Water Solutions

inge Ultrafiltration Process Control Philosophy In-Out Pressurized Technical Manual

Version 2

October 2022

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1 Introduction

1.1 inge® UF Process Operating Description

This document has been designed to assist in creation of detailed process logic for inge® ultrafiltration (UF) automation. Document is in compliance with inge® UF process requirements and limitations. Target audience of this document are process engineers as well as instrumentation & control (I&C) professionals on inge®'s customer side.

Document is designed to be used for all standard inge® UF applications, is thus created in parts of general nature, and will therefore not replace detail I&C engineering and other considerations for the particular customer project. Please refer to inge®'s Process and Design Guidelines for further information to UF process design and warranty conditions.

The inge® UF Process & Instrumentation Diagram should be referenced for details on each operating step, please refer to the latest version of inge®'s process and design guidelines for further information hereto. Valve sequencing, pump operations, duration of each step, and operating rates are provided within this document. General sequence of operations contains operating modes as follows:

- Filtration
- Forward Flush
- Backwash
- CEB

Additional to the general sequence of operation, the following operating modes are considered maintenance procedures and applicable only on demand:

- Fill UF Rack
- Integrity Test
- CIP

Filtration

During filtration mode, raw feed water is filtered in inside-out configuration through the UF membrane. Filtration is performed at a preset rate (flux, described as membrane surface loading rate in $l/(m^2h)$) and will last for a fixed duration (filtration time) or until a fixed volume is reached (filtration volume). Filtration occurs in dead-end mode. In the filtration sequence, raw feed water is pumped into the UF module through the bottom feed inlet, leaving the UF module through the filtrate port.

Forward Flush

A forward flush can be performed before or after completion of the BW to assist removal of solids from the UF capillaries. Here, UF feed water is pumped longitudinally through the membrane capillaries at the same rate as during the filtration sequence. Forward flushes are typically not used during regular operation, however in some cases they may need to be implemented to improve solids removal before and/or after backwash.

Backwash

Suspended particles from UF feed water will form a fouling layer on the UF membrane during the filtration process. The fouling layer is periodically removed by backwashing the UF membrane. UF filtrate water is pumped at a high rate in reverse direction, from the outside of the membrane capillaries through the UF membrane towards the inside of the capillary. In all inge® UF processes, the BW flux rate is specified to occur at a minimum of 230 l/(m²h). The BW lasts for a fixed duration (BW time).

Optionally, BW flow rate can be split in half by sequentially backwashing first half of the UF train (stream A) followed by the second half of the UF train (stream B). This sequential backwash is referred to as split backwash and requires two additional isolation valves in the filtrate/backwash header of each train. Split backwash sequence is detailed within this document.

CEB

During the course of operation, UF membranes will slowly loose permeability due to build-up of a hard-to-remove fouling layer on the membranes. Fouling layers consist of water impurities and can either be of organic or inorganic nature. The latter is also referred to as scaling due to the precipitation of minerals, such as CaCO3. Hence, UF membranes must utilize a Chemically Enhanced Backwash (CEB) in certain intervals to maintain design filtration performance.

As a default, each CEB for the inge® UF process comprises of two individual cleaning steps:

CEB1.1 is the inge® UF standard CEB and active in every UF application. CEB1.1 comprises of a caustic/alkaline cleaning step which can be performed as caustic soda only or together with sodium hypochlorite, depending on the application.

CEB1.2 must always be performed at the same frequency and preferably soon after CEB1.1. CEB1.2 comprises of an acidic cleaning step.

Please note that for some applications, CEB1.1 as well as CEB1.2 can be required to be added to the cleaning regime as standalone procedures. When performed as standalone procedures, the caustic/alkaline CEB1.1 is referred to as CEB3. When acidic CEB1.2 is implemented as a standalone procedure, CEB1.2 is referred to as CEB2.

The following operating modes are considered maintenance procedures:

Fill UF Rack

Filling the UF rack is applicable only during commissioning and after repairs or maintenance work. Fill UF rack is also used after completion of the Membrane Integrity Test (I-Test or MIT) to prime the UF rack for further operation.

Integrity Test

Verification of membrane integrity is achieved by using membrane's ability to completely retain air while allowing passage of water. This sequence is referred to as the Integrity Test (I-Test). Alternatively, the expression Membrane Integrity Test (MIT) or Air Integrity Test (AIT) can be used.

During the air integrity test, compressed, oil-free air at 1,0 barg is introduced to the feed side of the UF modules until pressure stabilization occurs. Filtrate is being dumped through the filtrate valve throughout this step. In a second step, the air supply is closed, and pressure decay is measured over a duration of e.g., 5 minutes. In a third step, the compressed air is released by the feed vent valve.

CIP

In order to restore UF membrane cleanliness and permeability, a Cleaning In Place (CIP) procedure should be performed once the permeability falls below 100 l/(m²hbar) during filtration and cannot sufficiently be recovered by the CEB procedures and/or if BW flux rate of 230 l/(m²h) can clearly not be reached.

CIPs are typically done in 2 steps, a high pH cleaning followed by a low pH CIP step. Refer to inge® Process and Design Guidelines for further detail hereto.

The UF train must be stopped after completion of BW before the procedure can be initiated.

1.2 Configuration & instrumentation of inge® Ultrafiltration system

In Figure 1, a schematic overview of the standard inge® UF configuration is presented. The automatic programs described in this document are based on this figure.

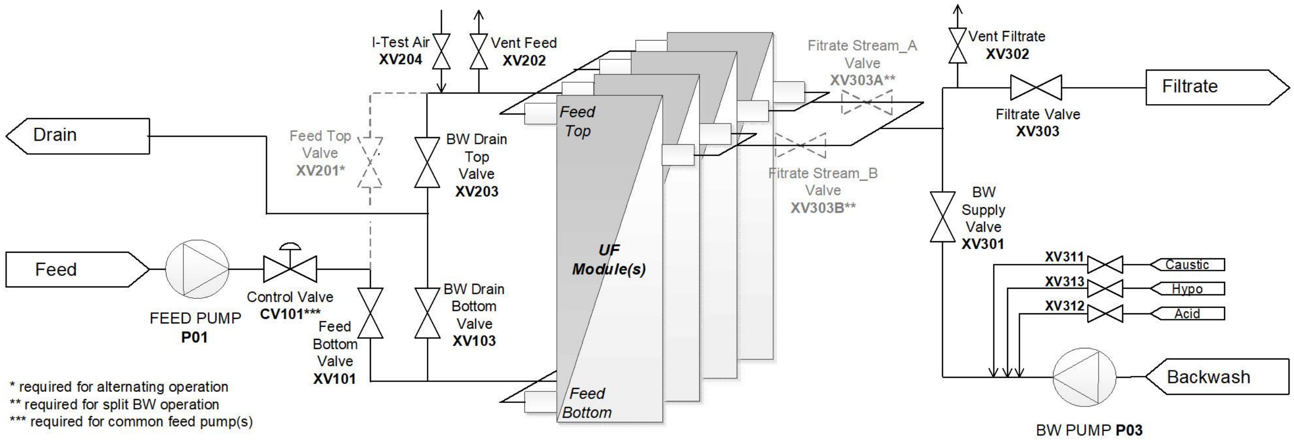

Figure 1. Standard inge® Ultrafiltration configuration

Figure 1 shows all mandatory as well as optional valves and piping required for the UF process. Please refer to the individual process description for further information on functionality.

All measurements described in this document are based on instrumentation, as shown in Figure 2. Mandatory equipment for all UF installation is shown in bold, while other instrumentation is considered application specific.

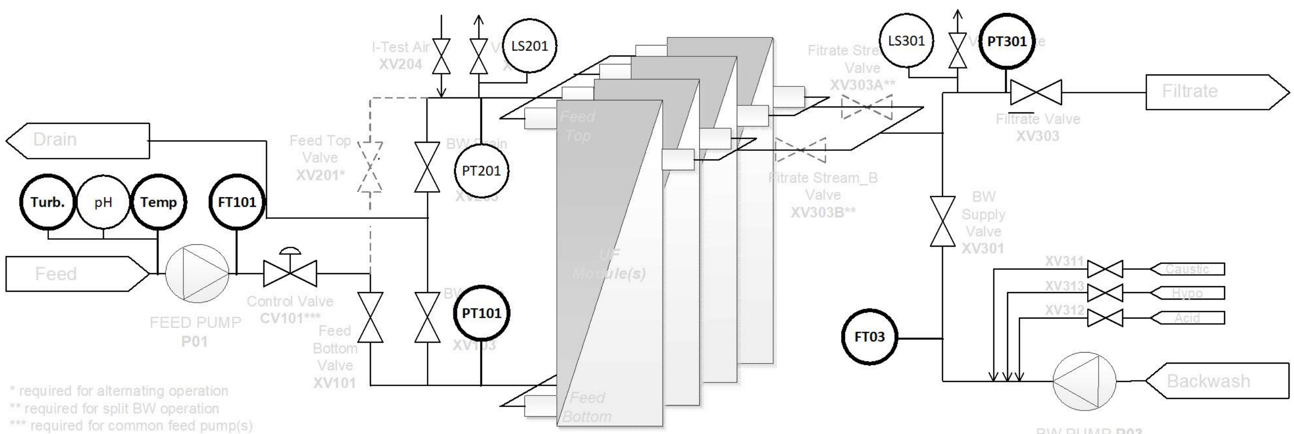

Figure 2. Standard inge® Ultrafiltration instrumentation

For the UF system, as shown in Figure 2, UF feed temperature, turbidity and pH is measured in the feed supply while backwash flow rate (FT03) is measured on the discharge of the backwash pump.

For each UF train, individual measurements of feed flow rate (FT101) and feed pressure (bottom inlet, PT101) as well as filtrate pressure measurement (PT301) are required. For alternating applications, an additional feed pressure transmitter on the feed top side (PT201) is recommended.

For venting automation, level switches (LS201, LS301) are recommended to be installed in the UF feed and filtrate vertical vent lines (compare to Figure 3).

2 Process description

2.1 Filtration

2.1.1 Introduction

The filtration sequence starts by opening the feed bottom valve and filtrate valve. Feed is then pumped by the UF feed pump at a fixed rate. As filtration progresses, a filter cake (fouling layer) build-up on the UF membrane will result in increasing feed pressure requirements to maintain design flow rate. Fixed flow rate can be maintained by either regulating individual UF feed pump flow rate or by adjusting UF feed control valve opening position for common feed pumps.

Feed and Filtrate venting must be always activated during the filtration process. For venting of both, the UF feed and filtrate side, inge® recommends the use of level-switch and shut-off valve combination in which the level switches are installed inside vertical pipes connected to the UF feed top and filtrate piping.

As can be seen in Figure 3-, each level switch is (through the automation control logic) connected to its corresponding shut-off valve. Any air entrapped in the manifold will rise into the vertical pipe, making the level switch sense "dry" conditions. On dry conditions, the shut-off valve opens until all air is purged, the level switch senses "wet" conditions, and the shut-off valve closes with adequate time delay for hysteresis purposes.

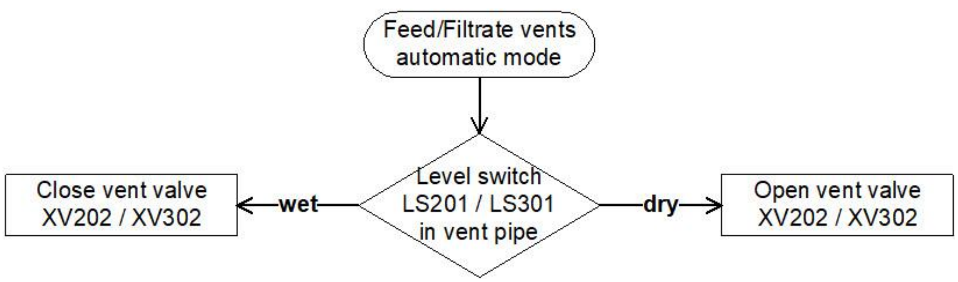

Figure 3. Recommended vent valve automation for UF feed and filtrate side

2.1.2 Process flow chart

In Figure 4, the process flow chart of the filtration program is presented.

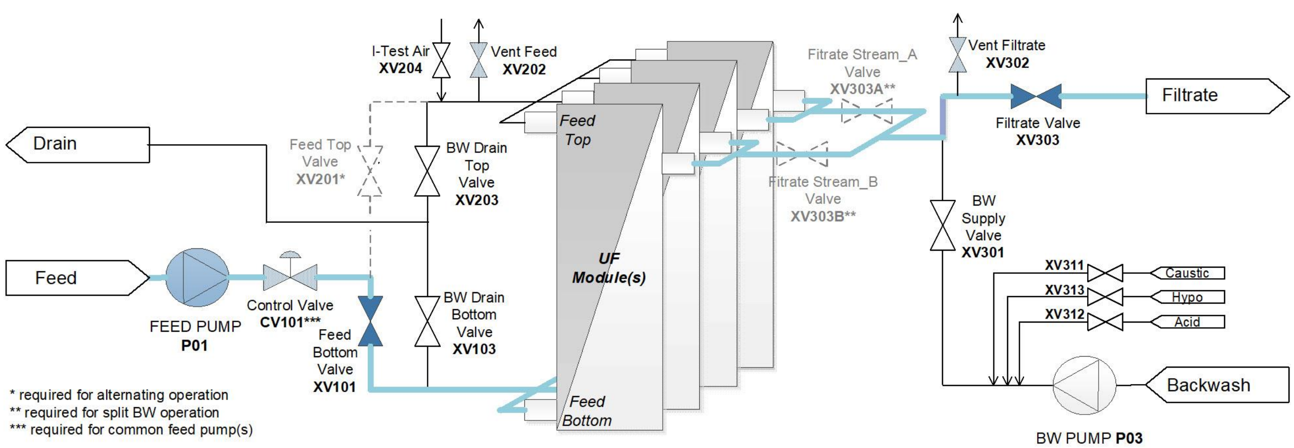

Figure 4. Process flow chart of the filtration program

2.1.3 Control sequence

In below tables, the filtration program control sequence, rates, and timers are presented.

