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Dow™ EDI Modules perform well at bioenergy combines in Scandinavia

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ABSTRACT

A modern bioenergy combine in Scandinavia that uses the combination of DOWEX™ ion exchange resins, DOW FILMTEC™ RO elements and DOW™ EDI technologies is presented in this article. There are two options to achieve a very low conductivity permeate required for the high purity boiler feed water; to use mixed bed ion exchange resins (IER) or electrodeionization (EDI) modules as polishers. The present study reflects the advantages of using EDI versus IER. It also describes the continuous and good performing capacity of DOW™ EDI units at a power plant in Sweden during 15 months.

Keywords: Electrodeionization (EDI); Ion exchange resins (IER)

1. Introduction

This Dow case study introduces Dow's spiral wound electrodeionization (EDI) technology and its excellent operation in one of the most modern bioenergy power plants in Sweden.

EDI technology is a separation process that combines electrodialysis and conventional ion exchange. EDI is used to polish reverse osmosis (RO) permeate of any residual ionic impurities. EDI is gaining popularity in Europe due to the environmental and economical benefits of eliminating acid and caustic regenerants used for mixed bed deionizers and because it is a continuous process not a variable batch operation.

DOW™ electrodeionization technology already has several reference plants in the USA and China in the water treatment industry including several cogeneration installations that were designed using DOW EDI technology.

The bioenergy combine power plant in Sweden generates around 48 GWh of electricity and 40 GWh of heat every year. The water available to the plant is tap water which needs to be demineralized before entering the boiler. The final polishing is done by EDI technology to remove the remaining silica and hardness to the level acceptable for the turbine. It has become a common water treatment sequence in the Nordic countries to use a softener followed by single pass RO and EDI system as a polisher.

In the present study Water Processing Sweden AB decided to select Dow as the supplier of the components to complete water treatment process. Water Processing Sweden AB is a Dow original equipment manufacturer (OEM) that relies on Dow Water & Process Solutions products to helping them succeed in the water treatment market segment.

Tap water is first softened with DOWEX™ ion exchange resins, demineralized with DOW FILMTEC™ RO elements and polished with DOW™ electrodeionization 210 modules. The capacity of the RO system is 6 m^3/h and that of the EDI is 5.5 m^3/h. The RO feed

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Table 1
Raw water analysis

Parameter	Measure (mg/L)
K	0.81
Na	1.10
Mg	2.10
Ca	11
CO_3	0.07
HCO_3	42
NO_3	0.50
Cl	1.80
F	0.18
SO_4	5.60
SiO_2	1
CO_2	1.86
TDS	66.17
pH	7.60

Table 2
Softened raw water analysis

Parameter	Measure (mg/L)
K	0.81
Na	19.55
Mg	0.00
Ca	0.10
CO_3	0.07
HCO_3	42.00
NO_3	0.50
Cl	1.80
F	0.18
SO_4	5.60
SiO_2	1.00
CO_2	1.89
TDS	71.62
pH	7.60

water has a silica concentration of 1 ppm and 71.6 ppm of total dissolved solids (TDS). EDI product water can help to satisfy the client's needs, with a silica concentration reduced to <10 ppb and product water resistivity increased to more than 15 Meg Ohm-cm.

Dow Water & Process Solutions can offer a broad range of high-class state of the art component technologies designed for water purification. DOW EDI modules are economical and reliable technology for boiler feed water to the power plants.

This paper will describe the design and construction of the makeup water system. It is intended to serve as a prototype for similar units around the world.

2. Power plant description

The bioenergy combine is operated by Skellefteå Kraft, which is Sweden's fourth largest energy producer and it is also a leader in the development of environmentally friendly electricity production.

The power plant is located in Storuman, Sweden, due to the easy access to raw biomaterial. One of the motivations to localize the plant there was to minimize the on-site bulk combustible materials storage as well as to eliminate transportation of these products.

The plant went online in 2008 and since then it produces district heating, biopellets and renewable electric power. It has an energy yield of 98%. The plant generates 32 MW of electricity in the boiler and produces 16 ton/h of biopellets.

