Solar-Nanofiltration User Manual

Abbreviated Version

(Mostly for use during start-up and shut down)

24 May 2019

Figure 1. Full front view of the mobile, solar-nanofiltration system. The system consists of (i) a raw water tank (at left), (ii) prefilters (blue, vertical) and (iii) nanofiltration canisters (horizontal, white), (iv) electrical control system (top front, boxes), (v) direct current pump and battery array (not visible) (vi) solar panels (top and back) and (vii) finished water tank (at right).

The purpose of the abbreviated manual is to instruct system users who are already modestly familiar with solar nanofiltration, summarizing the steps necessary to operate the system during **start up**, **shut down** and under several additional **special operations**. For simplicity, much of the complete instruction manual has been omitted while preserving (i) the valve positions corresponding to each operational condition, (ii) electrical switch settings necessary to energize the system, (iii) the method for selecting the desired combination of feed pressure and brine-side flow rate, (iv) instructions for shutting the system down, and (v) valve conditions to carry out functions that are herein referred to as "special operations". These special operations include emptying the finished water or feed water tank, among others.

Refer primarily to Figures 2-5 to locate specific valve positions and to Figure 6 for normal electrical switch positions. Valve positions for start-up in all of the six available modes of operation are summarized in Table 1. Modes of operation differ in terms of (i) the nanofiltration membranes that are in use (NF 270, NF 90, or both) and (ii) the destination selected for the rejected (brine) stream after if leaves the membrane units (recycle to the feed tank or discharge to surroundings). Please note—the proper valve settings should be reinforced by a thorough understanding of corresponding fluid transport routes (hydraulic pathways). Tracing fluid pathways in relation to each set of valve positions is recommended.

i. **Selecting the "normal" mode of operation.** Refer to Figures 2-5 for valve locations.

Table 1. ***Valve positioning for normal operation options.*** **Valve locations are illustrated in Figures 2-5. In "recirculation" mode, feed water returns to the raw water tank, *bypassing* NF treatment.**

Valve ID	Operational condition (all from "normal" operation mode)						Operational condition—"recirculation" mode
	M1/B1	M1/B2	M2/B1	M2/B2	M3/B1	M3/B2	
V3a	closed						
V3b	open						
V3c	closed						
V3d	closed	open	closed	open	closed	open	closed
V2a	open	open	closed	closed	open	open	closed
V2b	closed	closed	open	open	open	open	closed
V2c	open	open	closed	closed	open	open	closed
V2d	closed	closed	open	open	open	open	closed
V4a	closed						
V5a	open	closed	open	closed	open	closed	open
V5b	closed	open	closed	open	closed	open	closed
V2e	throttle	throttle	closed	closed	throttle	throttle	closed
V2f	closed	closed	throttle	throttle	throttle	throttle	closed
V2g	open						
V2h	Closed (open initially during start up, to avoid overpressure)						

- M1—Upper membrane canister with NF 90 is in use; lower canister closed M2—Lower membrane (NF 270) in use; upper canister closed M3—Both membranes in use.
- B1—Rejected brine goes to raw water tank.
- B2—Rejected water is discharged; available for non-potable use

- Throttle position—valve is partially open—necessary to produce back pressure in membrane canisters for nanofiltration without eliminating the flow of brine (membrane-rejected water).

Figure 2. Side view of water purification system. The feed tank is at left and finished water tank is at right. The blue vertical cylinders are prefiltration units, and the horizontal cylinders house the NF membranes. Hinged solar panels are atop and behind (not shown). Valve (V), flowmeter (FM), filter (FT), membrane canister (M) and pressure gage (PG) positions are as indicated. Numbers correspond to figures where equipment is shown. The same designations are used in the text and tables.

Figure 3. Raw water feed manifold. In normal operation, water is drawn from the raw water tank (partially visible atop the figure), through the red valve (partially shown) and valve V3b, past the black screening device at FT3a and then back (under the tank) to the pump (Figure 4).

Figure 4. View of pump and piping behind the (blue) prefiltration units. V4a should be closed during normal operation to prevent pumped water from simply returning to the feedwater tank or to discharge without passing through the prefilter or membrane arrays.

