Volume 2 : Edition 6 – Reverse Osmosis Design from Software and Pre-treatment Significance Jun 30, 2022

Dear Water Warriors,

TDS transfer from water (Feed) into water (Reject) is an interesting water treatment technology, where we concentrate the impurities in small quantity of water making rest of the water free of TDS.

Reverse Osmosis is in in every process scheme these days and we use software to design and optimize the right RO system.

This issue of '**Waughter**', we requested SSr to design a plant for us and explain the way he thinks.

Let's design together.

Nidhi Jain – Civil Engineer

Down the Memory Lane.. IMS Design

Was the First software Sanjeev Srivastava our Lead Technology ever used. Over the years many other software and Knowledge Partners also contributed to improving design thinking: Dupont, Dow, Suez, Toray, CSM, these names became synonym to Reverse Osmosis Know how and all are good.

He still remembers his first design, that was done through complicated Integral Calculus method manually without software. Unfortunately, he does not have hand notes of that and has forgotten manual calculations now.

Defining the Input Required for RO Design?

In order to design a good RO system, one must have all the data mentioned in below table:

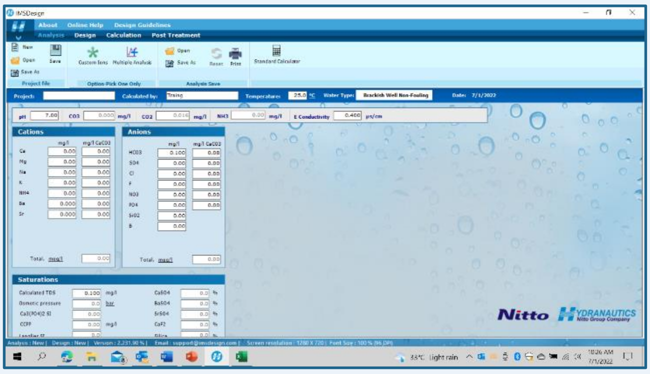
Sr No	Description	Unit	Value
1.01	Treated Water Quantity	m^3/d	600
1.02	RO Operating hours	h	24
1.03	Permeate Flow Rate	m^3/h	25
1.04	Feed Water Source		Borewell
	Feed Water Quality		
2.01	TDS	mg/l	2310
2.02	Conductivity	µS/Cm	3513
2.03	pH	-	7.8
2.04	TSS	mg/l	12
2.05	Turbidity	mg/l	6
2.06	Hardness	mg/l as CaCO3	250
2.07	Ca Hardness	mg/l as CaCO3	150
2.08	Mg Hardness	mg/l as CaCO3	100
2.09	Na+K	mg/l	By Calculation
2.10	Chloride	mg/l as Cl	700
2.11	Sulphate	mg/l as SO4	135
2.12	Nitrate	mg/l as NO3	12
2.13	M-Alkalinity	mg/l as CaCO3	210
2.14	P-Alkalinity	mg/l as CaCO3	0
2.15	Phosphate	mg/l as PO4	1
2.16	Boron	mg/l as B	0.1
2.17	Reactive Silica	mg/l as SiO2	23
2.18	F,NH4,Ba,Sr etc	mg/l as Such	If Available
	Treated Water Quality		
3.01	TDS	mg/l	100
3.02	Hardness	mg/l as CaCO3	10
3.03	Reactive Silica	mg/l as SiO2	1

Before you design.. with us together!

For the given data if you wish to design together for better learning. Please:

1. Read Waughter Volume 1 Edition 7
2. Download IMS Design on your computer

Once down you will reach the WINDOW as shown below



Now follow magazine and software together.

PureCODe™

COD REDUCTION MEDIA

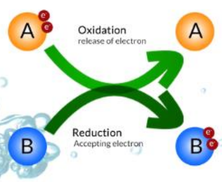
PureCODe is an absorbent media for the **lowering of recalcitrant COD** (Fine polishing of tough to treat COD) which subsequently helps in meeting stringent discharge norms in various industries such as textiles, chemicals, pharmaceuticals, etc. **This media is also regenerable on-site.**

PureCODe specialty media - helps in **lowering COD significantly** to meet stringent discharge norms and **recycle maximum amout of water.**

WORKING PRINCIPLES OF THE MEDIA:

ABSORPTION
(INSIDE THE MEDIA)

