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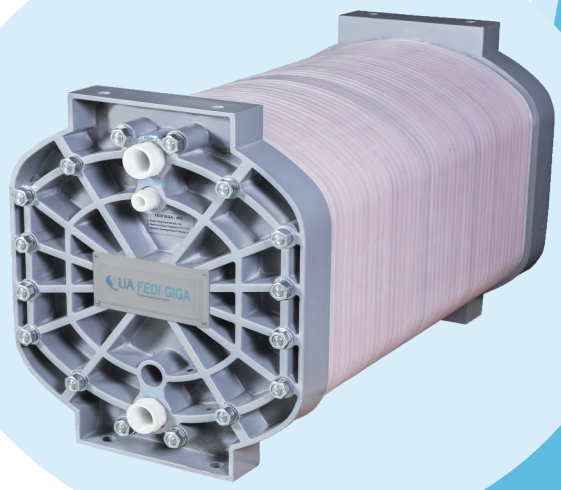


FEDI® GIGA Fractional Electrodeionization Pilot Study: Silica and Boron Removal Efficiency

Objective:

This pilot case study aims to evaluate the efficiency of QUA's FEDI® GIGA stack in removing silica and boron from reverse osmosis (RO) permeate and to assess the product resistivity.

Introduction:

Ultrapure Water (UPW) is a highly purified form of water that undergoes advanced filtration and treatment processes to remove impurities and contaminants, achieving an extremely high purity level. UPW is essential in industries such as semiconductors, pharmaceuticals, and electronics, where stringent water quality standards are necessary.

For the desired UPW grade, water should have high electrical resistance and be free of weakly ionized species such as boron and silica. These ions, particularly boron and silica, are often the first to break through into purified water during UPW production. The combination of multiple stages of purification and separation processes, such as reverse osmosis and electrodeionization (EDI), effectively produces high-quality UPW.

The FEDI® GIGA, a next-generation EDI stack developed by QUA, is designed to produce high-quality UPW with high flow capacity while maintaining a small footprint. Its innovative design features a unique port configuration with one intake and two outlet ports, reducing the amount of piping and instruments required. It is the first EDI stack with three ports (feed, product, and reject).

Methods:

Study Design: A six-month pilot study evaluated the FEDI® GIGA's boron and silica rejection performance.

Interventions: The study was divided into two phases. The FEDI® GIGA stack was tested in the initial phase with 10-20 µS/cm feed conductivity equivalent (FCE). In the second phase, the FEDI® GIGA stack was extensively tested with RO permeate with an FCE load of <10 µS/cm for evaluating silica and boron removal efficiency.

Data Collection: Feed water characteristics and operating conditions of the FEDI® GIGA stack are tabulated in Tables 1 and 2. Product resistivity was measured using an online conductivity sensor, while silica and boron were analyzed using ICP instruments.

Outcome Measures: Primary outcomes included product resistivity, silica removal efficiency, and boron removal efficiency.

Results:

Feed Water Characteristics and Stack Operating Conditions:

The FEDI® GIGA stack was tested with RO permeate characteristics summarized in Table 1. Stack operating conditions are summarized in Table 2.

Table 1: FEDI® GIGA Feed Water Characteristics

Parameter	Unit	Value
pH		6.5 - 8.0
Feed Conductivity Equivalent (FCE)	µS/cm	10 - 20 (initial 250 hours) 5 - 6 (After 250 hours)
Silica	ppb	100 - 250
Total Hardness	ppm	< 0.5
Boron	ppb	50 - 100

Table 2: FEDI® GIGA Operating Conditions

Parameter	Unit	Value
Feed Flow	m^3/hr	7.35 - 8.8
Product Flow	m^3/hr	6.7 - 8.0
Reject Flow	m^3/hr	0.65 - 0.8
Recovery	%	90
DC Current	Amp	8 - 10
DC Voltage	V	200 - 250
DC Power Consumption	KWH/ m^3	0.20 - 0.30

FEDI® GIGA Stack Performance:

The FEDI® GIGA consistently produced high-purity UPW with an average resistivity of 18 MΩ.cm. Silica removal exceeded 95%, and boron removal exceeded 98-99%+. The boron reduction could be greater than 99% because it was below the detection level of the instrument. Performance details are summarized in Table 3.

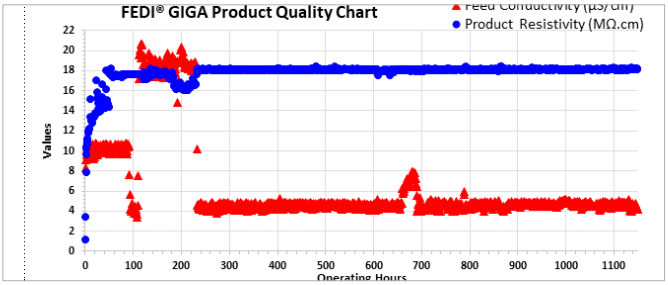
Table 3: FEDI® GIGA Stack Product Quality

Parameter	Unit	Value
pH		6.8 - 7.2
Product Resistivity	MΩ.cm.	17.5 to 18.2
Silica	ppb	<10 ppb
Boron	ppb	<1

Product Resistivity:

In the initial phase, the FEDI® GIGA stack showed 16-17.5 MΩ.cm product resistivity with 10-20 µS/cm feed conductivity. In the later stage, it achieved consistent 18+MΩcm resistivity with <10 µS/cm conductivity. Feed conductivity and product resistivity data are summarized in Figure 1.