Table 1. Filtration program control sequence

Filtration Program	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5
Feed pump	S	S	R	R	S	S
Control Valve (CV101)	●	●	○	○	●	●
Feed Bottom Valve (XV101)	●	○	○	○	○	●
Filtrate Valve (XV303) opt: (XV303A&B	●	○	○	○	○	●
Feed Vent Valve (XV202)	○	A	A	A	A	○
Filtrate Vent Valve (XV302)	○	A	A	A	A	○
○ Open			R Running			
● Close			S Stopped A Automated			

Table 2. Process variables filtration program

Process Variable Description	Abbreviation	Default / Typical
Filtration Timer	FLT	45 min
Filtration Volume	FLV	___ m^3
Feed Flow Rate	Q_{FE}	50-100 $l/m^2/h$ * Module Surface Area * Modules per Train

Note: In UF projects equipped with a feed top valve for alternating operation, the feed top valve can be used in alternation to the feed bottom valve for every 2nd filtration cycle. Described process is referred to as "filtration top".

In below figure, the detailed description of each step is presented in SFC language.

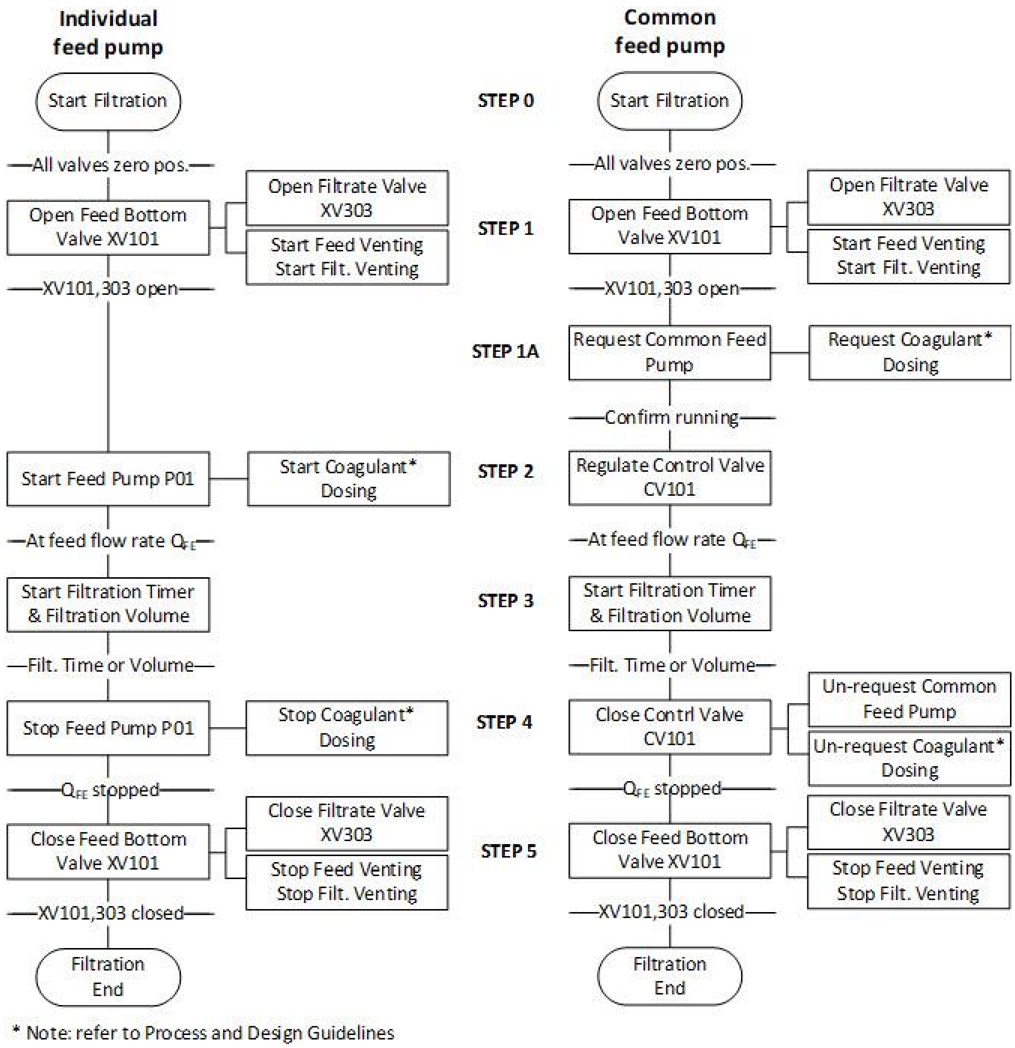

Figure 5. Detailed description of filtration program

2.2 Forward flush

2.2.1 Introduction

During forward flush bottom, feed water is pumped into feed bottom valve, then through the UF capillaries and ultimately out through the BW drain top valve to drain. Venting routines for feed and filtrate header are active during the forward flush (refer to Figure 3)

2.2.2 Process flow chart

In Figure 6, the process flow chart of the forward flush program is presented.

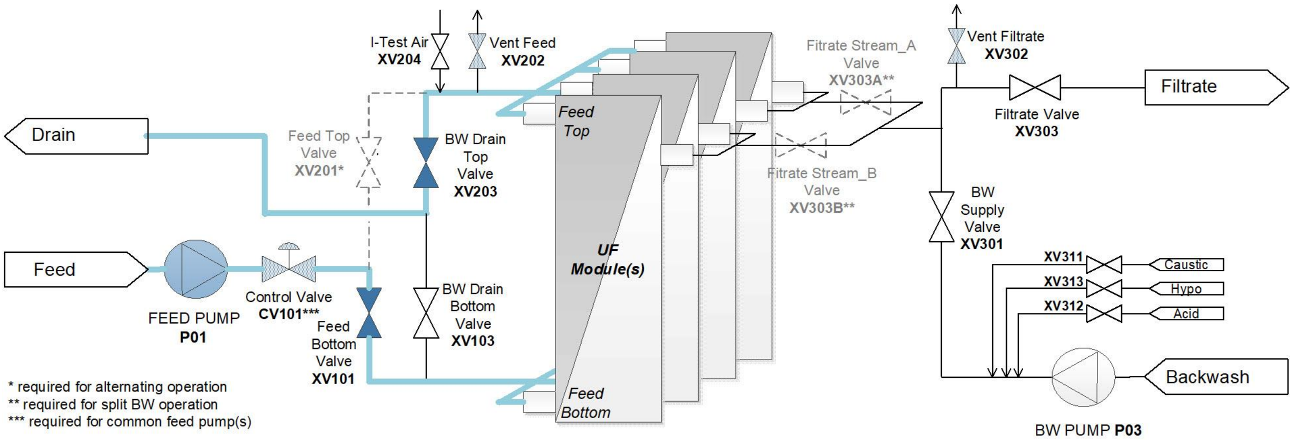

Figure 6. Process flow chart of the forward flush program

2.2.3 Control sequence

In below tables, the forward flush program control sequence, rates, and timers are presented.

Table 3. Forward flush program control sequence

Filtration Program	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5
Feed pump	S	S	R	R	S	S
Control Valve (CV101)	●	●	○	○	●	●
Feed Bottom Valve (XV101)	●	○	○	○	○	●
BW Drain Top Valve (XV203)	●	○	○	○	○	●
Feed Vent Valve (XV202)	○	A	A	A	A	○
Filtrate Vent Valve (XV302)	○	A	A	A	A	○
○ Open			R Running			
● Close			S Stopped A Automated			

Table 4. Process variables forward flush program

Process Variable Description	Abbreviation	Default / Typical
Forward Flush Timer	FFT	40 s
Feed Flow Rate	Q_{FE}	50-100 l/m²/h * Module Surface Area * Modules per Train

In below figure, the detailed description of each step is presented in SFC language.

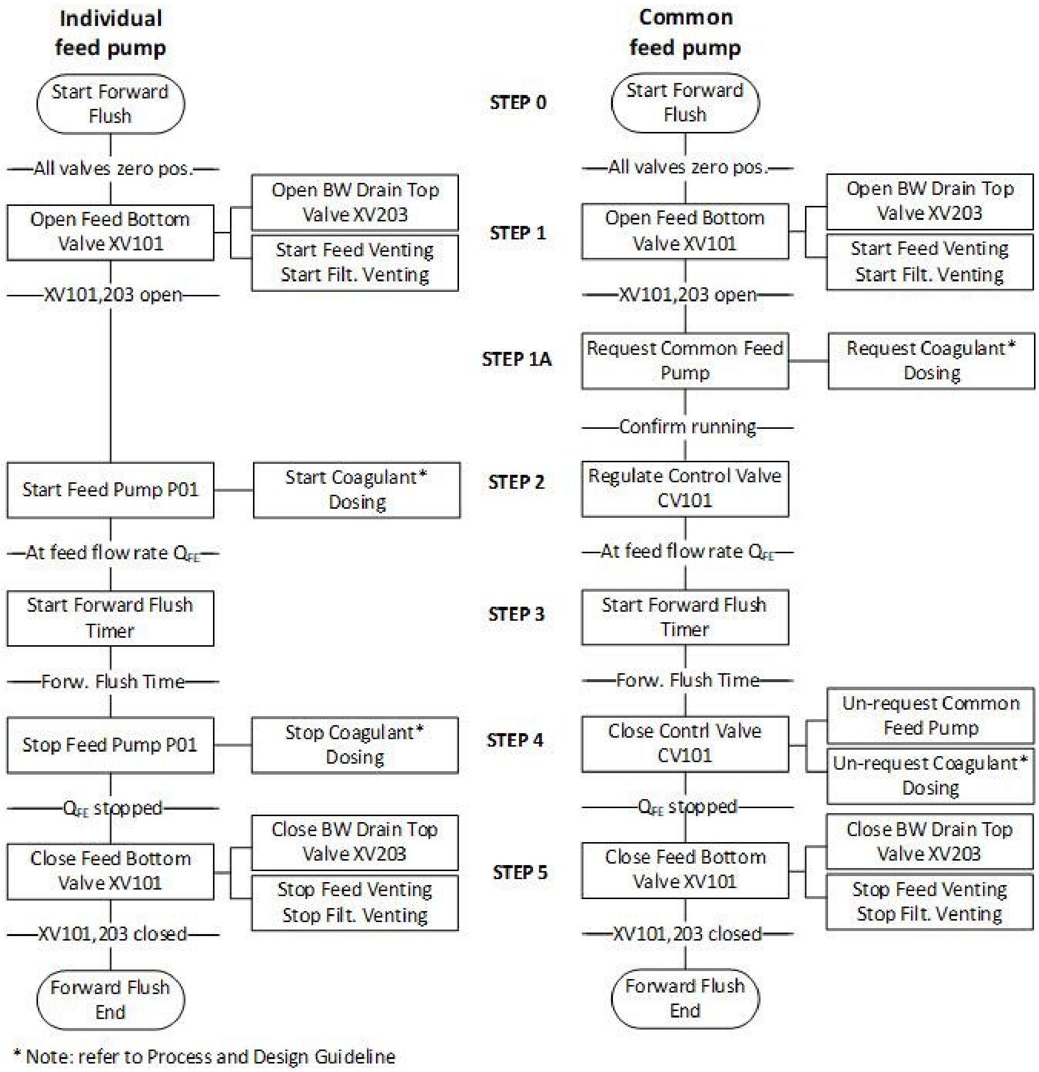

Figure 7. Detailed description forward flush program

Note: In UF projects equipped with a feed top valve for alternating operation, the feed top valve can be used instead of the feed bottom valve and BW drain top valve instead of the BW drain bottom valve to perform a forward flush top. Forward flush top is always performed in combination with the filtration top step.

2.3 Standard Backwash

2.3.1 Introduction

The BW sequence of events starts by isolating the UF train (closing Feed Bottom valve and Filtrate valve), open the BW Supply valve and the BW Drain Bottom valve. The BW pump is started and ramped up (ramp up time) to the speed at which the flow rate represents 230 l/(m²h) and stays at this position for the BW Drain Bottom time. The BW Drain Top valve is now opened, and the BW Drain Bottom valve subsequently closed. The BW pump is kept at the BW flow rate until expiration of the BW Drain Top timer. After the timer expires, the BW pump is ramped down (ramp down time), all BW related valves are closed.

Operation of BW Drain Top & Bottom valves must be performed in timely manner to minimize downtime of the UF train and therefore maximize availability of the UF train. Maximum time to open and/or close BW Drain Top & Bottom valves must be adjusted to not exceed 7 s for each valve.

Duration of valve actuation and BW pump ramping must be in line with projections to reduce downtime of the UF train (s) and / or minimize water losses beyond specified limitations. BW flow during the ramping stage does not have the required velocity for effective backwashing and filtrate water usage during BW pump ramping is thus considered a loss. Standard projected duration for BW pump ramping to allow 90% of the BW flow rate to be reached is 7 s.

2.3.2 Process flow chart

In Figure 8 and Figure 9, the process flow charts of the backwash (bottom) and backwash (top) programs are presented.