ADSORPTION
(SURFACE OF MEDIA)



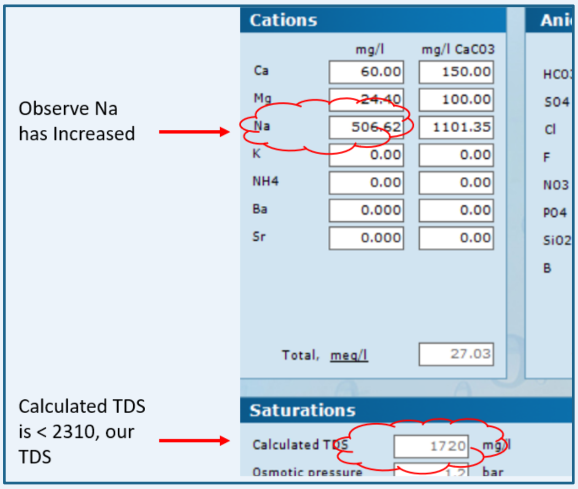
REDOX
(OXIDATION REDUCTION)

www.purewaterent.net
+91 9820173817
info@purewaterent.net
rahul@purewaterent.net

Feed Data into Software

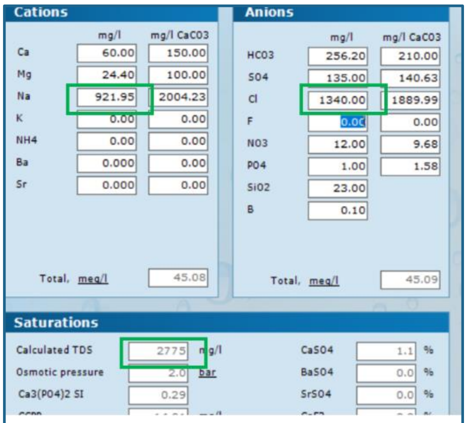
When we enter the data available to us, the software suggested see below: (Warning! 81% Difference in Ions). This is because Na + K is not yet entered.

We need to Click on Na to adjust the same.



For TDS balance designer need to increase the Cl Value as well as Na value to reach design TDS of 2310 mg/l.

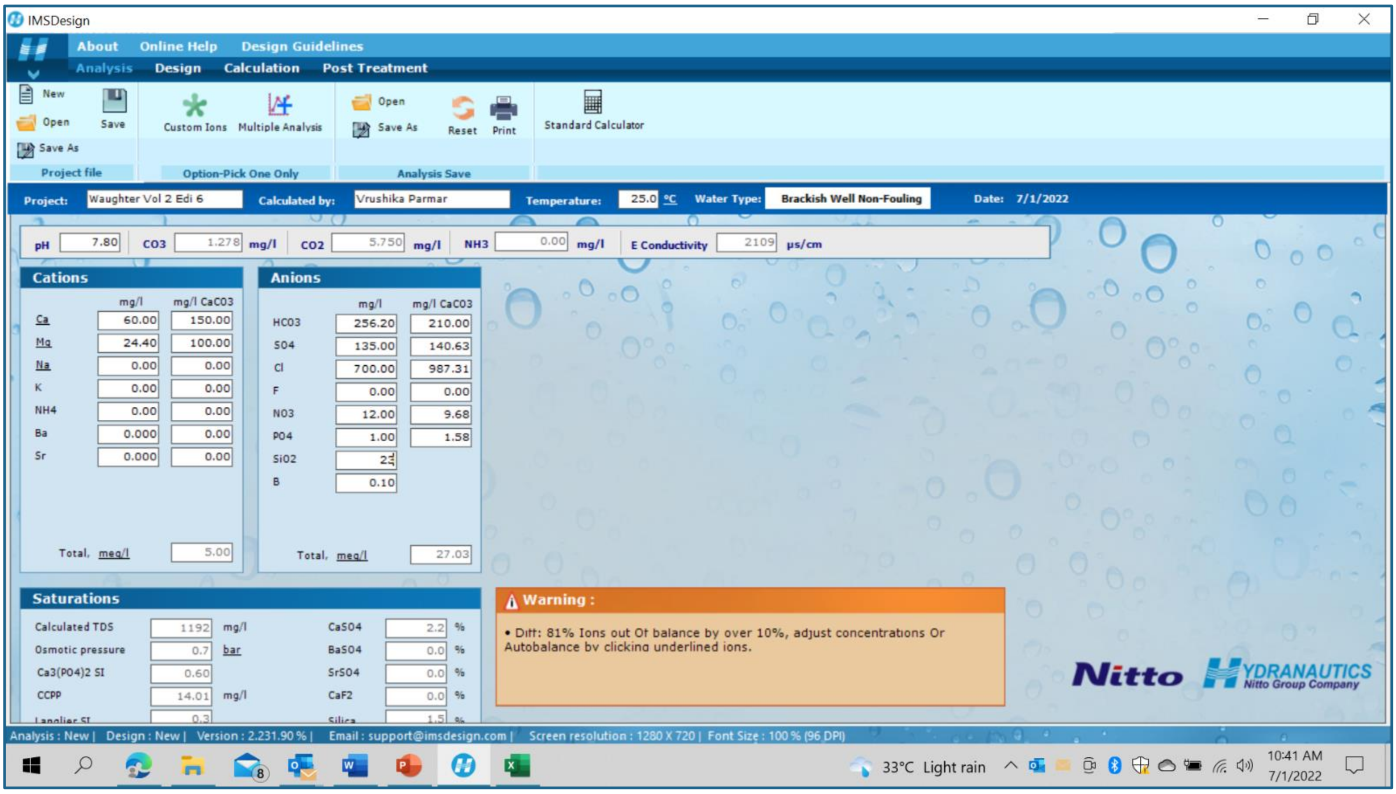
It is better to have 20% extra margin wrt to TDS. Remember Osmotic Pressure is directly proportional to the Feed TDS and thus 20% over design over design value is a good practice in designing RO system.