Figure 1:



Silica Removal Efficiency:

Feed silica (SiO_2) ranged between 100-250 ppb with product silica <10 ppb, summarized in Figures 2 and 3. This resulted in more than 95% removal efficiency, as summarized in Figure 4.

Figure 2:

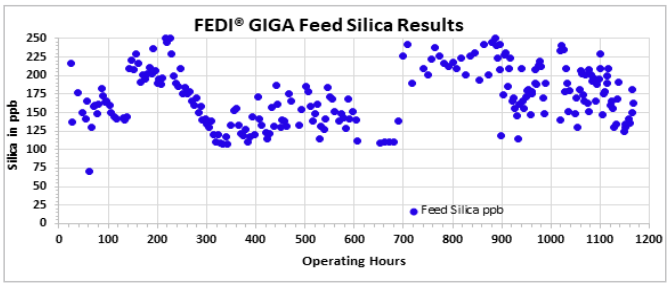


Figure 3:

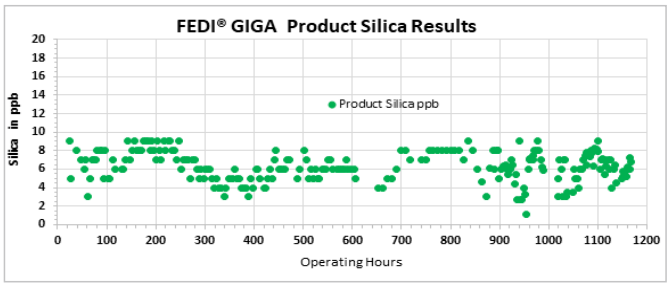
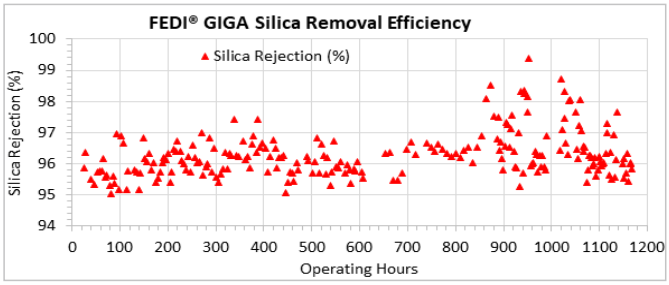


Figure 4:



Boron Removal Efficiency:

During the initial testing phase, boron monitoring was not conducted due to the unavailability of the ICP-MS instrument. After 500 hours of operation, regular boron monitoring was completed through an external lab. The boron level in the FEDI® GIGA stack feed ranged between 50-100 ppb, and the system demonstrated more than 98% boron removal efficiency at a flow rate of 6.7 m^3/hr and DC current of 8-10 amperes. The boron results of the study are summarized in Table 4. The limit of quantification (LOQ) of the ICP instrument was 1 ppb; therefore, any value below this threshold was reported as <1LOQ in the FEDI® GIGA product sample. Several lab reports are attached in the Appendix.

Table 4: Boron Results of FEDI® GIGA Stack

Stack Operating Hours	Feed Water (ppb)	Product Water (ppb)	Removal Efficiency (%)
552	60	< 1	> 98.33
771	60	< 1	> 98.33
773	50	< 1	> 98.00
780	40	< 1	> 97.50
782	40	< 1	> 97.50
791	55	< 1	> 98.18
800	62	< 1	> 98.39
802	61	< 1	> 98.36
809	74	< 1	> 98.65
818	80	< 1	> 98.75
827	88	< 1	> 98.86
836	82	< 1	> 98.78
906	79	< 1	> 98.73
915	78	< 1	> 98.72
924	78	< 1	> 98.72
933	98	< 1	> 98.98
942	100	< 1	> 99.00
1036	95	< 1	> 98.95
1044	88	< 1	> 98.86
1052	99	< 1	> 98.99
1060	108	< 1	> 99.07
1068	101	< 1	> 99.01

Conclusion:

The pilot study demonstrated that the FEDI® GIGA stack effectively yields high-purity water and removes weakly ionized ions like silica and boron. The technology consistently achieved product resistivity around 18 MΩ.cm with a 5-6 µS/cm FCE load, and removed over 95% of silica and over 98-99% of boron from the feed water. The boron value in FEDI® GIGA product water was < 1 ppb from a feed range between 50-100 ppb and was less than the level of quantification, as seen in Appendix Report 2. These results meet the water quality requirements of the semiconductor and microelectronics industries.