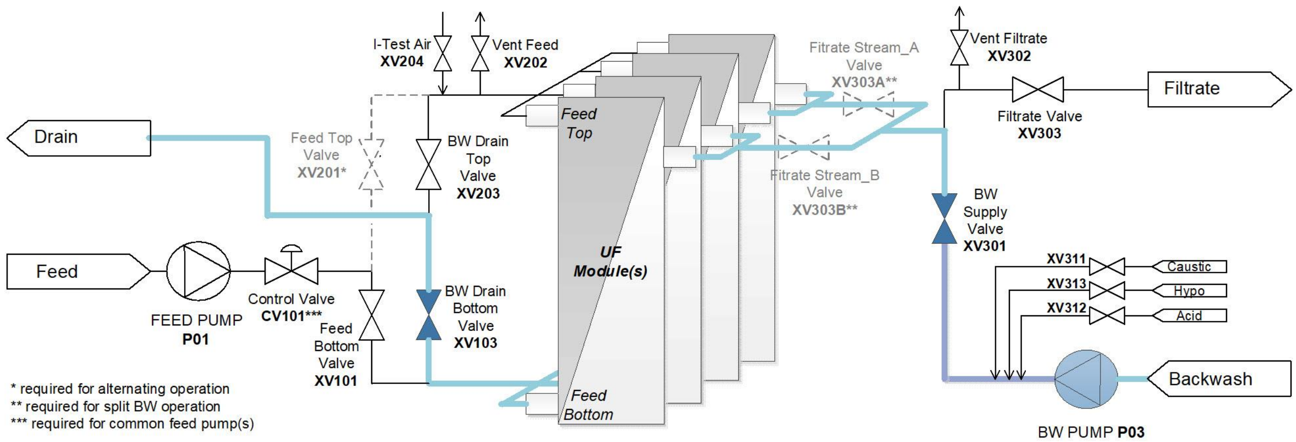

Figure 8. Process flow chart of the backwash drain bottom program

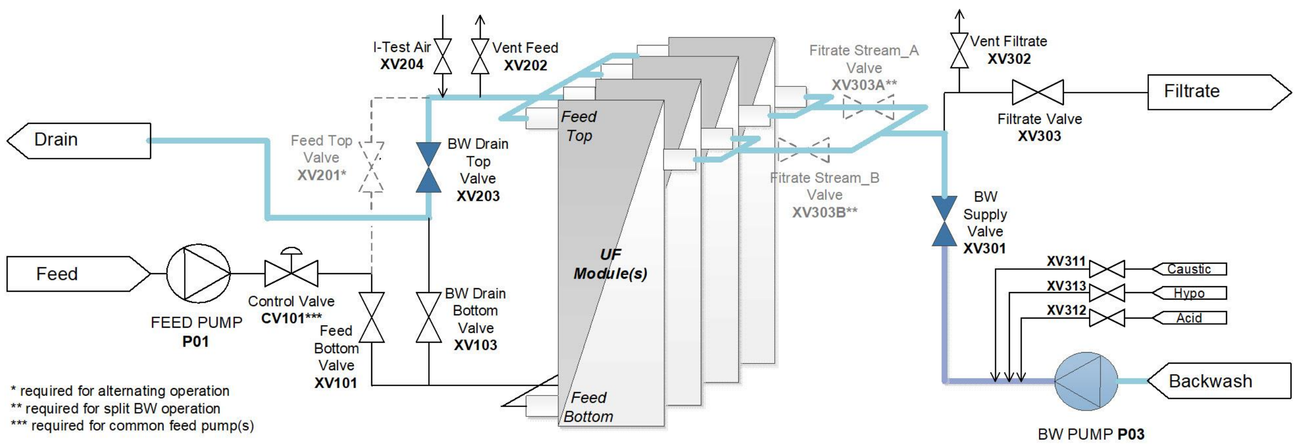

Figure 9. Process flow chart of the backwash drain top program

2.3.3 Control sequence

In below tables, the backwash program control sequence, rates, and timers are presented.

Table 5. Backwash program control sequence

Backwash Program (Standard)	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Backwash (BW) Pump	S	S	R	R	R	R	S	S
BW Supply Valve (XV301) opt: (XV303A&B	●	○	○	○	○	○	○	●
BW Drain Bottom Valve (XV103)	●	○	○	○	○	●	●	●
BW Drain Top Valve (XV203)	●	●	●	●	○	○	○	●
○ Open			R Running					
● Close			S Stopped					

Table 6. Process variables backwash program

Process Variable Description	Abbreviation	Default / Typical
Backwash Drain Bottom Timer	BWDB	20 s
Backwash Drain Top Timer	BWDT	20 s
Backwash Flow Rate	Q_{BW}	230 l/m²/h * Module Surface Area * Modules per Train

In below figure, the detailed description of each step is presented in SFC language.

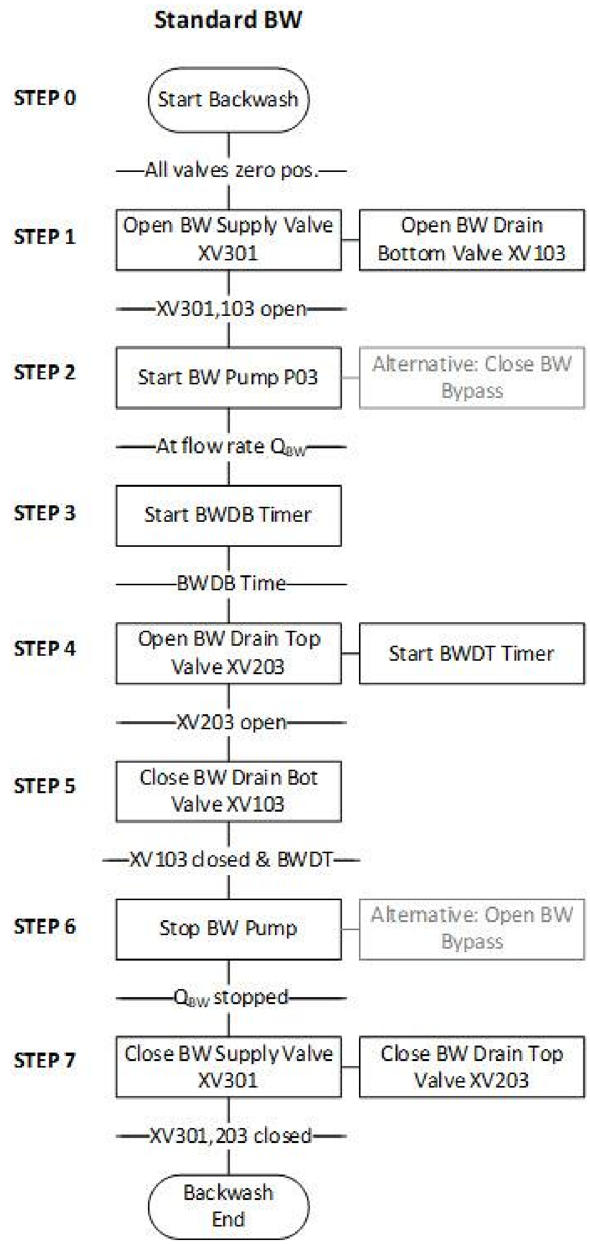

Figure 10. Detailed description backwash program

Note: UF systems with alternating operation, BWDB step is skipped after feed bottom filtration (XV101), BWDT skipped after feed top filtration (XV201)

2.4 Split Backwash (optional, replaces Section 2.3)

2.4.1 Introduction

The BW sequence of events starts by isolating the UF train (closing Feed Bottom valve and filtrate valves), open the BW Supply valve and the BW Drain Bottom valve. UF BW flow is directed to Stream A via the Filtrate Stream A valve initially. The BW pump is started and ramped up (ramp up time) to the speed at which the flow rate represents 230 l/(m²h) and stays at this position for the BW Drain Bottom time. After the BW Drain Bottom A time expires, Filtrate Stream B valve is opened, and Filtrate Stream A valve subsequently closed. BW continues once more for the BW Drain Bottom time. The BW Drain Top valve is now opened, and the BW Drain Bottom valve subsequently closed. After the BW Drain Top time expires, Filtrate Stream A valve is opened, and Filtrate Stream B valve subsequently closed. BW continues once more for the BW Drain Top time. The BW pump is kept at the BW flow rate until expiration of the BW Drain Top timer. After the timer expires, the BW pump is ramped down (ramp down time), all BW related valves are closed.

2.4.2 Process flow chart

In below figures, the process flow charts of the backwash (bottom) and backwash (top) programs for backwash stream A and B are presented.

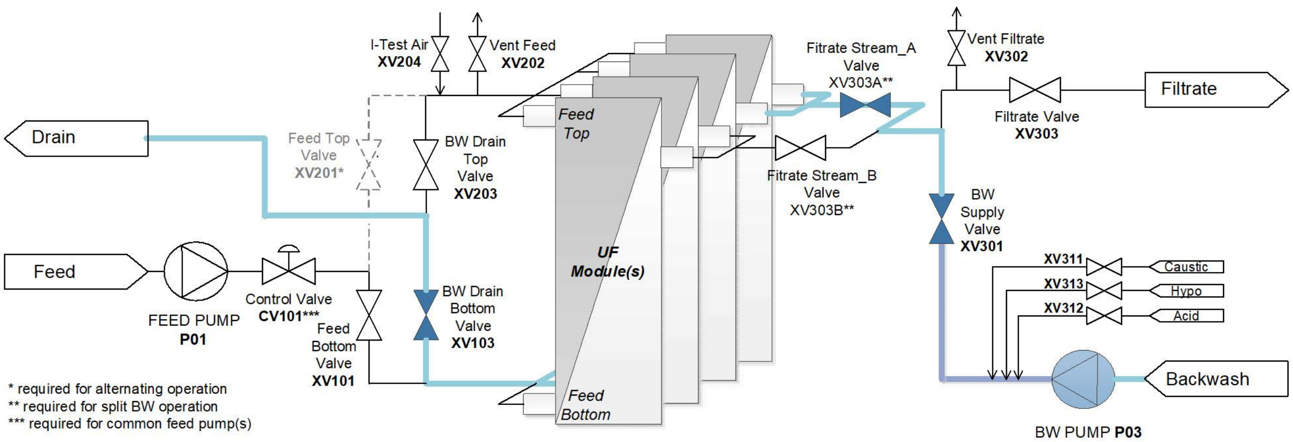

Figure 11. Process flow chart of the split backwash drain bottom A program

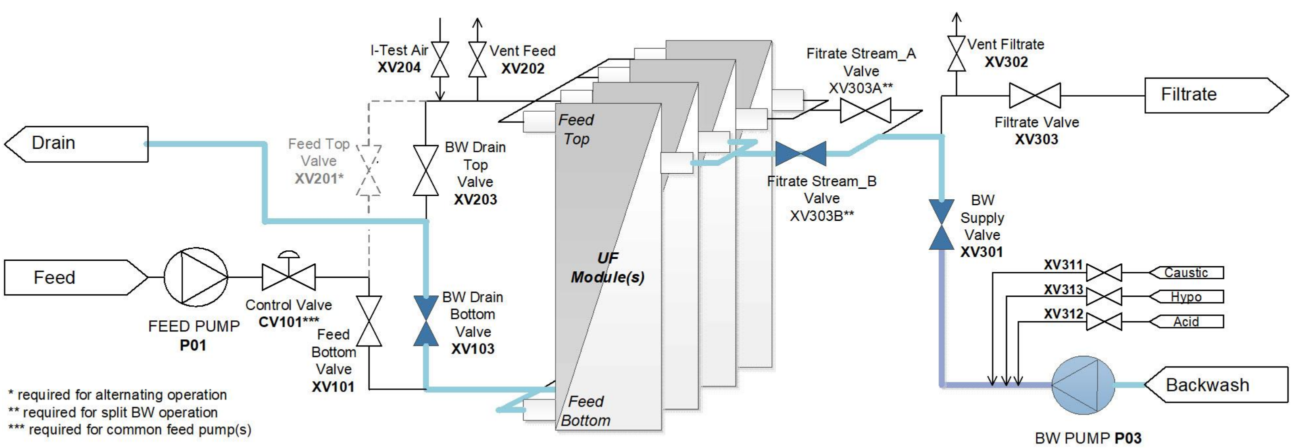

Figure 12. Process flow chart of the split backwash drain bottom B program

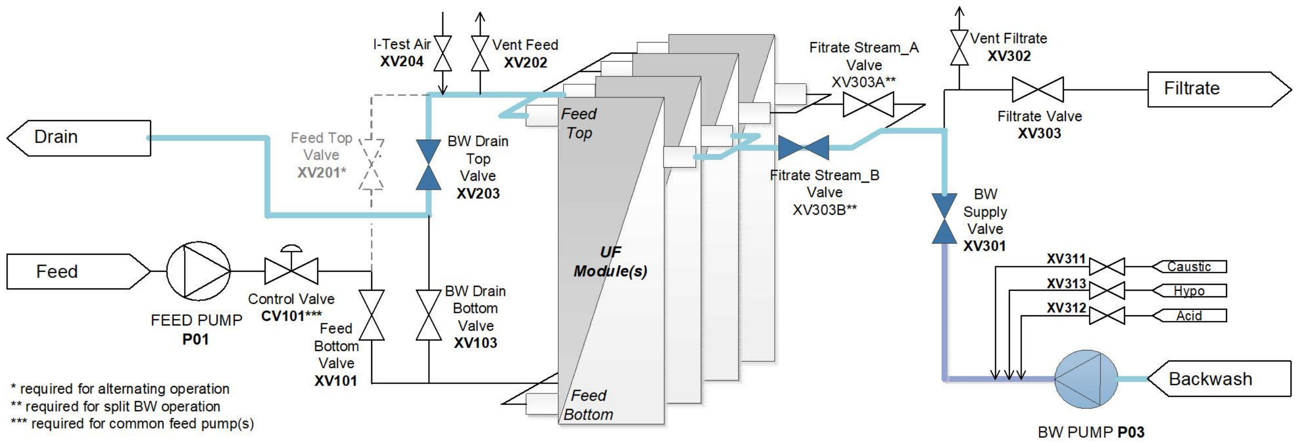

Figure 13. Process flow chart of the split backwash drain top B program

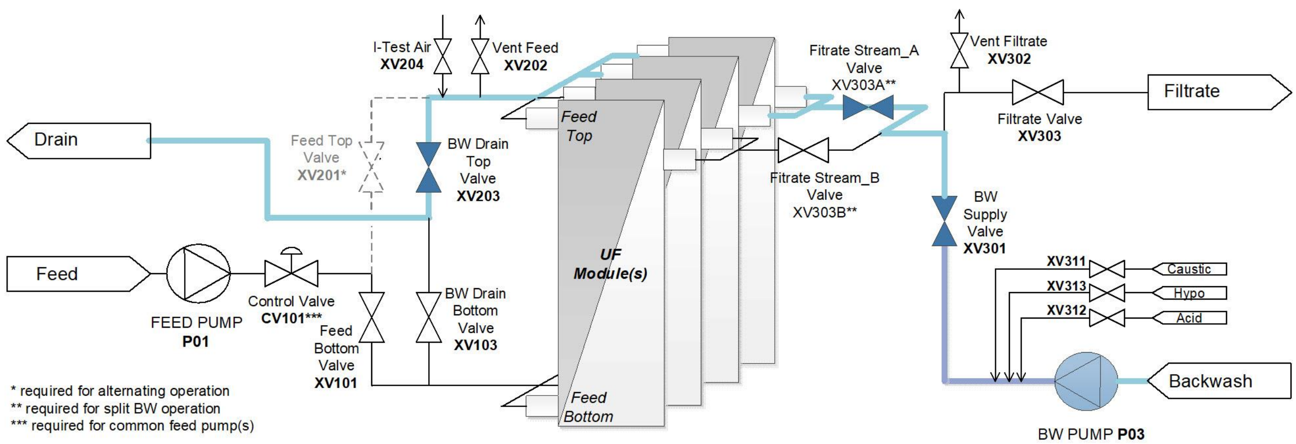

Figure 14. Process flow chart of the split backwash drain top A program

2.4.3 Control sequence

In below tables, the backwash program control sequence, rates, and timers are presented.