Cl and Na adjustment for TDS 2772 mg/l

Press Save As above Analysis Save and Continue...

Temperature is an important no in design (25 deg C), at higher temperature Feed Pressure reduced and quality deteriorates and vice versa.



Design the RO system?

For a proper design we have several steps that need attention, let's move 1 by 1 to all steps and understand the significance of each.

Step 1

Understand Feed Water. For TDS up-to 8000 mg/l safely take Brackish Water RO membranes and above 22000 mg/l Sea Water RO membranes.

Selection of membrane also depends upon treated water quality. For stringent quality, you may have to select High Rejection membrane. (Feed Already Entered in previous Page)

Step 2

Define Recovery. One would like to go for highest recovery. High Recovery means less volume on Reject or more concentrated Reject. That means:

a. Higher Osmotic Pressure barrier and hence high Feed Pressure.
b. Solubility Concerns of Ca*HCO_3 and SiO_2
c. Long Train of RO elements, remember 1st element recovers max 15% and next 15% from the balance 85% and so on…

The point c above defines no of stages. Since we have 6 Element long Pressure Tube, beyond 6 Serial no of stages increase. Let's design for 75% Recovery, i.e. 2 stages.

System Recovery	No of Elements in Series	No of Stages
40-60	6	1
60-80	12	2
80-94	18	3

Step 3

Element Diameter. Membranes are available in dia 2.5", 4" & 8". Generally, for flow rate < 200 lph we use 2.5" element and flow > 3 m^3/h we use 8" element. In between it's better to use 4" element.

For special reasons or if low recovery is acceptable e.g. RO plants on boats, designer may use 8" membrane even at lower flow rates.

Step 4

Flux Selection. Flux means productivity of membrane per m^2 of its surface used for Filtration of clean water. Naturally it depends upon the amount (concentration) of unwanted materials. SDI usually is the measure of presence of impurities before the water is Fed to Reverse osmosis element. A sample of Flux guidelines is attached (All Membrane Suppliers issue such guidelines in their software):

Table 3.4 Design guidelines for 8-inch FILMTEC elements in water treatment applications

