: Starting sequence with three APP 43 pumps in parallel.

- First pump does not start against pressure. Starting torque is about 160 Nm.
- Second pump sees 38 bar starting pressure. Starting torque is about 480 NM
- Third pump sees 47 bar starting pressure. Starting torque is about 680 NM.



All numbers are guidelines only and should be calculated for each project.

## 7. APP pump and iSave® protection

Both the iSave® and the electric motor must be protected against overload..

### 7.1 Motor protection

Protecting the electric motor can be done with a thermal relay, electronic relay, PTC sensor inside the motor or a VFD.

- One VFD on each electric motor is always capable of protecting the motor and is the recommended solution.
- One VFD with multiple motors: The VFD is typically not able to protect the individual motor.
- Thermal relay: Danfoss Power Electronics has the experience, that a thermal relay of the bimetal type works well with a VFD.

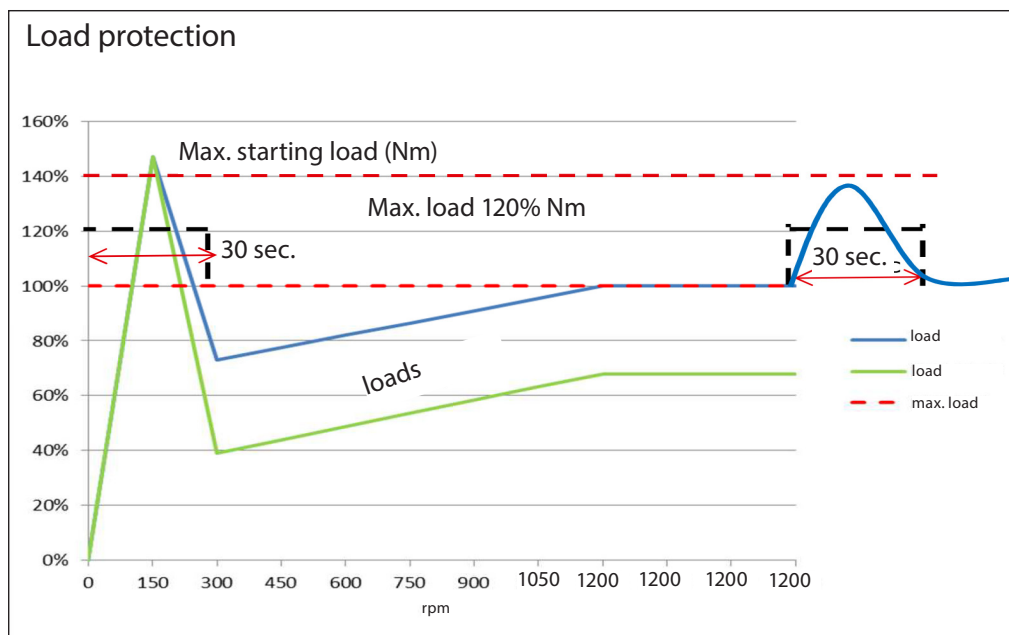
- Electronic relay: Because of the harmonic voltage from the VFD, using an electronic relay together with a VFD is not recommended.
- PTC sensor: Assure that the PTC sensor inside the motor can handle the harmonic voltage from the VFD.

### 7.2 iSave® and APP pump protection

When protecting the pump and iSave® against overload both the maximum torque and maximum pressure must be taken into account.

- Maximum allowable operating pressure according to IOM.
- Maximum allowable operating torque according to IOM. See principle requirements of load protection below.

- Using a thermal relay of the bimetal type: Calculating the current drawn by the electric motor according to torque is possible. As the response time is much too slow, a thermal relay is many times NOT capable of protecting the APP pump or iSave®.
- Using a VFD with a single motor: Follow the guideline in the IOM.



Start up (Control of stick-slip):

- Ramp up speed from 0 to set-point.
- The starting torque must not exceed 140% of max allowable working torque according to IOM.

Ongoing operating:

- Continuously the torque must not exceed 120% of max. allowable working torque for more than 30 sec.
- The torque can periodically go up to 140% of max. allowable working torque as long as the time is no longer than 5 sec.

### 7.3 Multiple VFD versa single VFD control

Multiple motors operation is a common application.

Using one VFD to control these multiple motors provides a host of advantages as summarized below.

- Money is saved because one high horsepower rated VFD is less expensive than multiple low horsepower VFDs. Each VFD requires its own circuit protection, so using one VFD reduces cost in this area as well.

