

Claims

1. A two-stage closed circuit desalination (CCD) system of two simultaneously operated CCD units under fixed flow and variable pressure conditions with brief brine flush-out steps between said sequences wherein, the non-pressurized brine of the first-stage stored in a brine reservoir (BR) serves as feed of the second-stage, said system comprising:

a first-stage CCD unit for $R(1)$ sequential recovery of $N(1)$ modules, each of $n(1)$ elements, with inlets and outlets of said modules connected in parallel to a closed circuit concentrate recycling line with a circulation means [CP(1)]; a feed line with pressurizing means [HP(1)] which merges with said concentrate recycling line at inlet to modules and thereby causing a dilution effect; a permeate release line off said first-stage modules; and a line off said concentrate recycling line with an actuated valve means [V(1)] for brief brine flush-out at low pressure from the first-stage modules into said BR after each said sequential recovery completed;

a second-stage CCD unit for $R(2)$ sequential recovery of $N(2)$ modules [$N(2) < N(1)$], each of $n(2)$ elements, with inlets and outlets of said modules connected in parallel to a closed circuit concentrate recycling line with a circulation means [CP(2)]; a first-pass brine line from said BR with pressurizing means [HP(2)] which merges with said concentrate recycling line at inlet to modules thereby causing a dilution effect; a permeate release line off second-stage modules; and a line off said concentrate recycling line with an actuated valve means [V(2)] for brief brine flush-out at low pressure from the second-stage modules after each said sequential recovery completed;

online monitoring means connected to a control board comprising flow/volume meters on inlet lines to said stages [F(1.1) and F(2.1)] to enable the fixed-flow operation of said pressurizing means through their variable frequency drive (vfd) control means and provide the required online flow rates and delivered volumes per each said stage; flow/volume meters on said recycled concentrate lines in said stages [F(1.2) and F(2.2)] to enable the fixed-flow operation of said circulation means through their variable frequency drive (vfd) control means and provide online data of flow rates and volumes of displaced brine during the flush-out steps of relevance to the recovery control of each of the said stages; pressure monitoring means at

inlet and outlet to skids in each said stage [P(1.1), P(1.2) P(2.1), P(2.2)] to enable a follow-up of the variable pressure progression and module pressure-difference during said CCD sequence in each said stage and to control of the brine flush-out desired low pressure in each said stage; electric conductivity means on inlet lines to said stages [EC(1.2) and EC(2.1)], and on permeates' outlet lines off first-stage [EC(p-1)], second-stage [EC(p-2)] and overall blend [EC(p)]; and

online control board with its fixed operational set-points of flux, module recovery (MR) and sequence recovery (R) per stage in the two-stage process dictates the followings - the parallel operation of the CCD sequences and brief brine flush-out steps between said sequences of the two-stage process; triggers through signals to the respective actuated valve means [V(1) for first-stage and V(2) for second-stage] the termination of CCD sequences and initiation the brine flush-out steps in both said stages simultaneously when the recovery set-point of first-stage [R(1) and the second-stage [R(2) are reached as well as the termination of said brine flush out- steps and resumption of said CCD sequences in each said stage when the monitored volume of replaced brine in the respective stages [F(1.2) for first-stage and F(2.2) for second-stage] complies with their respective intrinsic volumes requirements; triggers the activation/deactivation of the circulation pumps in said stages [CP(1) for first-stage and CP(2) for second-stage] when the CCD sequences in said stage are activated/deactivated, respectively;

wherein information stored in the control board regarding design features, online monitored data and operational set points dictates the simultaneous operation of both stages with said CCD sequences and said brine flush-out steps experienced in parallel over the same respective time duration, with said CCD sequences experienced most of the time ($\geq 90\%$) and brief brine flush-out steps executed between said sequences with feed water volume used in the first-stage amounting to sum of the intrinsic volumes of both stage in order to enable an uninterrupted continuous operation of the entire two-stage CCD system.

2. A two-stage CCD system according to claim 1, wherein said pressurizing means of both said stage [HP(1)] and HP(2)] are high pressure pumps with variable frequency drive means for controlled flow rates.

3. A two-stage CCD system according to any of the preceding claims, wherein said circulation means of both said stages [CP(1)] and CP(2)] are circulation pumps with variable frequency drive means for controlled flow rates.
4. A two-stage CCD system according to any of the preceding claims, wherein all modules in said system are identical and operated with the same flow rates per module by the same operational set-points of flux, module recovery $[MR=MR(1)=MR(2)]$ and recovery $R=[R(1)=R(2)]$ of same CCD cycle-number, cycle-time and sequence duration of an overall recovery expressed by $[1-(1-R/100)^2]*100$ such as 87.5%(R=65%), 91.0(R=70%), 93.75%(R=75%), 96%(R=80) and 97.75(R=85%); with permeates production ratio of said first-stage expressed by $N(1)/[N(1)+N(2)]$ and that of said second-stage by $N(2)/[N(1)+N(2)]$; with said permeate ratio per stage also expressing its relative contributions to the overall average specific energy and the average total dissolved salt (TDS) of permeates of the entire two-stage process.
5. A two-stage CCD system according to any of the preceding claims, wherein an increased modules' ratio $[N(1)/N(2)]$ affecting the production of lower salinity permeates with lower energy requirements.
- 6.. A two-stage CCD system according to any of the preceding claims, wherein modules of a larger element-number enable the selection of a higher MR of a lower concentration polarization factor and thereby allow CCD sequences of a smaller cycle-number per designated said set-point recovery with cited trend of increased MR implying declined average specific energy and salinity of permeates.
7. A two-stage CCD system according to any of claims 1, 2 and 3, wherein said first and second stages comprise modules of a different element-type and/or element-number $[n(1) \neq n(2)]$ which are operated by different operational set-points of flux $[\mu(1) \neq \mu(2)]$, module recovery $[MR(1) \neq MR(2)]$ and recovery $[R(1) \neq R(2)]$ of same CCD sequential periods and brief duration brine flush-out steps between said sequences, such that the two said stages proceed continuously in parallel with an overall recovery expressed by $\{1-[1-R(1)/100]*[1-R(2)/100]\}*100$ with preference given to a first-stage of higher flux $[\mu(1) > \mu(2)]$ and recovery $[R(1) > R(2)]$ in order to enable milder conditions in second-stage in light of expected increased fouling and scaling propensity; with permeates production ratio of said first-stage expressed by

$N(1)*V(1)/[N(1)*V(1)+N(2)*V(2)]$ and of second-stage by $N(2)*V(2)/[N(1)*V(1)+N(2)*V(2)]$; wherein, V stands for volume of product permeate per module per sequence per stage; and said permeate production ratio per stage also expressing its relative contribution to the overall average specific energy and the average total salinity of produced permeates.

8. A two-stage CCD system according to any of the preceding claims made of staged modules ratio $[N(1)/N(2)]$ of 4.0 or 5.0; for recovery of 75%-85% per stage; applied for high recovery low energy production of low salinity permeates from one of the following feed (<0.5%) sources: surface water, ground water, brackish water, domestic water supplies, treated domestic effluents, and treated industrial effluents.
9. A two-stage CCD system according to any of the preceding claims, wherein said system provides better quality permeates at high recovery with lower energy requirements than that of a single-staged CCD unit design under the same operational set-points conditions with the same feed source.