Feed source			RO Permeate	Well Water	Surface Supply		Wastewater (Filtered Municipal Effluent) MF[1]	Wastewater (Filtered Municipal Effluent) Conventional	Seawater Well or MF[1]	Seawater Open intake
Feed silt density index			SDI < 1	SDI < 3	SDI < 3	SDI < 5	SDI < 3	SDI < 5	SDI < 3	SDI < 5
Average system flux	gfd		21-25	16-20	13-17	12-16	10-14	8-12	8-12	7-10
	l/m²h		36-43	27-34	22-29	20-27	17-24	14-20	13-20	11-17
Maximum element recovery %			30	19	17	15	14	12	15	13
Active Membrane Area			**Maximum permeate flow rate, gpd (m^3/d)**							
320 ft² elements			9,000 (34)	7,500 (28)	6,500 (25)	5,900 (22)	5,300 (20)	4,700 (18)	6,700 (25)	6,100 (23)
365 ft² elements			10,000 (38)	8,300 (31)	7,200 (27)	6,500 (25)	5,900 (22)	5,200 (20)		
380 ft² elements			10,600 (40)	8,600 (33)	7,500 (28)	6,800 (26)	5,900 (22)	5,200 (20)	7,900 (30)	7,200 (27)
390 ft² elements			10,600 (40)	8,900 (34)	7,700 (29)	7,000 (26)	6,300 (24)	5,500 (21)		
400 ft² elements			11,000 (42)	9,100 (34)	7,900 (30)	7,200 (27)	6,400 (24)	5,700 (22)		
440 ft² elements			12,000 (45)	10,000 (38)	8,700 (33)	7,900 (30)	7,100 (27)	6,300 (24)		
Element type			**Minimum concentrate flow rate[2], gpm (m^3/h)**							
BW elements (365 ft²)			10 (2.3)	13 (3.0)	13 (3.0)	15 (3.4)	16 (3.6)	18 (4.1)		
BW elements (400 ft² and 440 ft²)			10 (2.3)	13 (3.0)	13 (3.0)	15 (3.4)	18 (4.1)	20 (4.6)		
NF elements			10 (2.3)	13 (3.0)	13 (3.0)	15 (3.4)	18 (4.1)	18 (4.1)		
Full-fit elements			25 (5.7)	25 (5.7)	25 (5.7)	25 (5.7)	25 (5.7)	25 (5.7)		
SW elements			10 (2.3)	13 (3.0)	13 (3.0)	15 (3.4)	16 (3.6)	18 (4.1)	13 (3.0)	15 (3.4)
Element type		**Active area ft² (m²)**	**Maximum feed flow rate[2], gpm (m^3/h)**							
BW elements		365 (33.9)	65 (15)	65 (15)	63 (14)	58 (13)	52 (12)	52 (12)		
BW or NF elements		400 (37.2)	75 (17)	75 (17)	73 (17)	67 (15)	61 (14)	61 (14)		
BW elements		440 (40.9)	75 (17)	75 (17)	73 (17)	67 (15)	61 (14)	61 (14)		
Full-fit elements		390 (36.2)	85 (19)	75 (17)	73 (17)	67 (15)	61 (14)	61 (14)		
SW elements		320 (29.7)	65 (15)	65 (15)	63 (14)	58 (13)	52 (12)	52 (12)	63 (14)	56 (13)
SW elements		380 (35.3)	72 (16)	72 (16)	70 (16)	64 (15)	58 (13)	58 (13)	70 (16)	62 (14)

[1] MF: Microfiltration - continuous filtration process using a membrane with pore size of <0.5 micron.

[2] The maximum recommended pressure drop across a single element is 15 psid (1bar) or 50 psid (3.5 bar) across multiple elements in a pressure vessel, whichever value is more limiting. We recommend designing at maximum of 80% (12 psid) for any element in a system.

Note: The limiting values listed above have been incorporated into the ROSA (Reverse Osmosis System Analysis) software. Designs of systems in excess of the guidelines results in a warning on the ROSA printout.

In our case let's take Borewell water treated with conventional sand filter and select the flux as 28 l/m^2.h (range 27 -34 l/m^2.h)

Step 5

Membrane Area Calculation. Since we have flow rate as 25 m^3/h and we have selected flux as 28 l/m^2.h, her membrane Area required for our design is:

Membrane Area = Flow ÷ Flux
= 25000 lph ÷ 28 l/m^2.h
= 892 m^2 = 9607 ft^2

So, our design shall have X Nos of membrane with Y ft^2 surface each membrane

and X.Y = 9607 ft^2

Step 6

Membrane Selection. In step 3 we understand 8" dia membrane is good for our design since flow rate is 25 m3/h.