Water Processing Sweden AB, an engineering company specializing in water treatment technologies, selected to use DOWEX™ ion exchange resin, DOW FILMTEC™ RO elements and DOW™ electrodeionization 210 modules to provide the demineralized water required as makeup to the steam generators.

One of the main factors in making this decision was that Dow could offer a suitable solution for the water makeup treatment. The integration of all these different technologies makes Dow an attractive supplier in the water treatment industry.

3. System design

Storuman's power plant employs a softener and single pass RO as a pretreatment to the EDI in order to reduce the chemical consumption and the possibilities of RO membrane fouling. There is no chlorination on the tap water.

Raw water at 15°C with a flow rate of 7.33 m^3/h enters the DOWEX™ ion exchange resin with a quality shown in Table 1. The water at 10°C leaves the softener with a quality shown in Table 2.

Table 3
RO water permeate

Parameter	Measure (mg/L)
K	0.02
Na	0.11
HCO_3	0.43
NO_3	0.03
Cl	0.01
SO_4	0.02
SiO_2	0.01
CO_2	1.89
TDS	0.64
pH	5.67

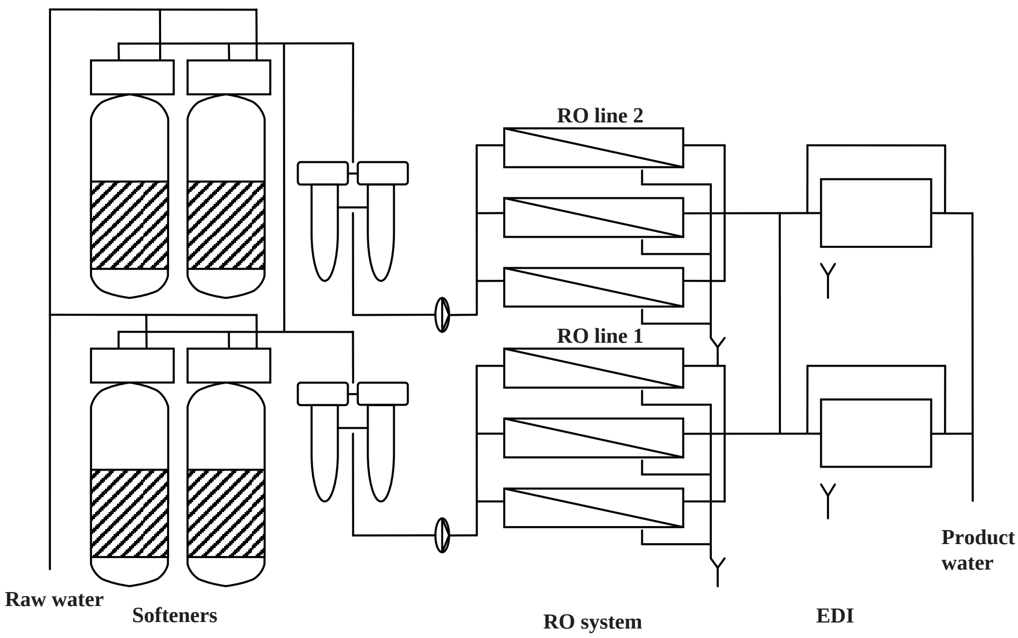

Fig. 1. System design for boiler feed water. Graph courtesy of water processing Sweden AB.

The RO water feeds the EDI system directly. Table 3 gives an analysis of the RO permeate.

Fig. 1 is a piping and instrumentation diagram (P&ID) of the water treatment plant granted by Water Processing.

EDI is used as an alternative to mixed bed ion exchange resins. The latter is the traditional technique, first introduced for commercial use during the 1930s, to detain cations and anions to produce pure water.

4. EDI and IX as water polishers

EDI is a process for removing the bulk of the salts still present in water after being processed by RO. EDI feed water quality can be met by using single or double pass RO, choosing one or the other depending on the raw water quality and pretreatment. If the hardness limit is still too high, either a second pass RO or a softener has to be used prior to the EDI.