Table 7. Split backwash program control sequence

Backwash Program (Standard)	**Step 0**	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**	**Step 7**	**Step 8**	**Step 9**
Backwash (BW) Pump	S	S	R	R	R	R	R	R	R	R
BW Supply Valve (XV301)	●	○	○	○	○	○	○	○	○	○
BW Drain Bottom Valve (XV103)	●	○	○	○	○	○	○	●	●	●
BW Drain Top Valve (XV203)	●	●	●	●	●	●	○	○	○	○
Filt. Stream A Valve (XV303A)	●	○	○	○	○	●	●	●	○	○
Filt. Stream B Valve (XV303B)	●	●	●	●	○	○	○	○	○	●
Backwash Program (Standard)	**Step 10**	**Step 11**								
Backwash (BW) Pump	S	R								
BW Supply Valve (XV301)	○	●								
BW Drain Bottom Valve (XV103)	●	●								
BW Drain Top Valve (XV203)	○	●								
Filt. Stream A Valve (XV303A)	○	●								
Filt. Stream B Valve (XV303B)	●	●								
○ Open			R Running							
● Close			S Stopped							

Table 8. Process variables split backwash program

Process Variable Description	Abbreviation	Default / Typical
Backwash Drain Bottom Timer	BWDB	20 s
Backwash Drain Top Timer	BWDT	20 s
Backwash Flow Rate	Q_{BW}	230 l/m²/h * Module Surface Area * Modules per Stream

In below figure, the detailed description of each step is presented in SFC language.

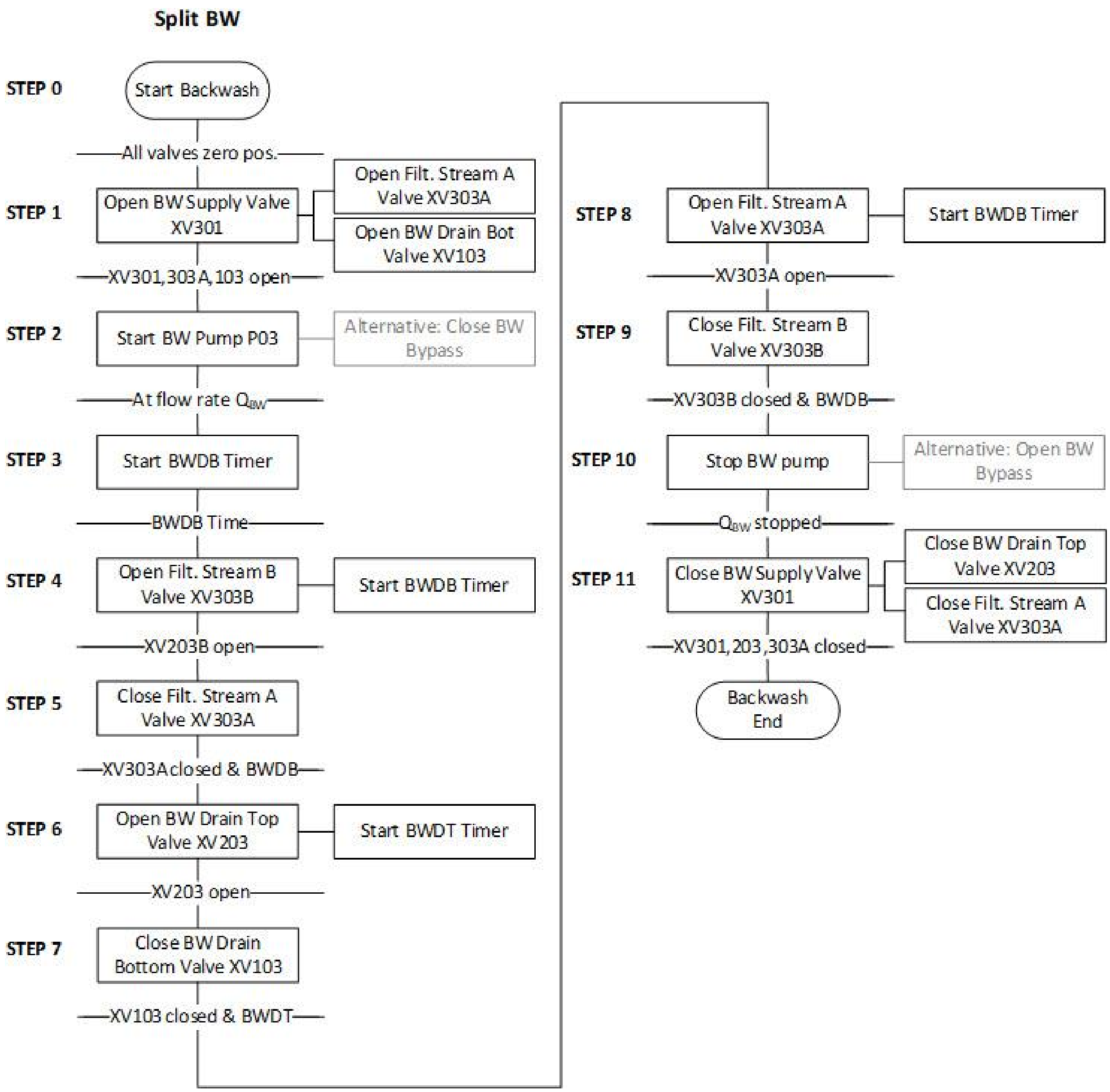

Figure 15. Detailed description split backwash program

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2.5 Chemically Enhanced Backwash

2.5.1 Introduction

CEB is required to occur on a regular base throughout the UF operation. There are various possibilities to implement CEB steps into the UF system automation. One possibility to implement CEB into the automation programming is by the use of CEB counters.

CEB counters are based on filtration cycle count. CEBs are triggered after completion of a defined number of filtration cycles. CEB counters are typically preferred in smaller UF systems and for continuous operation.

Alternatively, particularly for larger UF systems, CEBs can be implemented based on initiation from control logic due to runtime accumulation or through other automatic or manual trigger

A CEB queue must be introduced to handle multiple CEB requests as only one UF train is allowed to perform CEB at any moment. UF train CEB requests are queued in the order received and performed after completion of subsequent CEB step, as directed by the program logic. It is essential to perform both CEB1 steps (CEB1.1 followed by CEB1.2) for any UF train before performing CEB on the subsequent UF train from the CEB queue.

Any CEB consist of a chemical injection step, a soaking step, and a rinsing step:

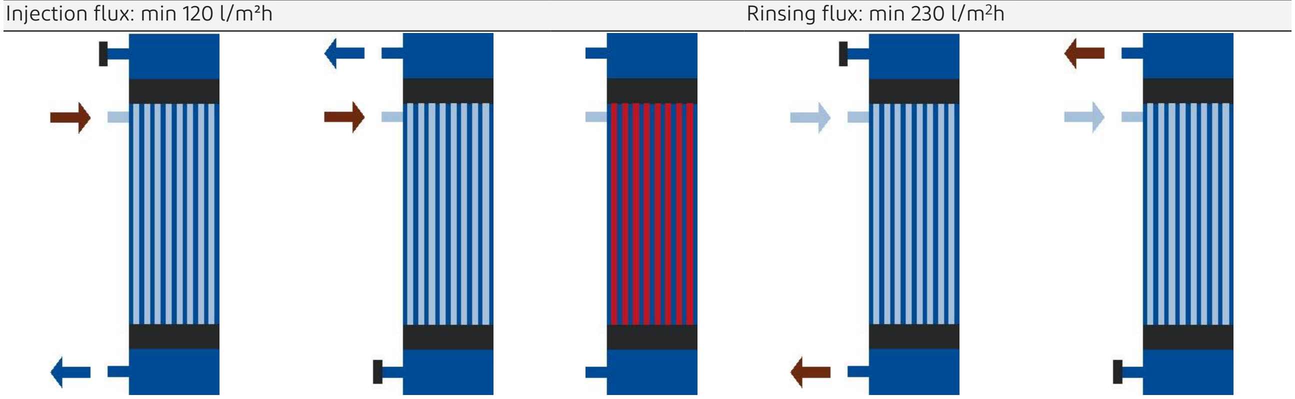
Chemical injection is initiated like a BW Drain Bottom. This step is referred to as Injection Drain Bottom. Here, the UF train is placed into BW Drain Bottom position. The BW pump(s) are initially operated at high rate of 230 l/(m²h) for backwashing the membranes (replaces BW after filtration) before chemical injection starts. When the BW pump flow target is reached, BW flow at high rate is maintained for a defined duration, then chemical pumps are started, and the BW pump flow rate is decreased to 120 l/(m²h). Injection drain bottom is continued until injection drain bottom timer expires.

After completion of the Injection Drain Bottom, the Injection Drain Top step begins. Injection process is switched to injection drain top by opening the BW Drain Top valve and in turn closing the BW Drain Bottom valve. Chemical pumps are turned off shortly before the end of the injection procedure to optimize chemical consumption.

Once the injection of chemicals is completed, the soaking step is started. Here, chemicals inside the UF train are allowed to break down the residual membrane foulants for a fixed duration, the soaking time. All valves are closed in this process step.

Once soaking is completed, the chemicals are rinsed out of the UF modules. Rinsing procedure follows the exact same process steps as backwash; however, rinsing duration may differ from BW duration.

Chemical injection		**Soak period**	**Chemical rinse-out**	
BW Drain Bottom	BW Drain Top		BW Drain Bottom	BW Drain Top
Injection flux: min 120 l/m²h			Rinsing flux: min 230 l/m²h	



e.g., 70 s	e.g., 20 s	5 – 60 min	e.g., 30 s	e.g., 30 s

Figure 16. The Chemically Enhanced Backwash (CEB) process with typical parameters (from UF Process and Design Guidelines)

2.5.2 Process flow chart

In below figure, the process flow charts of the CEB1.1 and CEB1.2 programs are presented.