Element type	
BW elements (365 ft²)	10
BW elements (400 ft² and 440 ft²)	10
NF elements	10
Full-fit elements	25
SW elements	10

Element type	Active area ft² (m²)	
BW elements	365 (33.9)	65
BW or NF elements	400 (37.2)	75
BW elements	440 (40.9)	75
Full-fit elements	390 (36.2)	85
SW elements	320 (29.7)	65
SW elements	380 (35.3)	72

[1] MF: Microfiltration - continuous filtration proc

[2] The maximum recommended pressure drop value is more limiting. We recommend desi

Note: The limiting values listed above have be guidelines results in a warning on the R

Close look of chart in Step 4 above suggests we have different elements with different active surface area. So let consider the membrane with Active Area of ~ 365 ft2

So our Nos of membranes required shall be

= 9607 ÷ 365 = 26.32
~ say 27

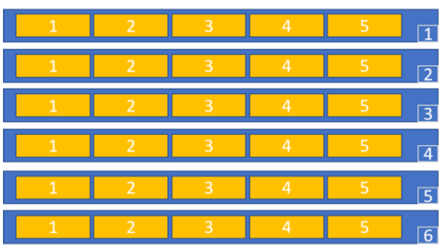
Step 7

RO Pressure Tubes. The 27 Nos membrane calculated above need to be put into pressure tubes. The standard length of the tubes are 1,2,3,4,5 & 6.

Further in Step 2 we understand the Nos of stage shall be 2. i.e. Reject of Stage 1 shall be Fed to Stage 2.

If we select 6 Element Pressure Tube, we will need 6*5 = 30 membranes to fill all pressure tubes. If we select 5 Element Tube then we will need 5*6 = 30 membranes to fill all pressure Tubes.

In short Total no of membranes used ÷ No of Elements in Tube shall be a whole number. Let's select the Pressure Tube length as 5 El Long, means 6 Pressure Tube. Like below:

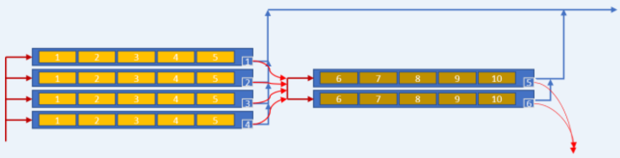


*6 * 5 = 30 membranes filled in 6 Pressure Tubes that are each 5 El long.*

Step 8

Staging Ratio. No of stages we selected depends upon recovery and for 75% we selected 2. The last stage shall always have ½ the element of previous stage. So for a two stage system:

No of membranes in last stage (2nd) = A
No of membranes in previous stage (1st) = 2A

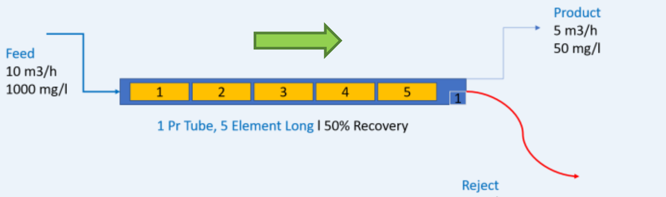


Thus 3A = 30 and A = 10. So our Staging would be as shown above. Here one can say that ~ 50% recovery is achieved in stage 1 and 50% of 50% balance that is ~ 25% is recovered is stage 2 making overall recovery as ~ 75%.

Final 25% is reject water that is removing TDS that has been rejected by membrane.

Step 9

For 9th step, we need to understand the word "Integral Calculations", Look at below Pressure Tube and understand what's happening when water is flowing:



a. Feed Flow is decreasing and becomes 5 m^3/h at end as some of it becomes permeate.
b. Osmotic Pressure keeps increasing as TDS becomes 1950 from starting 1000 mg/l
c. Since Feed Pressure say ~ 12 kg/Cm^2, will keep reducing, NDP (Nett Drive Pressure = Feed Pr – Osmotic Pr) will decrease.
d. Thus, the Permeate production shall decrease as we travel down the tube means 1st element will produce most of the permeate and last the least.
e. Bottom line: Flux is always reducing.