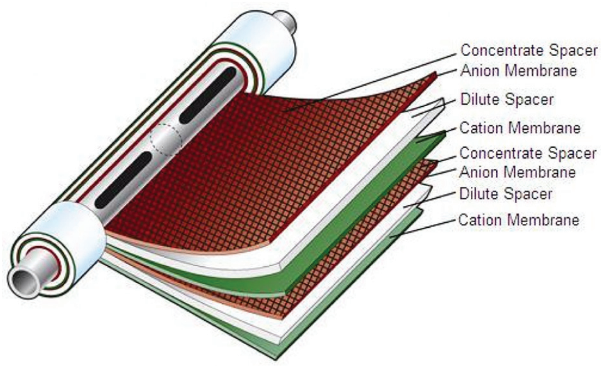

Fig. 2. DOW EDI spiral wound design.

Fig. 3. DOW EDI module.

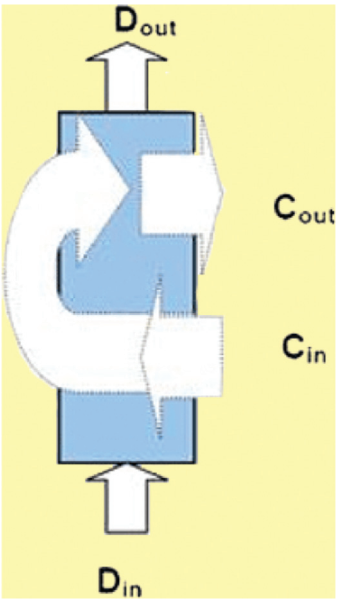

Fig. 4. Flow direction for dilute and concentrate chambers.

Mixed bed exchangers have several disadvantages compared to EDI relatively new technology, commercialized during the 1950s.

Mixed bed resins (IX) reach exhaustion after some time of operation and they need to be regenerated. Regeneration implies a cost in which it is included the acid, the caustic and the rinse water. The personal labor is also a significant part of the cost. Besides this, working with acid and caustic implies the risk of handling hazardous chemicals. Regeneration takes several hours in which the plant has to be shut down. It requires bulk storage and pumping facilities for the chemicals.

Another disadvantage of IX resins is the generation of a waste stream that needs to be neutralized prior to be released to the environment.

The EDI process is a continuous process. It does not need chemicals to regenerate the resin and the operator does not need to pay as much attention as the needed for a proper IX resin continuous operation.

EDI systems run between 90% and 95% of water recovery. EDI can provide ultra or high purity water of greater quality when operated after a two pass RO process than after a single pass RO.

DOW EDI modules utilize few space. Each EDI module is 270 mm diameter and 890 mm length. The EDI gross weight is 49 kg per module.

EDI systems are used to produce high purity water for the boiler makeup in the power industry, as the case study presented here, as feed for water injection, in microelectronics, as semiconductor makeup, as rinsewater and in the optical industry, among others.

5. EDI module design

In an EDI device, direct current (DC) is continuously causing removal of ionic pollutants while electrochemically regenerating a portion of the ion exchange resin. Resins and ion selective membranes are designed to allow ions to move easily and more efficiently through the EDI chambers.

The first EDI designs were plate-and-frame type. The plate-and-frame type EDI devices are similar in construction to a plate heat exchanger, with multiple fluid chambers sandwiched between a set of endplates (and electrodes) that are held in compression by bolts or threaded rods.

Plate-and-frame devices can eventually suffer from leaks because of the difficulty of sealing large vessels. Any leakage from concentrate compartments results in the buildup of salt deposits due to subsequent water evaporation. These deposits can form a bridge between the cell pairs and the metallic frame of the modules and lead to module damage. Compression devices are needed to seal the membrane stack.

Improvements have been made and new designs have been launched that avoid old deficiencies.

DOW™ electrodeionization modules are made using a patented spiral wound design containing membrane and ion exchange resins wound around the central pipe of a vessel (Fig. 2). The EDI element is manufactured by placing a stainless steel concentrate pipe on a rolling machine and winding the membrane and spacers around the pipe. The element is then placed into a fiberglass pressure vessel and dilute chamber spacers are filled with resin. The unit is sealed inside the pressure vessel (Fig. 3). As a result, these

Fig. 5. Photo of the two DOW EDI skids used at Storuman power plant.