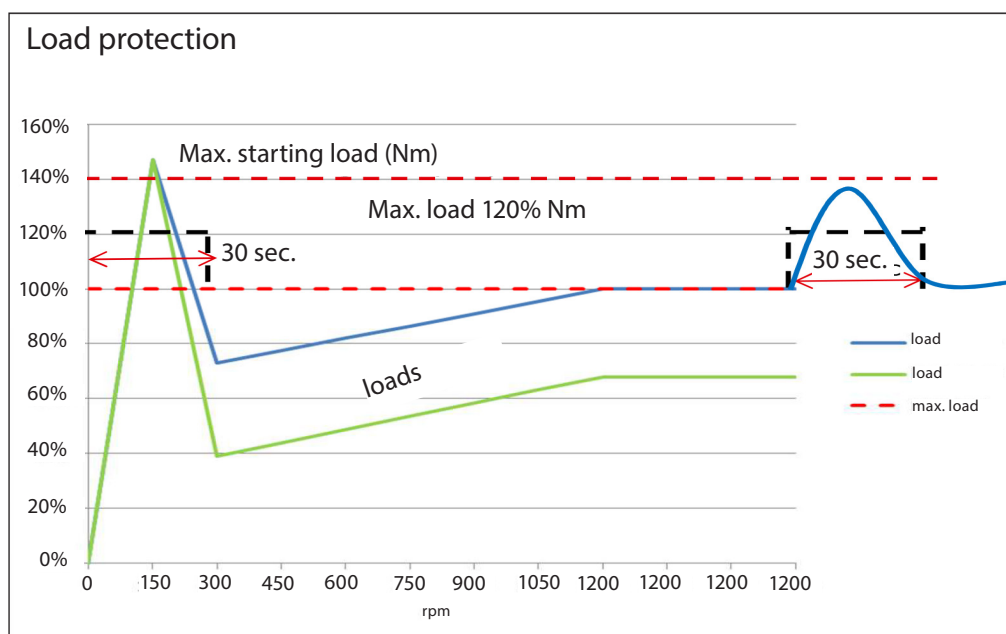
- The VFD enclosure can be smaller because one large VFD requires less cabinet space than multiple smaller units. This saves space and money, complexity and design costs.
- Maintenance time and costs are cut because only one VFD has to be serviced as opposed to multiple smaller VFDs
- The overall control system also becomes much simpler. Instead of connecting many VFDs to the main controller, usually a PLC, and synchronizing their operations; only one connection is required. When programming the PLC, only one VFD speed control loop needs to be configured, instead of multiple instances.

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- The VFD enclosure can be smaller because one large VFD requires less cabinet space than multiple smaller units. This saves space and money, complexity and design costs.
- Maintenance time and costs are cut because only one VFD has to be serviced as opposed to multiple smaller VFDs
- The overall control system also becomes much simpler. Instead of connecting many VFDs to the main controller, usually a PLC, and synchronizing their operations; only one connection is required. When programming the PLC, only one VFD speed control loop needs to be configured, instead of multiple instances.

## 8.2 Flow control - iSaves®

### 8.2.1 High pressure circulation flow

The vane pump in the iSave® is a positive displacement pump. This means:

- The iSave® HP-flow is proportional to iSave® speed. This means that e.g. adding 10% more speed gives 10% more flow – regardless of the differential pressure of the iSave®.
- The H-Q characteristic is almost vertical. Q values for each iSave® are added, giving the combined flow.

### 8.2.2 LP flushing flow

The flow through the LP side on the iSave® is controlled by the pressure difference between  $LP_{in}$  and  $LP_{out}$ . If the pressure drops are equal the flows are equal.

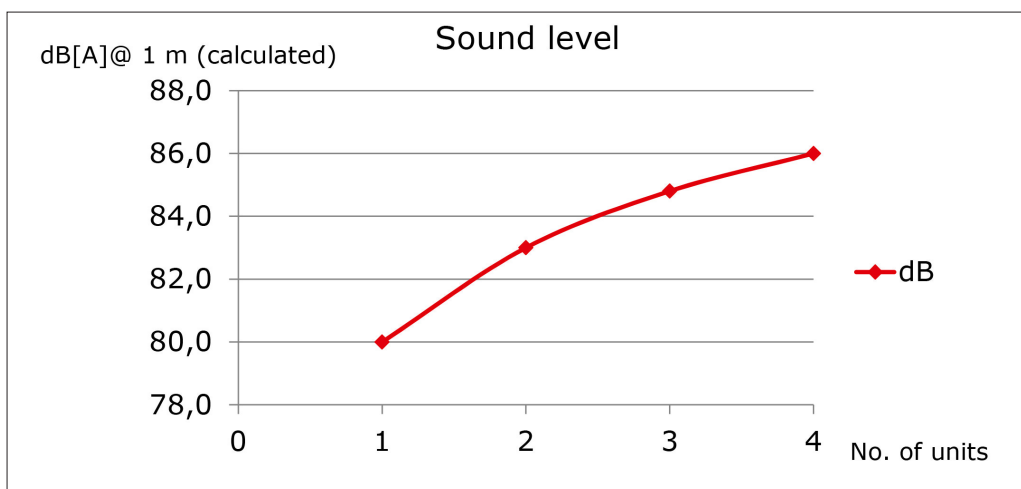
- The pressure difference changes with the speed of the iSave®.
- When running multiple iSaves® in parallel it is recommended that all iSaves® are running at the same speed.

## 9. Noise level

### 9.1 Noise level with multiple sources

If multiple acoustic sources are running next by each other the total sound level (pressure) of all sources is higher than the sound level for each source.

Example: Below graph shows the combined sound level for multiple iSaves® or pumps each making 85 dB.



## 10. Disclaimer

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