Step 10

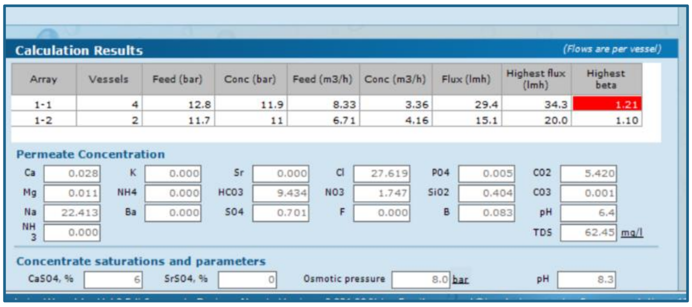
Software Use. The design obtained from above 9 steps is transported on a software to perform calculations and check if the guidelines for membrane use are violated. One must balance the flow (Flux) to ensure:

a. Lead Element flux is not higher than the limit set.
b. Brine leaving from last element should not be lower than defined value, else scaling/fouling. Minimum Sweep velocity to be maintained.
c. Make better use (Flux) of tail end elements
d. Many more reasons as we learn along

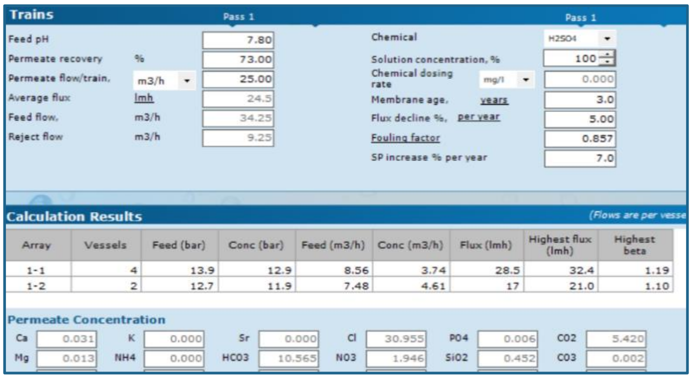
Our design as entered in software shall look as in below figures.

A. Press Run to check if design is OK, the calculations are performed and we have:

1. Beta High 1.21 marked in Red
2. TDS < 63 mg/l as per our design.

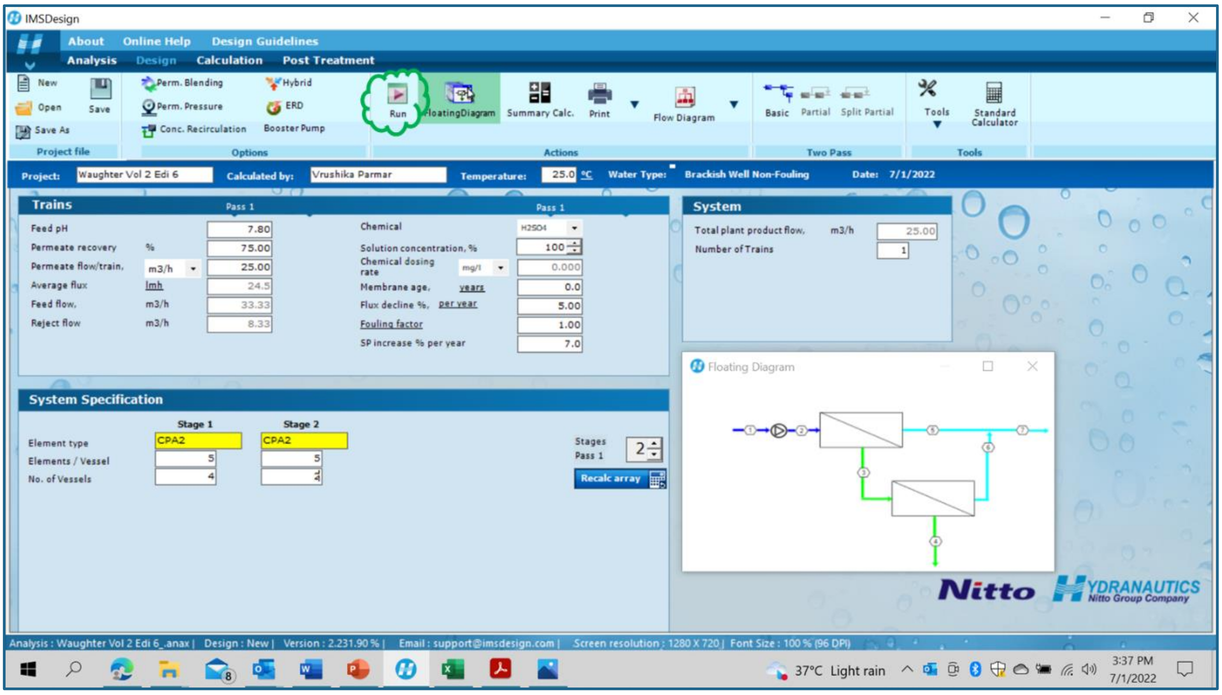


To correct Beta, reduce recovery and enter correct membrane age as 3 years, we get final design as:



The Screen shot of data entry, please mark membrane age 0 is a wrong entry it must be 3.