Fig. 6. Flowmeters and manometers used in the system.

devices are not susceptible to salt bridging. The central stainless steel pipe acts as the concentrate distributor/ collector and the cathode. A titanium anode lines the inside of the fiberglass pressure vessel and becomes the anode.

The spiral-wound EDI module in Fig. 4 employs a cross-flow design where the direction of flow in the concentrate chambers is perpendicular to that in the diluting chambers. The concentrate stream enters the EDI from the bottom of the unit and only goes half way through the module while it is distributed into the central end of the spiral concentrate chamber and its flow spirals outward. When the concentrate reaches the outside of the module, a portion feeds the anode chamber located around the outside of the module. The feed stream enters the same end of the element but flows along longitudinally, perpendicular to the spiral flow of the concentrate stream.

This configuration has the benefit of removing the hardness ions at the first part of the process. Divalent ions of hardness will move first into the concentrate stream, reducing the scaling possibilities as the water is being purified, at the other end of the module, where water splitting and the creation of hydroxide ions will be the greatest.

Dow spiral wound EDI uses IX resin in the dilute chamber in order to increase its conductivity. Other suppliers offer designs with mixed bed resin in the concentrate chamber too for the same purpose. Although the latter method has the advantage of decreasing the potential for scale formation, the resin reduces the ability to create the agitation that assists in cleaning the chambers (due to scaling and/or fouling). Higher cleaning flow rates cannot be achieved because of the flow restriction created by the filler. DOW EDI uses salt injection and concentrate recycle to facilitate the migration of ions coming through one of the membrane sheets through the concentrate chamber to balance the charge of counter ions coming from opposite sheet.

Fig. 7. Current and voltage displays.

With proper system design and operation, expected DOW EDI module life is normally 5 years. Some systems, however, can achieve continuous operation for longer time.

6. Implementation

The water treatment system for the bioenergy combine was designed to consist of two trains, with each train having three EDI modules (Fig. 5).

The system produces an average of 5.5 m^3/h of product water meeting the following specifications:

Specific resistivity < 10.0 Meg Ohm-cm,
Product silica < 10 ppb,
Product sodium < 10 ppb.

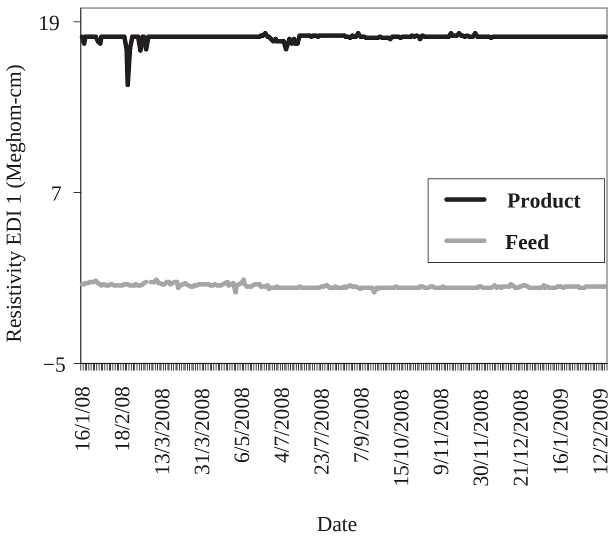

Fig. 8. Product and feed resistivity over time (skid 1).

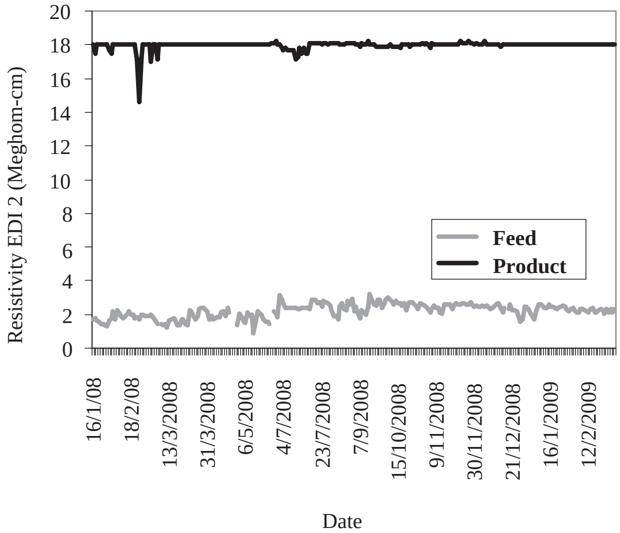

Fig. 9. Product and feed resistivity over time (skid 2).