Figure 5. Lines returning flow from either the NF canisters (P5a upper pipe carrying concentrated reject flow) or prefiltratration units (P5b lower pipe) as they reenter the raw water (feed) tank from the top. Valves are positioned for the three *normal* modes of operation in which brine is recycled to the feed tank (both V5a (top, right) and V5b (lower left) are closed). ii.

Energizing the system pump. Refer to Figure 1 and Figure 6(a-e) to identify specific control points in the power train. To initiate operations, electrical controls should be positioned as indicated in Table 2. Basically, the operator should position circuit breakers to "on" positions. When the pump readiness light turns green (Figure 6e) the battery is sufficiently charged. Operator can then move the pump starter switch (toggle, Figure 6e) to the "on" position to start the pump. The pump power output and speed can then be adjusted using the peak power adjustment screw (Figure 6e).

Pump control element	"On" position for pumping	Relevant figure(s)
Main breaker lever	Up	6(a) & 6(b)
Small circuit breakers (2)	1 up, 2 up	6(a) & 6(c)
Charge controller box; small circuit breakers (4)	From left, as shown, 1 up, 2 up, 3 up. 4 down except as explained in a later section	6(a) & 6(d) Pump readiness light Figure 6(e) should show green in pump control unit
Pump control unit	Toggle switch to "up" position	6(a) and 6(e)
Peak power adjustment screw	Clockwise to increase pump speed	Figure 6e

Table 2. Pump power control summary. Positions of control pieces to turn on pump and adjust the pump speed controller.

Figure 6a. Electrical control boxes located above the prefilter array. Individual boxes and interior switches are shown in Figures 6(b-e).

Figure 6b. Main breaker box with lever in the "off" position. The solar array is disconnected from other elements of the power train.

Figure 6c. Left-most of four electrical boxes in Figure 6a. To operate the pump, circuit breakers should be positioned as follows—nos. 1 and 2 "on".

Figure 6d. Interior of the charge control box. During normal operation, the first three circuit breakers should be in the "on" position, as shown. The fourth switch should be off unless the finished water is being disinfected using the UV lamp—later section. The charge controller is at left.

Figure 6e. Pump control unit. Pump readiness is indicated by a green light on the battery ready indicator. The toggle switch turns the pump on and off. Pump speed is controlled by the peak power adjustment screw (shown).

iii. Establishing the target feed side pressure and feed-water flow rate simultaneously.

For these purposes, consider the target feed-side pressure to be selected arbitrarily. Membrane operating pressures can be read on the gages shown in Figure 2 (PG2c and PG2d). When water is flowing through the feed side of the membrane canisters, the feed-side pressure can be manipulated by throttling the flows through valves V2e and V2f in order to alter the pressures in the top (NF 90) and/or bottom (NF 270) canister(s), respectively. For the moment, it is not necessary to consider the merits or drawbacks of higher or lower pressure, other than to note that there is a direct relationship between net pressure (basically, the mechanical pressure minus the osmotic pressure on the feed side of the membrane) and the resultant permeate flow rate. For purposes of this document, it is sufficient to simply establish the target feed-side pressure for the canister(s) or membranes in use by adjusting the throttling valve(s) (V2e and V2f).

After the feed-side pressure is established, it will probably be necessary to set or reset the flow rate(s) through the canister(s) selected for use. This is accomplished using the peak power adjustment screw, located as shown in Figure 6e. Clockwise adjustment will increase the pump speed (power) and consequent flow rate. Flow rate is indicated for each canister on the flow meters shown in Figure 2. In actual operation, the feed-side flows would be selected to (i) maintain sufficient crossflow velocity and lower concentrations of rejected ions to levels necessary to avoid precipitation events and membrane scaling and (ii) minimize concentration polarization at the membrane surface (beyond the scope of this treatment). Recovery during membrane treatment is the ratio of permeate flow to the canister influent flow rate (sum of the permeate and rejected flow rates**).** ***For simplification in this abbreviated manual, set the rejected rate of flow on the Figure 2 flow meter(s) to 10 gpm for the canister that is selected for use (single-membrane operation), or 5 gpm (each meter) when both membranes are in use.***

Notice that, in general, adjustment of flow will affect the feed side pressure of the same membrane, so that iterative adjustments of pressure and flow using the peak power adjustment screw and throttle valves will be necessary to arrive at the preselected combination of operational pressure and flow for each membrane in use. ***Simultaneous control of two operational parameters requires manipulation at two control points.***

Figure 7. Batteries (four, 12V lead/acetate) and battery containment box. The four batteries shown are connected in series to provide a working voltage of 48-52V, depending on battery state of charge.

iv. System shut down.