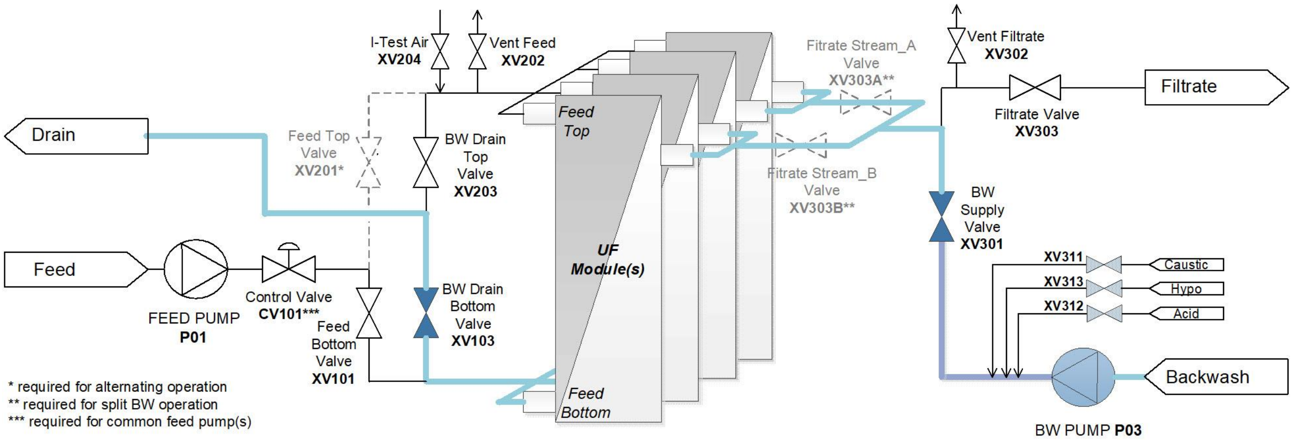


Figure 17. Process flow chart of the CEB 1.1/1.2 program: Injection bottom

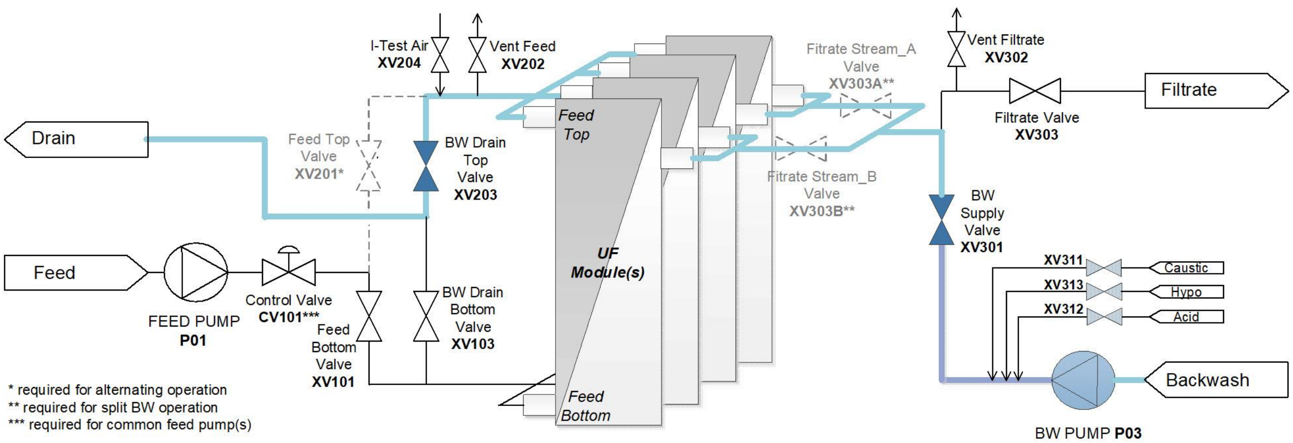


Figure 18. Process flow chart of the CEB1.1/1.2 program: Injection top

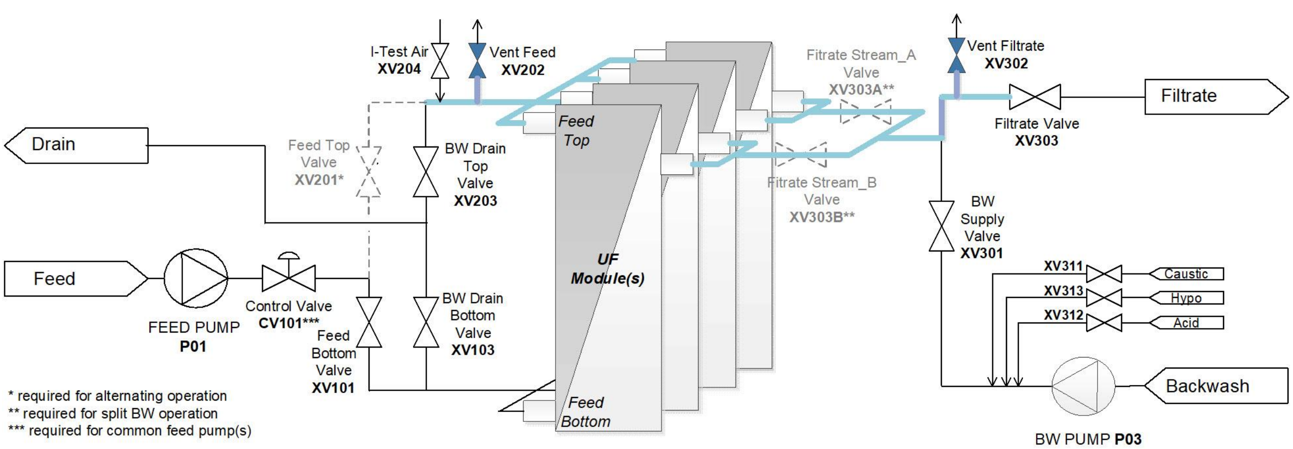


Figure 19. Process flow chart of the CEB1.1/1.2 program: Soaking

2.5.3 Control sequence

In below CEB programs, the following chemical dosing sets are applied:

CEB 1.1 { Caustic soda (NaOH) dosing
Sodium hypochlorite (NaOCl) dosing

CEB 1.2 { Hydrochloric acid (HCl) or sulfuric acid (H_2SO_4) dosing

In below tables, the control sequence for above specified CEB1.1 and CEB1.2 program control sequence, rates, and timers are presented:

Table 9. CEB 1.1 program control sequence

CEB1.1 Program	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9
Backwash Pump (P03)	S	S	R	R	R	R	R	S	S	S
Acid dosing flow/valve (XV312)	●	●	●	●	●	●	●	●	●	●
Caustic dosing flow/valve (XV311)	●	●	●	○	○	○	●	●	●	●
Hypo dosing flow/valve (XV313) *	●	●	●	○	○	○	●	●	●	●
BW Supply Valve (XV301) opt: (XV303A&B)	●	○	○	○	○	○	○	○	●	●
BW Drain Top Valve (XV203)	●	●	●	●	○	○	○	○	●	●
BW Drain Bot Valve (XV103)	●	○	○	○	○	●	●	●	●	●
Feed Vent Valve (XV202)	●	●	●	●	●	●	●	●	○	○
Filtrate Vent Valve (XV302) opt: (XV303A&B)	●	●	●	●	●	●	●	●	○	○
○ Open			Step 10: all valves closed; all pumps off R Running (* optional, application specific)							
● Close			S Stopped							

Table 10. CEB 1.2 program control sequence

CEB1.2 Program	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9
Backwash Pump (P03)	S	S	R	R	R	R	R	S	S	S
Acid dosing flow/valve (XV312)	●	●	●	○	○	○	●	●	●	●
Caustic dosing flow/valve (XV311)	●	●	●	●	●	●	●	●	●	●
Hypo dosing flow/valve (XV313) *	●	●	●	●	●	●	●	●	●	●
BW Supply Valve (XV301) opt: (XV303A&B)	●	○	○	○	○	○	○	○	●	●
BW Drain Top Valve (XV203)	●	●	●	●	○	○	○	○	●	●
BW Drain Bot Valve (XV103)	●	○	○	○	○	●	●	●	●	●
Feed Vent Valve (XV202)	●	●	●	●	●	●	●	●	○	○
Filtrate Vent Valve (XV302) opt: (XV303A&B)	●	●	●	●	●	●	●	●	○	○
○ Open			Step 10: all valves closed; all pumps off R Running (* optional, application specific)							
● Close			S Stopped							

Table 11. Process variables CEB program

Process Variable Description	Abbreviation	Default / Typical
Injection Drain Bottom Timer	IDB	70 s
Injection Drain Top Timer	IDT	20 s
Post Dosing Timer	PDT	tbd
CEB 1.1 Soak Timer	ST1	15 min
CEB 1.2 Soak Timer	ST2	15 min
CEB Backwash Flow Rate	Q_{CEB}	120 $l/m^2/h$ * Module Surface Area * Modules per Train

In below figure, the detailed description of each step is presented in SFC language.

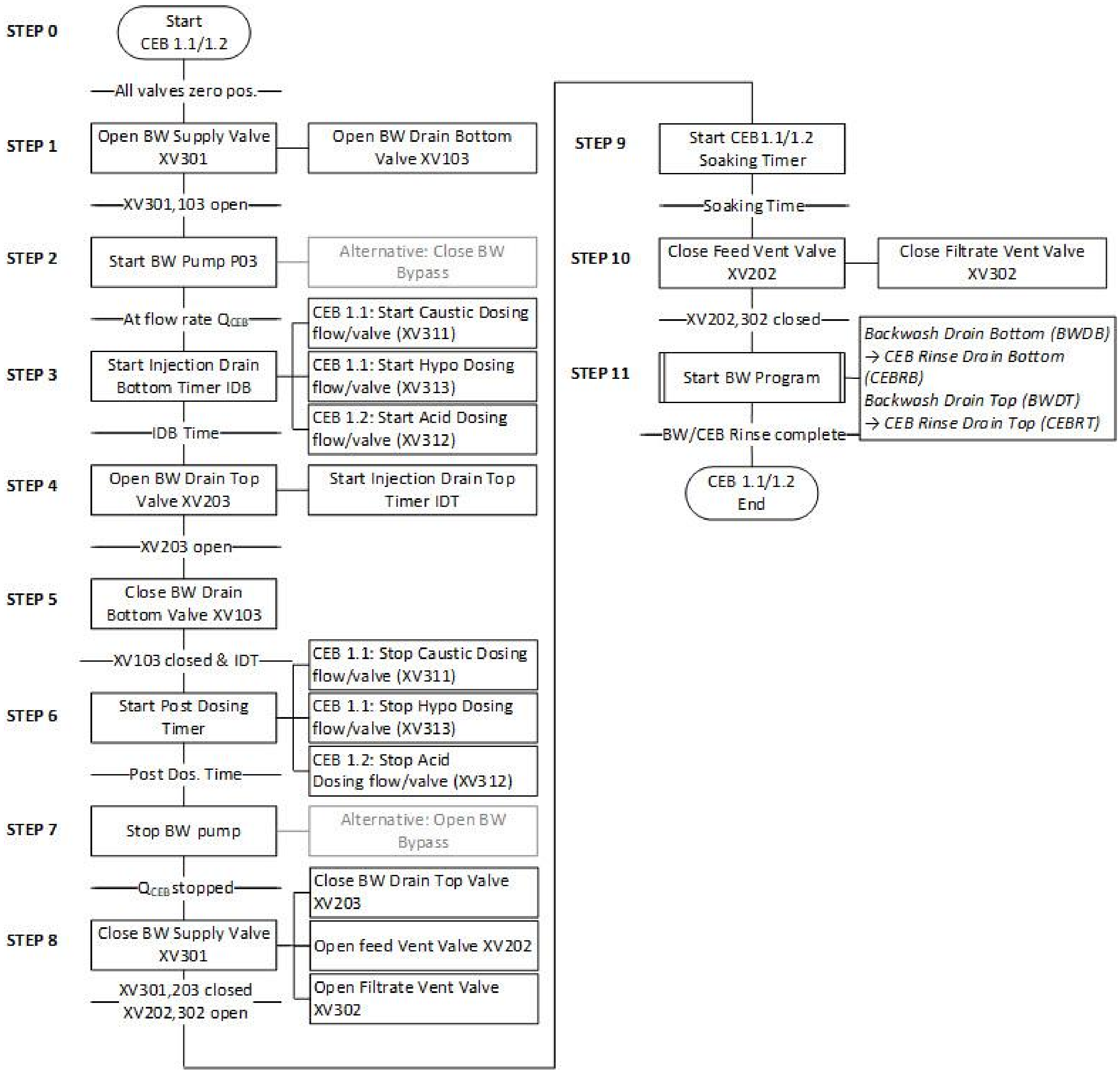


Figure 20. Detailed description of CEB 1.1/1.2 program

2.6 Fill UF Rack

2.6.1 Introduction

Filling the UF rack is accomplished by opening Feed and Filtrate Vent valves. Next, pressurized UF feed is supplied by opening the Filtration Bottom valve and ultimately the UF feed Control valve. Feed flow rate is set to 0.5m^3/h per UF module. Thus, a UF train with 120 UF modules is filled at a rate of 60m^3/h. Filling the UF rack lasts as a default for 10 minutes or as determined during commissioning. Filling the UF rack is completed when a continuous water flow is observed from both, Feed and Filtrate Vent valves.

2.6.2 Process flow chart

In Figure 21, the process flow chart of the Fill UF Rack program is presented.

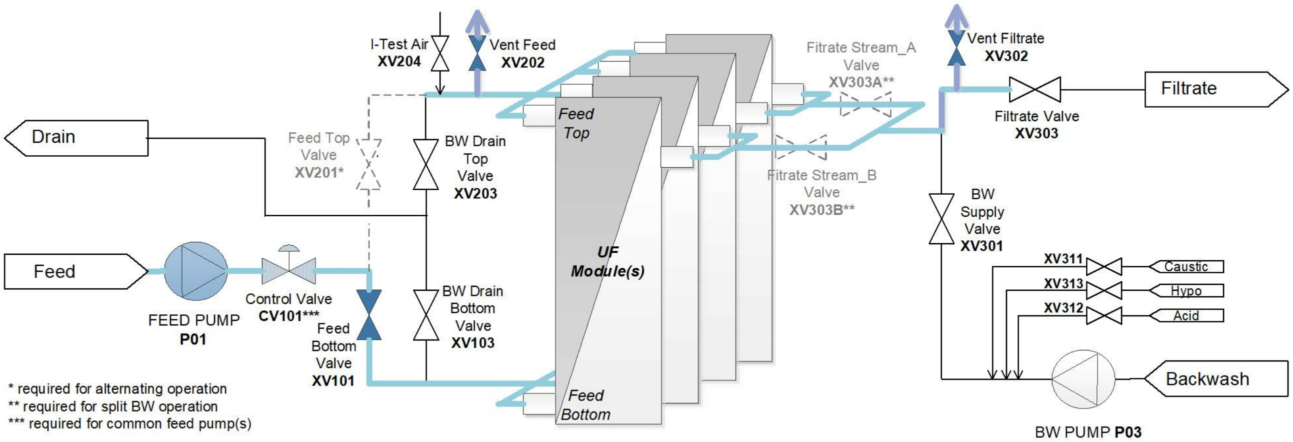


Figure 21. Process flow chart of the Fill UF Rack.

2.6.3 Control sequence

In below tables, the Fill UF Rack program control sequence, rates, and timers are presented.

Table 12. Fill UF Rack program control sequence

Air Integrity Test Program	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Feed pump	S	S	R	R	S	S			
Control Valve (CV101)	●	●	○	○	●	●			
Feed Bottom Valve (XV101)	●	○	○	○	○	●			
Feed Vent Valve (XV202)	●	○	○	○	○	●			
Filtrate Vent Valve (XV302) opt: (XV303A&B)	●	○	○	○	○	●			
○ Open			R Running						
● Close			S Stopped						

Table 13. Process variables Fill UF Rack program

Process Variable Description	Abbreviation	Default / Typical
Fill UF Rack Time	FILT	600 s
Fill UF Rack Flow Rate	Q_{FILL}	0,5m^3/h * no. of modules per train

In below figure, the detailed description of each step is presented in SFC language.