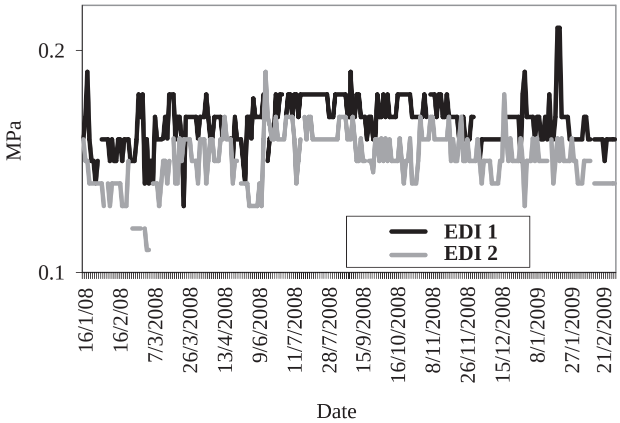

Fig. 10. Pressure losses through the dilute chamber.

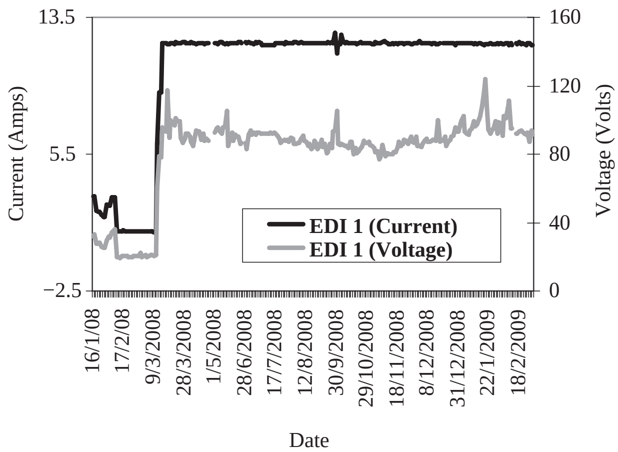

Fig. 11. Current and voltage through EDI 1 skid over time.

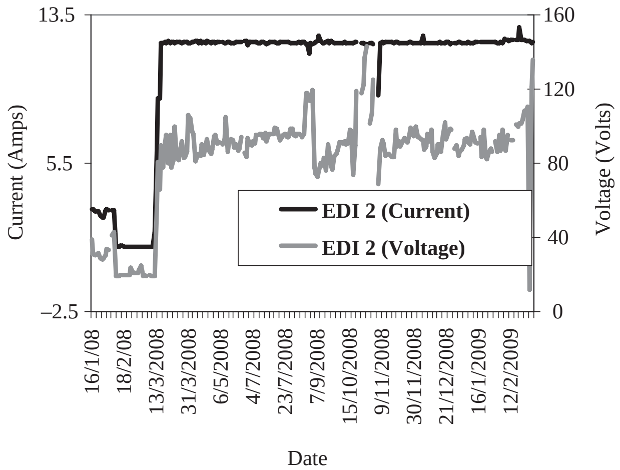

Fig. 12. Current and voltage through EDI 2 skid over time.

This power plant has achieved 1-year of service in January 2009.

The water is pumped from the RO system to the EDI. An isolation valve prevents water from enter the EDI if the RO is not working. The water system operates in ''start/stop'' mode. This means that it operates only when the deionized water storage tank needs demineralized water.

The system incorporates four flowmeters to keep track of the different flow stream levels. There are also four manometers to keep track of the pressures through each stream, as shown in Fig. 6. These devices are essential. Operating at high voltage with insufficient flow could result in a serious destruction of the EDI modules. Any stoppage of flow for any reason in any of the streams results in an alarm and disengagement of the high voltage power.

The Programmable Logic Controller (PLC) monitors the EDI voltage and current. The system current is set up to a certain value. If the resistance through the system increases too much, the voltage has to be adjusted in accordance to keep the current steady through each module (Fig. 7).