- Concentrate Recirculation is a way to increase recovery and control Beta Factor (Higher flow from lead element)
- Booster Pump design is to ensure better flux distribution through-out membrane train and energy optimization
- Permeate Back Pressure design controls higher flow from lead elements. Can pose engineering challenge while construction, be careful.



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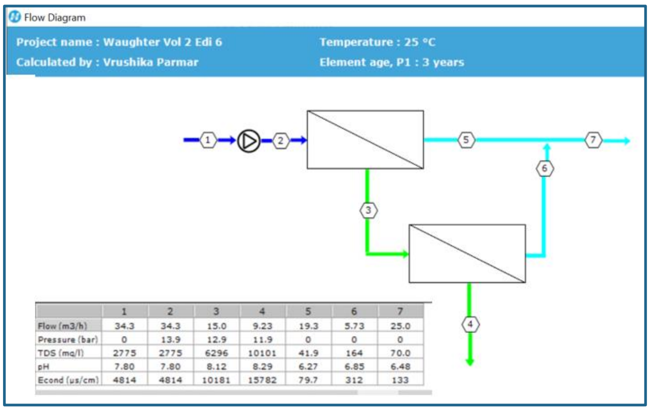
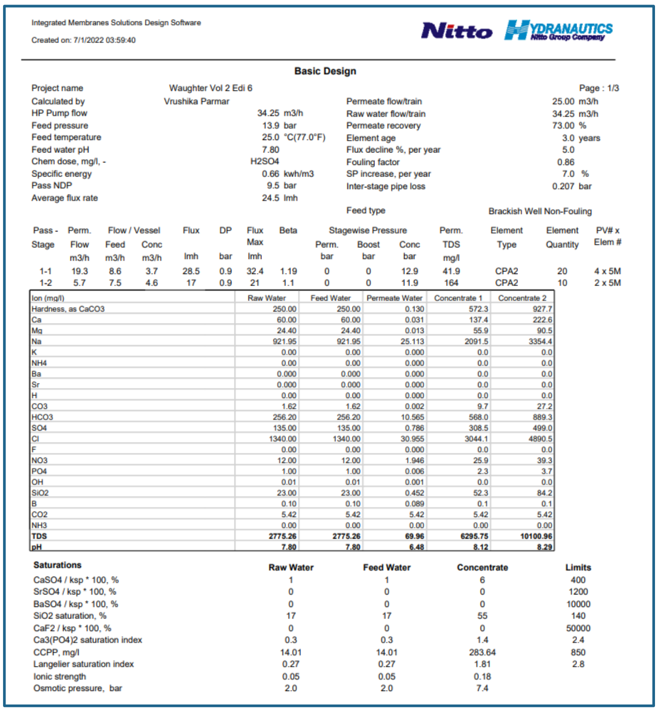
Final Design

The Final design thus has 73% recovery, TDS < 70 mg/l and designer can take a complete 3 page print to see the design and performance of each element.



	1	2	3	4	5	6	7
Flow (m3/h)	34.3	34.3	15.0	9.23	19.3	5.73	25.0
Pressure (bar)	0	13.9	12.9	11.9	0	0	0
TDS (mg/l)	2775	2775	6296	10101	41.9	164	70.0
pH	7.80	7.80	8.12	8.29	6.27	6.85	6.48
Econd (us/cm)	4814	4814	10181	15782	79.7	312	133

The PDF of 1st page of design is of interest wrt to solubility points:



Integrated Membranes Solutions Design Software

Created on: 7/1/2022 03:59:40

Nitto HYDRANAUTICS Nitto Group Company

Basic Design

Project name	Waughter Vol 2 Edi 6		Page : 1/3
Calculated by	Vrushika Parmar	Permeate flow/train	25.00 m3/h
HP Pump flow	34.25 m3/h	Raw water flow/train	34.25 m3/h
Feed pressure	13.9 bar	Permeate recovery	73.00 %
Feed temperature	25.0 °C(77.0°F)	Element age	3.0 years
Feed water pH	7.80	Flux decline %, per year	5.0
Chem dose, mg/l, -	H2SO4	Fouling factor	0.86
Specific energy	0.66 kwh/m3	SP increase, per year	7.0 %
Pass NDP	9.5 bar	Inter-stage pipe loss	0.207 bar
Average flux rate	24.5 lmh		
		Feed type	Brackish Well Non-Fouling

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	19.3	8.6	3.7	28.5	0.9	32.4	1.19	0	0	12.9	41.9	CPA2	20	4 x 5M
1-2	5.7	7.5	4.6	17	0.9	21	1.1	0	0	11.9	164	CPA2	10	2 x 5M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1	Concentrate 2
Hardness, as CaCO3	250.00	250.00	0.130	572.3	927.7
Ca	60.00	60.00	0.031	137.4	222.6
Mg	24.40	24.40	0.013	55.9	90.5
Na	921.95	921.95	25.113	2091.5	3354.4
K	0.00	0.00	0.000	0.0	0.0
NH4	0.00	0.00	0.000	0.0	0.0
Ba	0.000	0.000	0.000	0.0	0.0
Sr	0.000	0.000	0.000	0.0	0.0
H	0.00	0.00	0.000	0.0	0.0
CO3	1.62	1.62	0.002	9.7	27.2
HCO3	256.20	256.20	10.565	568.0	889.3
SO4	135.00	135.00	0.786	308.5	499.0
Cl	1340.00	1340.00	30.955	3044.1	4890.5
F	0.00	0.00	0.000	0.0	0.0
NO3	12.00	12.00	1.946	25.9	39.3
PO4	1.00	1.00	0.006	2.3	3.7
OH	0.01	0.01	0.001	0.0	0.0
SiO2	23.00	23.00	0.452	52.3	84.2
B	0.10	0.10	0.089	0.1	0.1
CO2	5.42	5.42	5.42	5.42	5.42
NH3	0.00	0.00	0.00	0.00	0.00
TDS	**2775.26**	**2775.26**	**69.96**	**6295.75**	**10100.96**
pH	**7.80**	**7.80**	**6.48**	**8.12**	**8.29**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	1	1	6	400
SrSO4 / ksp * 100, %	0	0	0	1200
BaSO4 / ksp * 100, %	0	0	0	10000
SiO2 saturation, %	17	17	55	140
CaF2 / ksp * 100, %	0	0	0	50000
Ca3(PO4)2 saturation index	0.3	0.3	1.4	2.4
CCPP, mg/l	14.01	14.01	283.64	850
Langelier saturation index	0.27	0.27	1.81	2.8
Ionic strength	0.05	0.05	0.18	
Osmotic pressure, bar	2.0	2.0	7.4	

The LSI of 1.8 indicates we need to add antiscalant.

Further SiO_2 saturation is in in limit so no worries, or else use antiscalant till SiO_2 in Concentrate 2 is up to 300 mg/l

For more practice and perfect your design.

जल जीवन जननी !!

Nidhi Jain • 1st
Civil Engineer
1w •

Dear Water Warrior,

Tendering is fun, exciting and precise!

Key Learnings :

1. Realization that one mistake and you lose the Tender.
2. Don't Park the work, do it first time when you are reading the Tender.
3. Do it yourself. Check. Recheck.
4. Contact Customer for any doubt, don't guess.
5. Understand Tender Packing and Labeling Instructions.
6. Don't rush up and finish the Tender the day before.

It was my first Tendering experience and I am still excited.
#work #experience #water #tender #tenderwriting #excitingopportunity #waterindustry

You and 42 others

Reactions

+35

Our world is Waughter

The technical knowledge share attempt of Aktion Consultancy and the contents in the magazine shall be qualified by Sanjeev Srivastava our Technology Lead.

Our next edition focuses on: "UF Design & BOQ Generation"

Please feel free to write or contact Mrs. Neha Deshpande 95129 55227

Aktion Consultancy
C 1305, Rajyash Rise
New Vasana,
Nr Vishala Circle,
NH-08,
Ahmedabad - 380 051 India

Alka Srivastava – Founder