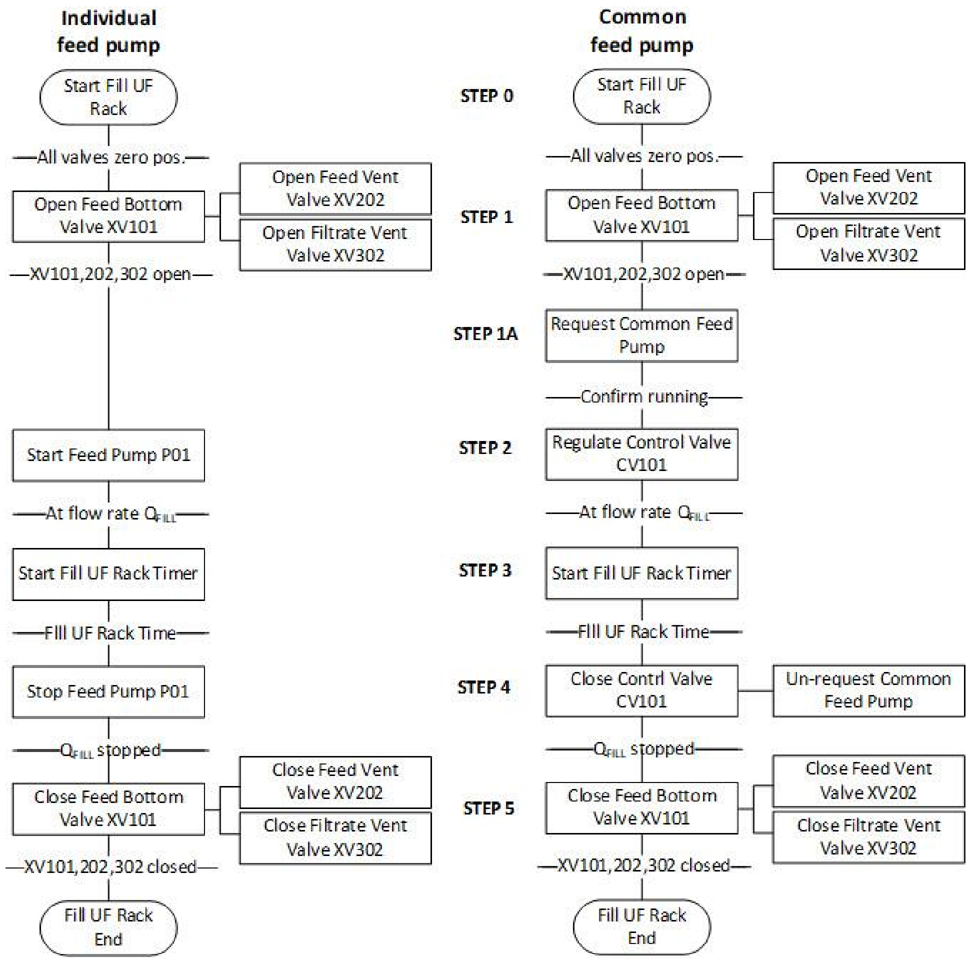


Figure 22. Detailed description Fill UF Rack program

2.7 Integrity Test

2.7.1 Introduction

Compressed air (air @ 1.0 barg, class 1.4.1) is introduced to the UF feed side during the first step of the integrity test. As the UF feed side is becoming filled with compressed air, residual feed water is pushed through the UF membrane to the UF filtrate side from where water is discharged through the filtrate vent valve or alternative points of discharge. Once only compressed air remains in the UF feed side, the air pressure stabilizes at the air supply pressure rate (must be set to 1.0 bar). Described sequence is referred to as I-Test de-watering.

After completion of the de-watering step, the air inlet valve is closed and air pressure should remain stable as enclosed compressed air has no means of escape, only through a potential rupture in the UF membrane. UF feed pressure is stored as the start I-Test pressure reading and a preset timer (e.g., 10 min) is initiated. Once timer expires, UF feed pressure is read once more and stored as the final I-Test pressure and pressure decay rate (if any) is calculated and displayed in mbar/min. The maximum allowed pressure decay is 10 mbar/min for all inge® UF train configurations. The described sequence is referred to as I-Test measurement.

Compressed air is relieved from the UF system by opening the feed vent valve, allowing compressed air to discharge. Described sequence is referred to as I-Test pressure relief.

Ultimately, after completion of the pressure relief sequence, a filling procedure is initiated to purge all remaining air from UF system. Once the filling procedure is completed, normal UF operation can be restarted.

The UF train must be stopped after previous BW before the procedure can be initiated.

2.7.2 Process flow chart

In below figure, the process flow chart of the air integrity test program is presented.

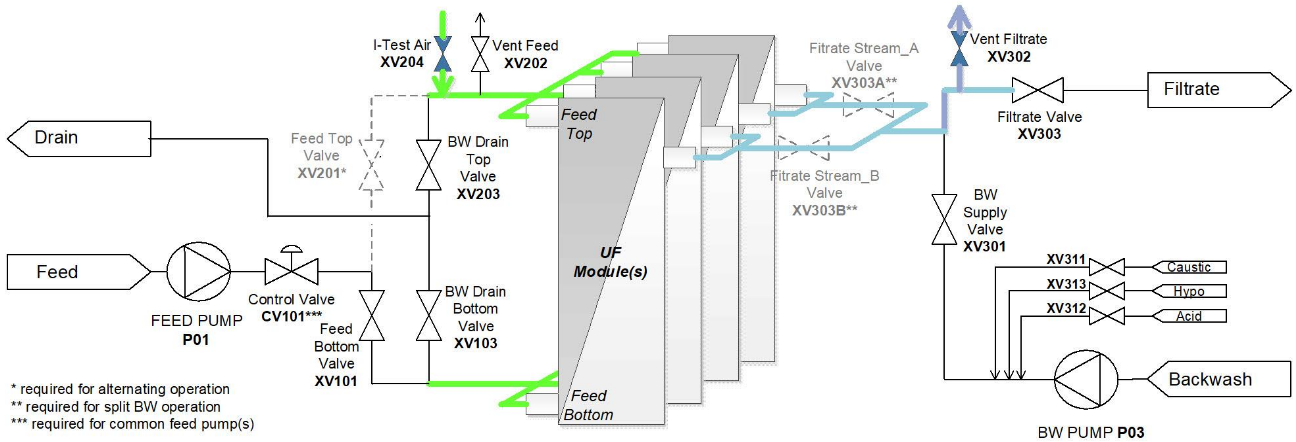


Figure 23. Process flow chart of the air integrity test. Pressurization with air @ 1,0 bar until stabilization

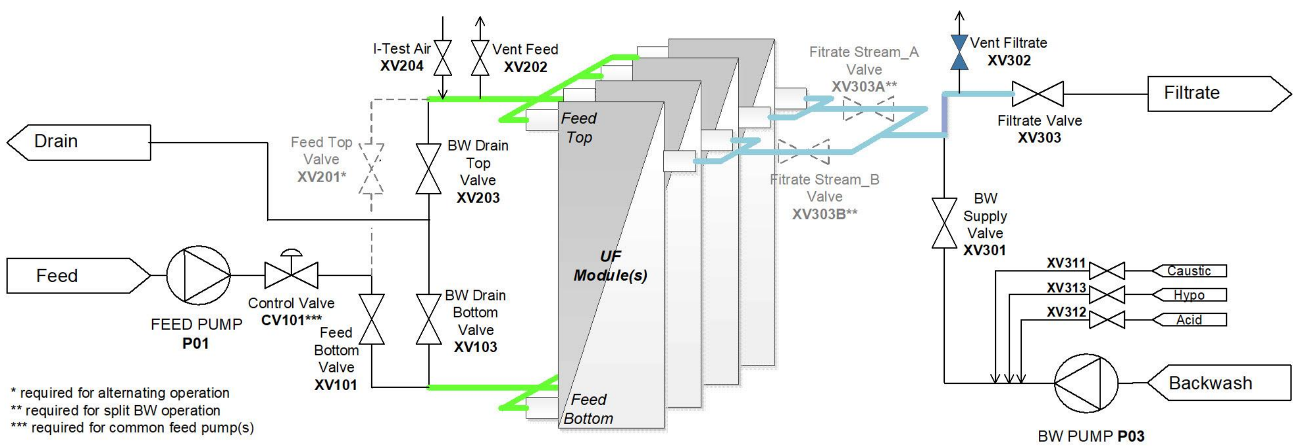


Figure 24. Process flow chart of the air integrity test. Measure pressure decay over 5 min with air supply closed

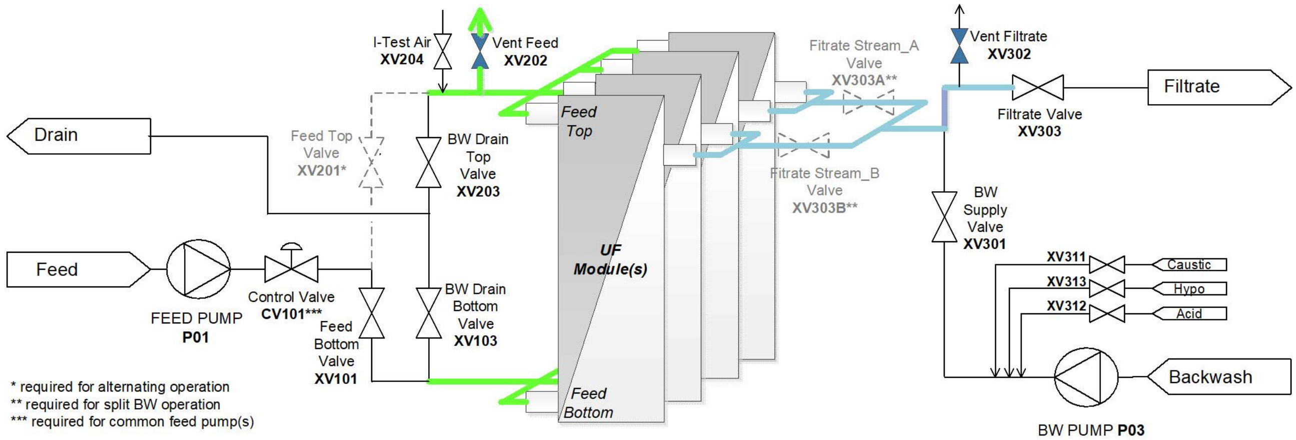


Figure 25. Process flow chart of the air integrity test. De-Pressurization

2.7.3 Control sequence

In below tables, the air integrity test program control sequence, rates, and timers are presented.

Table 14. Air integrity test program control sequence

Air Integrity Test Program	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
I-Test Air Valve (XV204)	●	●	○	○	●	●	●	●	●
Feed Vent Valve (XV202)	●	●	●	●	●	●	○	○	●
Filtrate Vent Valve (XV302)	●	○	○	○	○	○	○	○	●
opt: (XV303A&B)									
○ Open				R Running					
● Close				S Stopped					

Table 15. Process variables integrity test program

Process Variable Description	Abbreviation	Default / Typical
AIT Pressurization Timer		tbd
AIT Measurement Timer		300 s
AIT Depressurization Timer		5 s

In below figure, the detailed description of each step is presented in SFC language.

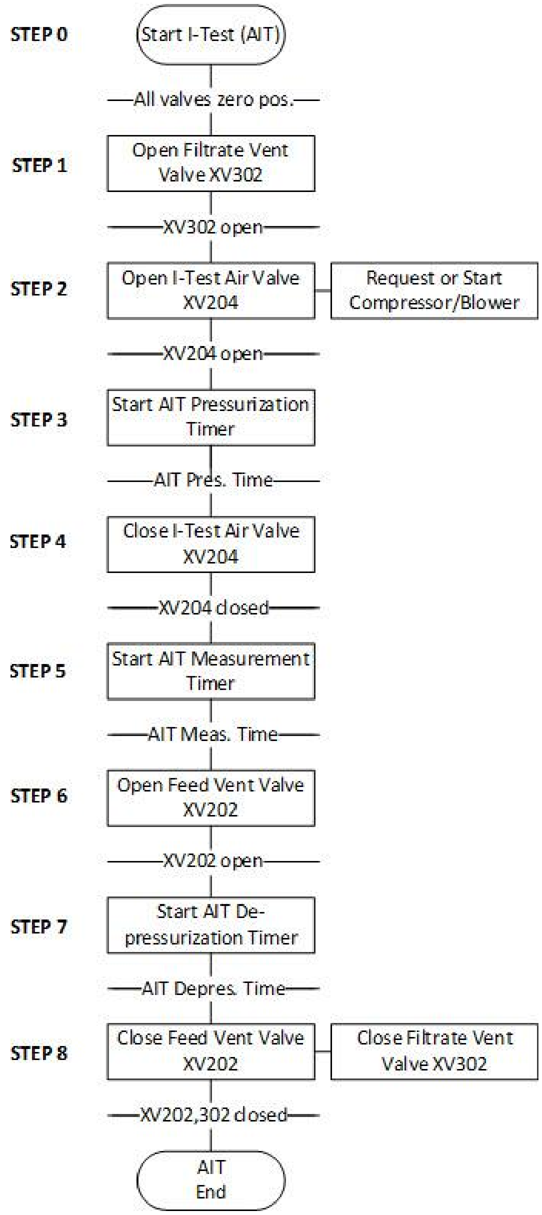


Figure 26. Detailed description air integrity test program

2.8 CIP

2.8.1 Introduction

A CIP is performed by recirculating a chemical batch solution from the CIP tank through the UF feed bottom port and returned through the UF feed top port back to the CIP tank. The process is allowing chemical cleaning solution to flow alongside the UF membrane (crossflow). Once the CIP feed recirculation is completed (e.g., after 1h), the UF filtrate port is additionally opened, and chemical cleaning solution is now allowed to flow alongside the membrane and also through the membrane into the UF filtrate side. Ratio of filtrate return flow rate compared to feed return flow is uncritical and acceptable is the range of 20-80%. This process is referred to as CIP feed filtrate recirculation.

Once the recirculation has been completed, the CIP pump is stopped, and all valves are closed. Now, the soaking time starts. Typically, soaking times can be 1-2 hours but also much longer, depending on nature of membrane fouling contaminants.

After completion of the soaking, the standard CEB rinsing procedure is used to rinse out the remaining chemicals and prepare the UF system for normal operation.

2.8.2 Process flow chart

In below figures, the process flow chart of the forward flush program is presented.