Normally, all that is required at the conclusion of operation is to shut off the pump using the toggle switch in Figure 2d. However, other power control circuit breakers should be restored to their respective "off" positions unless additional, immediate use is planned.

Under circumstances in which the NF system is used to desalinate a particularly saline raw feed solution, it may be well to wash the residual feed solution from the canister at the end of the operational period using a relatively small amount of the pure water product. Valve settings necessary to carry this out are summarized in the section devoted to **"special operations"**. To conduct such a washing step, however, the pump must be re-activated, per above, after respective valves are positioned as indicated in Table 3, below, under "membrane rinsing".

v. Special operations.

Valve positioning for all so-called "special operations" is as summarized in Table 3. For these purposes, definitions of all special operations are omitted as titles are self-explanatory. At the conclusion of any of the special operations listed, the pump power should be discontinued by placing the Figure 6e toggle in the "off" position and returning the circuit breakers in Figure 6c to their respective "off" positions. Valves at the exit of the finished water tank are identified in Figure 8. Valves controlling water flow during UV disinfection are shown in Figure 9.

	Valve positioning for special system operations (those indicated below)					
Valve ID	**Membrane rinsing at shutdown**	**Emptying feed tank by gravity**	**Emptying feed tank by pumping**	**Non-potable use of product water**	**Delivery of UV-treated potable water**	**UV-purification of water in pure water tank**
V2a	open	closed	closed	----------	----------	----------
V2b	open	closed	closed	----------	----------	----------
V2c	closed	closed	closed	----------	----------	----------
V2d	closed	closed	closed	----------	----------	----------
V2e	open	closed	closed	----------	----------	----------
V2f	open	closed	closed	----------	----------	----------
V3a	open	closed	closed	----------	----------	----------
V3b	closed	closed	open	----------	----------	----------
V3c	closed	open	closed	----------	----------	----------
V3d	closed	closed	closed	----------	----------	----------
V4a	closed	closed	open	----------	----------	----------
V4b	closed	closed	closed	----------	----------	----------
V4c	closed	closed	closed	----------	----------	----------
V5a	closed	closed	closed	----------	----------	----------
V5b	closed	closed	closed	----------	----------	----------
V8a	closed	closed	closed	open	closed	closed
V8b	closed	closed	closed	closed	open	open
V8c	open	closed	closed	closed	closed	closed
V9a	closed	closed	closed	closed	closed	open
V9b	closed	closed	closed	closed	open	closed

Table 3. Summary of valve positioning for special operations including membrane rinsing, feed tank evacuation and finished water delivery.

Figure 8. Bottom exit of the finished water tank. From here water can be withdrawn or released by gravity for (i) direct use—lower pipe with exit shown, (ii) UV treatment prior to potable use (pipe at left) or (iii) membrane rinsing during system shut-down (pipe at right). Corresponding valves are V8a, V8b and V8c, as shown. Valve V8d can remain open.

Among the special operations listed in Table 3 is the "delivery of potable water". This is accomplished using a small pump in the finished water tank that is operated by its own toggle switch (Figure 9). This water passes an ultraviolet light prior to exiting the system. Power for the UV source and small pump is taken directly from the batteries. The UV treatment is a safeguard against bacterial regrowth in the finished water tank. ***From a regulatory perspective, the finished water treated in this fashion does not represent an approved potable water supply.*** Nevertheless, it should be purified water.

Figure 9. Ultraviolet disinfection system. The system is located adjacent to the finished water tank. UV treatment can be provided via two means: Single pass operation for disinfection prior to delivery of water from the stainless steel spout at right or continuous re-purification with water taken from and returned to the finished water tank.

vi. Deploying the solar array. (incomplete)

Acknowledgments:

Yaser Mehdipour, PhD, Biosystems Engineering, for engineering and construction of the NSF unit.

Christopher Yazzie, PhD Candidate, Chemical & Environmental Engineering, for assistance creating the NSF user's manual.

Robert Arnold, PhD, Professor Emeritus, Chemical & Environmental Engineering, for mentoring.

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This material is based upon work supported by the National Science Foundation under Grant #DGE1735173.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.