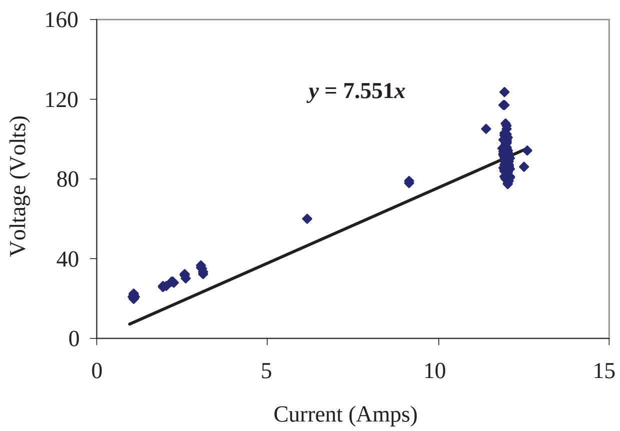

Fig. 13. Voltage versus current (EDI 1 skid).

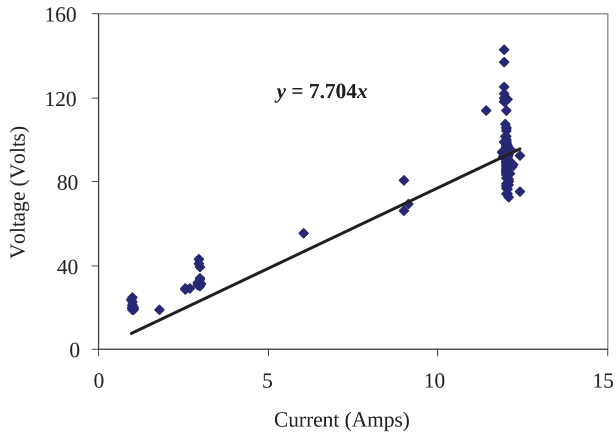

Fig. 14. Voltage versus current (EDI 2 skid).

Each skid employs one single rectifier as the system power supply. This is possible because the modules are electrically wired in parallel pairs. The resistance through the different parallel pairs can be the same because the modules are combined in a way that each module's resistance is balanced with the other module's resistance that integrates the series. The use of a single rectifier reduces the total system cost considerably.

7. Operating results

The system startup took place on January 2008, and after 1 year and 3 months of steady operation, the EDI system has been running smoothly and has not yet required any cleaning. The system has provided a final product water quality that meets the outlet water quality specifications.

Figs. 8 and 9 show the EDI feed and product water quality over more than a year of continuous operation since startup.

These graphs show that the specifications for the resistivity are by far achieved in this process. The feed water resistivity is around 0.5 Meg Ohm-cm while the product water resistivity has an average value of 18 Meg Ohm-cm.

Pressure drop through the dilute chamber is shown in Fig. 10. The value is almost constant during the time the plant was started up, which means there is not fouling nor scaling through the system (Fig. 11).

Current and voltage values are low at the start up of the plant, but these values increase and remain almost constant until now. Fig. 12 shows some voltage values not following the linear trend during the winter months. High temperatures increase the rate at which ions migrate through the solution or, in other words, the solution carrying capacity (conductivity) increases at high temperatures. During the cold winter months, conductivity decreases through the dilute chambers, and so, voltage has to be increased to maintain a constant current passing through the system.

Figs. 13 and 14 show a linear relationship between the voltage applied to the system and the current passing through the chambers.

8. Conclusions

DOW EDI modules can help to optimize performance, maintain continuous product quality and can produce up to 18 Meg Ohm-cm product water for high purity and ultrapure industrial water applications.

The Storuman's plant has an EDI system that has demonstrated to operate successfully during fifteen months under varying temperature conditions.

To integrate in a single design and operation the pretreatment, the RO and the EDI systems is a very valuable benefit for OEMs. Dow can offer its customers this possibility. Water Processing Sweden AB and other OEMs recognize this as a distinctive advantage compared to other water treatment supplier companies.

Dow offers competitive and cost effective EDI modules that use low energy consumption and practically avoid the use of regenerant chemicals.