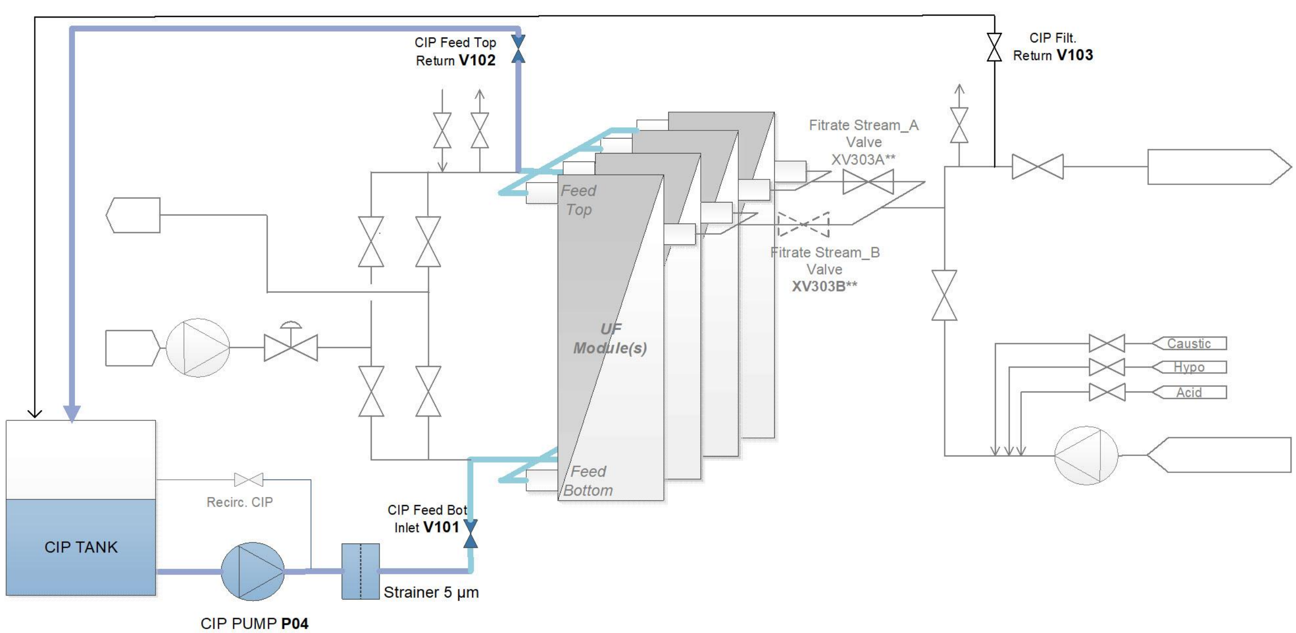


Figure 27. Process flow chart of the CIP backwash top recirculation program

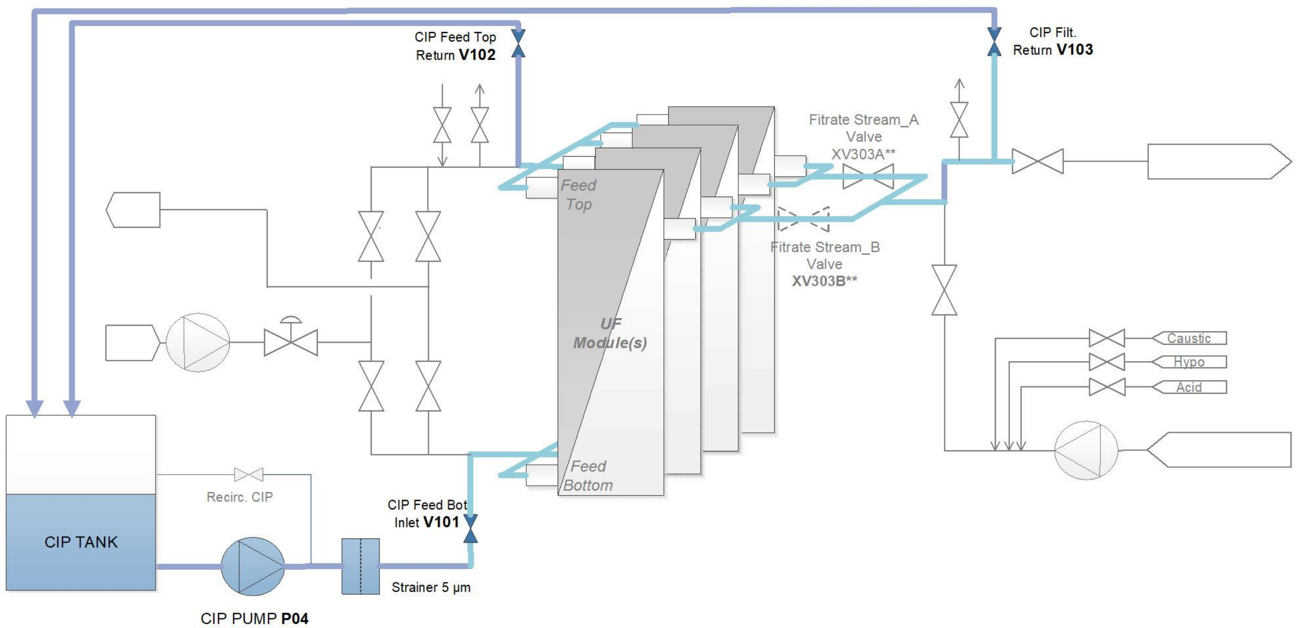


Figure 28. Process flow chart of the CIP backwash top & filtrate recirculation program

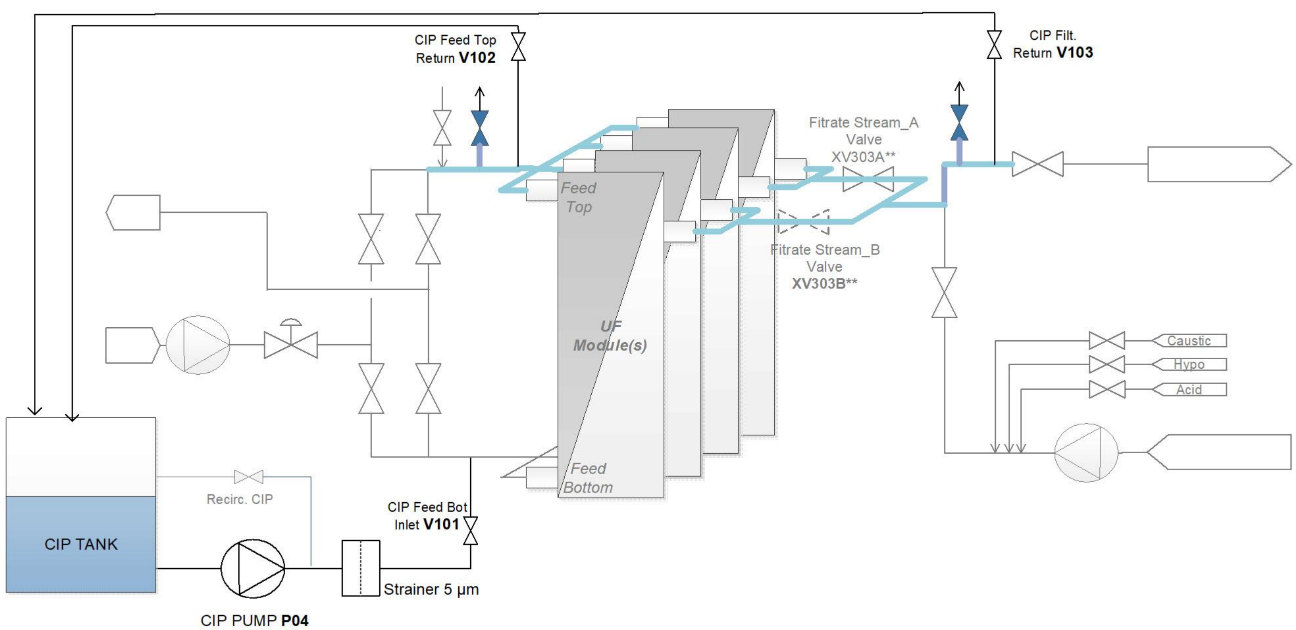


Figure 29. Process flow chart of the CIP soaking program

2.8.3 Control sequence

In below tables, the CIP program control sequence, rates, and timers are presented.

Table 16. CIP program control sequence

CIP Program	Step 0	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9
CIP pump P04	S	S	R	R	R	R	S	S	S	S
CIP Feed Bot Inlet Valve (V101)	●	○	○	○	○	○	○	●	●	●
CIP Feed Top Ret Valve (V102)	●	○	○	○	○	○	○	●	●	●
CIP Filtrate Return Valve (V103) opt: (XV303A&B)	●	●	●	●	○	○	○	●	●	●
Feed Vent Valve (XV202)	●	●	●	●	●	●	●	○	○	●
Filtrate Vent Valve (XV302) opt: (XV303A&B)	●	●	●	●	●	●	●	○	○	●
○ Open			R Running							
● Close			S Stopped							

Table 17. Process variables CIP program

Process Variable Description	Abbreviation	Default / Typical
CIP Flow Rate	Q_{CiP}	25 l/m²/h * Module Surface Area * Modules per Train
CIP Recirculation Feed Timer		60 min
CIP Recirculation Feed / Filtrate Timer		60 min
CIP Soak Timer		120 min
CIP Flush Timer		5 min

In below figure, the detailed description of each step is presented in SFC language.

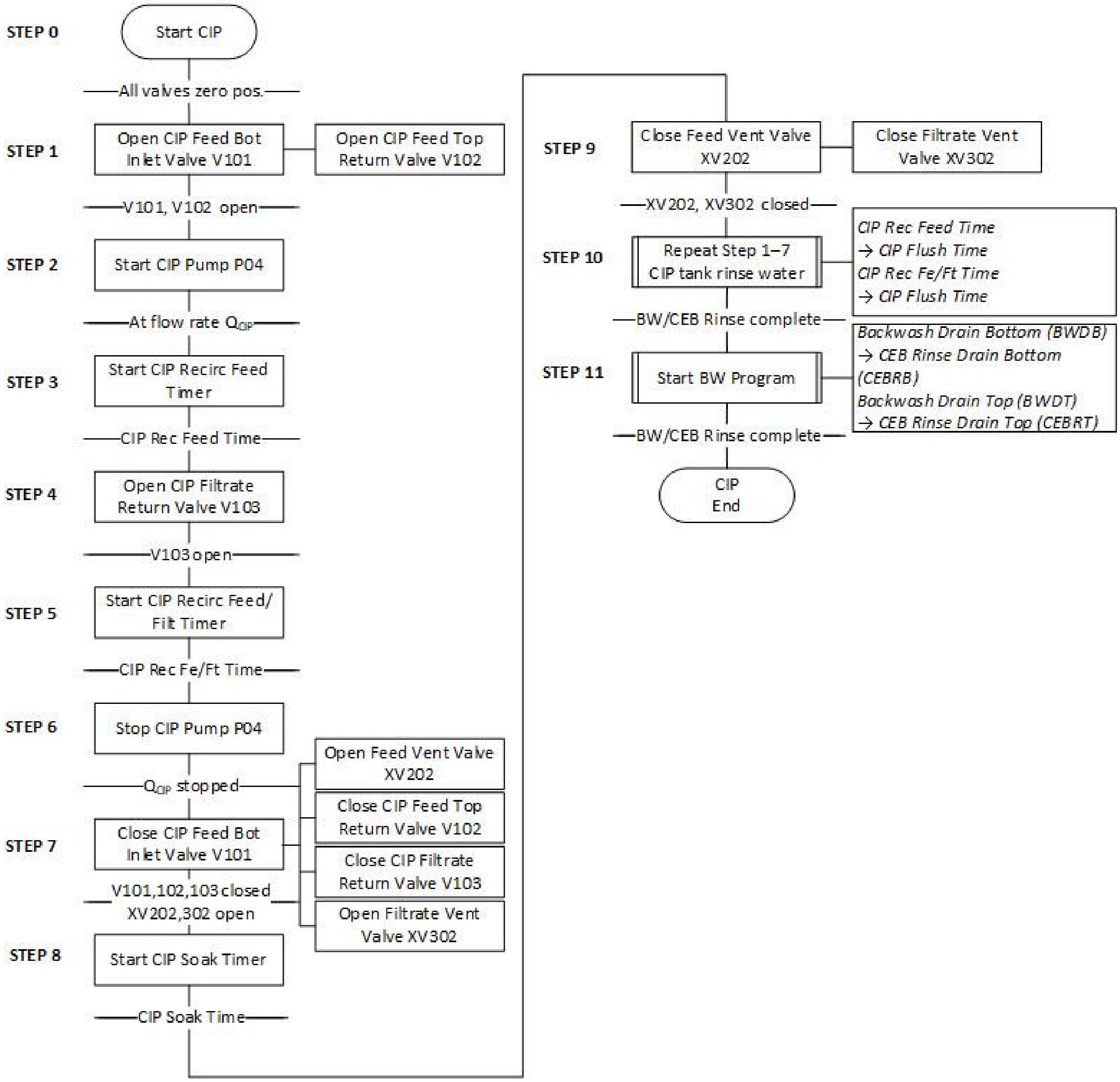


Figure 30. Detailed description CIP program

3 Automatic Operation

3.1 inge® UF Automatic Program Sequence

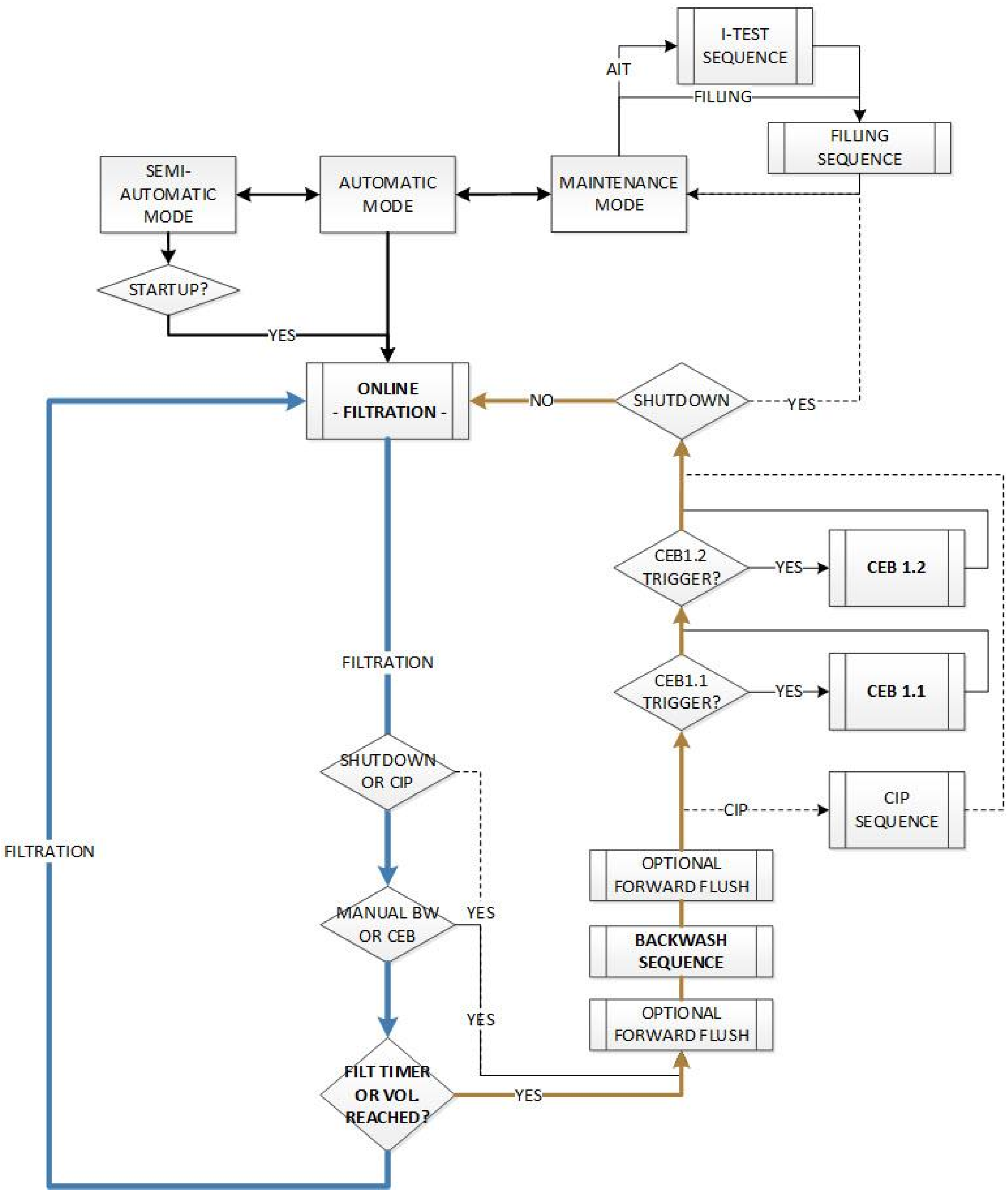


Figure 31. inge® UF Automatic Program Sequence

Figure 31 depicts the automatic operation sequence. In automatic operation, the UF unit starts with the filtration program. When the filtration time or volume is reached, the backwash including optional forward flush is activated. After completion of the backwash, the backwash counter is incremented and checked for required count to start CEB1.1. Once CEB1.1 is completed, CEB1.2 is typically activated, however, CEB1.2 can be delayed by one or more backwash counts, depending on project preference. After completion of the CEB, the program returns to filtration mode.

Sequence functionality should include the option to interrupt the filtration program for CEB or CIP even without reaching the required filtration time or volume. This option can be requested by intervention of the PLC or by manual process selection. In each case, a backwash with optional forward flush is performed, optionally followed by selected CEB or CIP protocol. After completion of the CEB or CIP protocol, the program is either stopped (selection shutdown, maintenance mode) or returned to filtration mode.

From maintenance mode, the program can either be returned to automatic mode or maintenance procedures, such as integrity test or filling can be performed.

The automatic program sequence as presented here is highly project/client specific and is shown in an exemplary version only.

3.2 Sensor Range, Interlocks & Alarm Limitations

Below table specifies standard limitation values for sensors used within the UF system. Actual process parameters and limitations measured within the UF system may differ from below table and must be adjusted as required on an individual case base.

Table 18. Sensor range, interlock, and alarm table

Parameter & Action Local Alarm (A) Fault UF Train (F)	P&ID Tag No.	Range / Unit	LL Alarm (AF)	L Alarm (A)	H Alarm (A)	HH Alarm (AF)	Alarm delay (typ.)
Direct Measurements							
Feed Turbidity		NTU*	0	0	50	100	600 s
Feed pH		pH units	1	2	12	13	600 s
Feed Temperature		°C	1	5	38	40	30 s
Feed Pressure	PT101	barg	0	0.1	5	6	1 s
Filtrate Pressure	PT301	barg	0	0.1	4	5	1 s
Feed Flow	FT101	m^3/h	0	tba	tba	tba	30 s
BW Flow	FT03	m^3/h	0	tba	tba	tba	30 s
CIP Flow	FT04	m^3/h	0	tba	tba	tba	30 s
Integrity Test Pressure	PT101	barg	0	0.1	1.5	1.6	2 s
Calculated Parameters							
TMP Filtration		barg	0	0.1	1.4	1.5	2 s
TMP Backwash		barg	0	0.1	2.4	2.5	2 s
Normalized Permeability		lmh/bar	0	50	800	1000	2 s
Filtration Flux		$l/(m^2h)$	0	20	100	120	30 s
BW Flux		$l/(m^2h)$	0	20	250	260	30 s
CEB Flux		$l/(m^2h)$	0	20	250	260	30 s
CIP Flux		$l/(m^2h)$	0	5	50	100	30 s
Tank Levels							
UF Feed tank		m	0 0	tba	tba	tba	30 s
UF BW tank		m	0	tba	tba	tba	30 s
CIP tank		m	0	tba	tba	tba	30 s
Neutralization Tank		m	0	tba	tba	tba	30 s
Chemical Tanks		m	0	tba	tba	tba	30 s

Parameter & Action Local Alarm (A) Fault UF Train (F)	P&ID Tag No.	Range / Unit	LL Alarm (AF)	L Alarm (A)	H Alarm (A)	HH Alarm (AF)	Alarm delay (typ.)
Process Timers (one setting for all UF units)							
Filtration Timer	FLT	min M3	tba	tba	tba	tba	1 s
Forward Flush Timer	FFT	sec	tba	tba	tba	tba	1 s
BW Drain Bot Timer	BWDB	sec	tba	tba	tba	tba	1 s
BW Drain Top Timer	BWDT	sec	tba	tba	tba	tba	1 s
Injection Drain Bot Timer	IDB	sec	tba	tba	tba	tba	1 s
Injection Drain Top Timer	IDT	sec	tba	tba	tba	tba	1 s
Post Dosing Timer	PDT	sec	tba	tba	tba	tba	1 s
CEB 1.1 Soak Timer	ST1	sec	tba	tba	tba	tba	1 s
CEB 1.2 Soak Timer	ST2	sec	tba	tba	tba	tba	1 s
Fill UF Rack Time	FILT	sec	tba	tba	tba	tba	1 s
AIT Pressurization Timer		sec	tba	tba	tba	tba	1 s
AIT Measurement Timer		sec	tba	tba	tba	tba	1 s
AIT Depressurization Timer		sec	tba	tba	tba	tba	1 s
CIP Recirc Feed Timer		sec	tba	tba	tba	tba	1 s
CIP Recirc Feed / Filtrate Timer		sec	tba	tba	tba	tba	1 s
CIP Soak Timer		min	tba	tba	tba	tba	1 s
CIP Flush Timer		min	tba	tba	tba	tba	1 s
Process Rates (one setting for all UF units)							
Feed Flow Rate	Q_{FE}	m^3/h	tba	tba	tba	tba	1 s
Filtration Volume	FLV	m^3	tba	tba	tba	tba	1 s
Backwash Flow Rate	Q_{BW}	m^3/h	tba	tba	tba	tba	1 s
CEB Flow Rate	Q_{CEB}	m^3/h	tba	tba	tba	tba	1 s
Fill UF Rack Flow Rate	Q_{FILL}	m^3/h	tba	tba	tba	tba	1 s
CIP Flow Rate	Q_{CIP}	m^3/h	tba	tba	tba	tba	1 s

4 UF Design Fundamentals and Definitions

Flux Rate (J)

$$J\left[\frac{l}{m^2h}\right] = \frac{Q_{Feed}}{A}$$

Q_{Feed} = Feed flow	in [l/h]
A = Active membrane area	in [m^2]

Transmembrane Pressure (TMP)

TMP = $P_{Feed} - P_{Filt}$ + Hydrostatic Offset

$$TMP\ [bar] = \left|\left(\frac{PR200 + PR201}{2}\right) - PR300 + \left[p \times g \times 10^{-5} \times \left(\frac{dh_1 + dh_2}{2} - dh_3\right)\right]\right|$$

PR200: Pressure Feed, Bottom in [bar]

PR201: Pressure Feed, Top in [bar]

PR300: Pressure Filtrate in [bar]

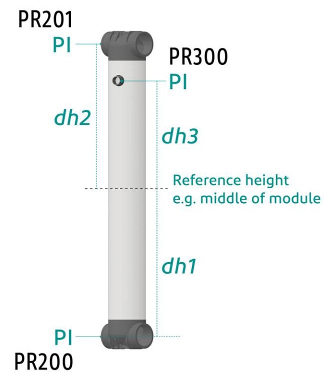
$$\text{Hydrostatic Offset} = \left[p \times g \times 10^{-5} \times \left(\frac{dh_1 + dh_2}{2} - dh_3\right)\right]$$

$dh_{1,2,3}$ = Relative height of pressure sensor

p = Density of filtrated medium (for water ≈ 1000)

g = Gravitational acceleration = 9.81

Note: Hydrostatic offset to be confirmed / measured during commissioning (UF rack filled, all pumps off → TMP=0)



Permeability (P)

$$P\left[\frac{l}{m^2h\ bar}\right] = \frac{J}{TMP}$$

J = Flux rate	in [$l/(m^2h)$]
TMP = Transmembrane Pressure	in [bar]

Temperature Corrected (Normalized) Permeability (P20)

$$P\ 20_{°C}\left[\frac{l}{m^2h\ bar}\right] = T_{K,\ 20°C}\ (T) \times P$$

$$T_{K,\ 20°C}\ (T) = \frac{n\ (T)}{n(20\ °C)} = \frac{n\ (T)}{1.007 \times 10^{-3}}$$

$$n\ (T) = (17.91 - 0.60T + 0.013\ T^2 - 0.00013\ T^3) \times 10^{-4}$$

P20 °C = Permeability	in [$l/(m^2hbar)$]
P = Permeability	in [$l/(m^2hbar)$]
= Temperature	in [°C]
$T_{K,\ 20°C}$ (T) = Temp. correction factor	in [-]
n = Dynamic viscosity	in [Pa s]
n (20 °C) =	

Temperature Corrected Permeability Rule of thumb: 3% per °C (very accurate > 20 °C)

Recovery (Φ)

$$\Phi\ [\%] = \frac{V_{Filt} \times 100}{V_{Feed} \times 100\%} = \frac{Q_{Feed} \times t_{Feed} - Q_{BW} \times t_{BW} - Q_{CEBinj} \times t_{CEBinj} - Q_{CEBrinse} \times t_{CEBrinse}}{Q_{Feed} \times t_{Feed} + Q_{FF} \times t_{FF}}$$

V_{Filt} = Usable filtrate volume per day

V_{Feed} = Feed volume per day

Q_{Feed} = Feed flow

Q_{BW} = Backwash flow

Q_{CEBinj} = CEB injection flow

$Q_{CEBrinse}$ = CEB rinse out flow

Q_{FF} = Forward flush flow

t_{Filt} = Net filtration time per day

t_{BW} = Net backwash time per day

t_{CEBinj} = Net CEB injection time per day

$t_{CEBrinse}$ = Net CEB rinse out time per day

t_{FF} = Net forward flush time per day

Daily average recovery (single value at 24 h interval):

$$\Phi_{\text{daily, avg.}} [\%] = \left(\frac{\text{Totalizer}_{\text{Flowmeter, Filt}} @23:59h}{\text{Totalizer}_{\text{Flowmeter, Feed}} @23:59h} - \frac{\text{Totalizer}_{\text{Flowmeter, Filt}} @0:00h}{\text{Totalizer}_{\text{Flowmeter, Feed}} @0:00h} \right) \times 100$$

Rejection (R)

$$R [\%] = \left(1 - \frac{C_{Filt}}{C_{Feed}} \right) \times 100\%$$

R = Rejection	in [%]
c = Concentration	in e.g. [mg/l], [mol/l]

Dosage of Coagulant (V_{coag})

$$V_{coag} \left[\frac{ml}{h} \right] = \frac{d \times Q_{Feed}}{c \times p \times 0.01}$$

c = Concentration of Me^{n} + in coagulant	in [% w/w]
d = Set point dosage Me^{n} +	in [mg/l]
Q_{Feed} = Feed flow	in [m^3/h]
p = Density of coagulant	in [kg/l]

5 Data display & logging

The measured data are logged by the PLC. With the flow measurement, both - the total flow volume and the flow rate - must be logged.

Table 19. Data display & logging

No.	Logging	Log Interval (Filt/BW)
1	Feed Pressure	180 s / 2s
2	Filtrate Pressure	180 s / 2s
3	Temperature	180 s / 2s
4	Feed flow rate	180 s / -------
5	BW/CEB flow rate	------- / 2s
6	Turbidity	180 s / -------
7	pH	180 s / -------

5.1 Operator Screens

There are several types of operator Screens required for UF control. Screens for operation must include:

Table 20. Operator screens

No.	Logging
1	Overview Screen: All UF trains with key parameters. Start/Stop and Auto/Manual Functionality. UF train process state such as Filtration, Air Scour, Backwash, Forward Flush or CEB must be displayed.
2	Common timing chart showing UF trains upcoming process steps
3	Common setup screens: Common setup for UF process parameters, incl. CEB set points, Filtrate Volume, Filtration Time etc.
4	Individual UF Screens: P&ID layout with all components and process parameters such as actual flux rate, actual filtration time, opening % control valves, etc. Individual manual initiation all process sequences.
5	Historical data screens: Flux rate, TMP & permeability curves for all UF trains, UF filtrate tank level, feed & filtrate water analytical data, etc.
6	Alarm status, history, and acknowledgement screens

6 List of abbreviations

Abbreviation	Description
AIT	Air Integrity Test
BW	Backwash
CEB	Chemically Enhanced Backwash
CEB 1.1	Chemically Enhanced Backwash 1.1 (NaOH+NaOCl)
CEB 1.2	Chemically Enhanced Backwash 1.2 (H_2SO_4 or HCl)
CIP	Clean In Place
FF	Forward Flush
H	High
H2SO4	Sulfuric acid
HCl	Hydrochloric acid
HH	High-high
L	Low
LL	Low-low
LMH	L/m^{2}h (membrane flux)
MIT	Membrane Integrity Test
NaOCl	Sodium hypochlorite
NaOH	Caustic soda
SFC	Sequential Functional Chart (defined by IEC 61131-3)
SP	Set point
TBD	To be determined
TBA	To be adjusted
UF	Ultrafiltration