Polymer film heat transfer elements for multi - effect and vapour compression desalination

by

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ABSTRACT

The continuing improvement of existing desalination processes – both distillation and membrane – is contributing significantly to reducing the cost of desalted water, and to the rapid growth of the desalination industry. Thus the world capacity has more than *doubled* during the two years 2000 - 2001, and desalination of seawater is at present the major source of potable water in arid coastal regions such as the Arabian Gulf region.

Conventional multi-effect distillation (MED) and multi-stage flash (MSF) desalinators use cupro-nickel and/or titanium heat transfer surfaces. Polyolefins such as high density polyethylene (HDPE) and polypropylene (PP) have better corrosion resistance than these, which permits much thinner walls. Depending on the internal & external convection coefficients, 20-50μ thick HDPE and PP film heat transfer elements have from 60-105% of the U value of 1mm cupro-nickel tubes. Experience has shown them to last as well as – and in some high-scaling water re-use applications better than – titanium elements. But per unit area they cost only about 1% as much.

In chapter 2 we show how the low cost permits the installation of much more thermal conductance (UA) than is economically feasible with metal heat transfer surfaces. This leads to a lower temperature difference ΔT_1 between the condensing and evaporating sides, and *a lower specific energy consumption.*

This thesis further describes the design, building and testing of a simple falling saline film

mechanical vapour compression (MVC) desalinator. With air mattress-shaped polyolefin film heat transfer elements. Designed for operation (under vacuum) at various temperatures in the range 50-65°C, with a *small* temperature difference ΔT_l between the condensing and evaporating sides.

In chapter 3 we determine the pressure drop of the condensing vapour for laminar flow inside a film tube, to obtain the relation between film tube diameter, length, U value, temperature and the ratio $R_T = \Delta T_l / \Delta T_f$ of temperature difference ΔT_l to frictional temperature drop ΔT_f.

We also determine, for $\Delta T_l = 1K$ and $R_T = 8$, the relation between tensile stress and temperature for the HDPE and PP films that we have used to fabricate HTE's. For 39μ HDPE film elements up to 60 - 65°C, and for 50μ PP ones up to 90 - 95°C, the stress is below 0.4 MPa – and in most cases well below the creep strength of the materials for a 10 year design life.

In chapter 4 we discuss the welding of thin HDPE and PP films on specially developed apparatuses to produce air mattress-like heat transfer elements (HTE's). Some of these were pressure tested (up to several bars at room temperature) to determine the strength of the weld lines.

Chapter 5 discusses the successful vapour inlet manifolding of the heat transfer elements into heat transfer units. Also the design, construction and testing of a vacuum vessel and a turbo vapour compressor. And of the other auxiliaries (feed water heater, vacuum pump with protecting pre-condenser, water pumps, instrumentation . .).

It also discusses problems encountered, and the merits of various possible remedies.

Chapter 6 discusses suitable surface treatments to increase their surface tension and wettabilityof the air mattress-like heat transfer elements (HTE's). As these are of a non-polar hydrophobic material, such treatment – aimed at creating charged, polar or polarizable sites – is essential for film evaporation. As our original process – oxyfluorination – was only partially successful after several year's work, we have started another surface treatment – sulfonation – which is in the early stages of evaluation.

Polimeerfilm hitte-oordrag elemente vir multi-effek en dampsaampersingsontsouting

deur

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SAMEVATTING

Die voortgesette verbetering van bestaande ontsoutingsprosesse – beide distillasie- en membraan- – dra beduidend by tot die vermindering van die koste van ontsoute water, en tot die snelle groei van die ontsoutingbedryf. So het die wêreld-ontsoutingsvermoë meer as verdubbel gedurende die jare 2000-2001, en is ontsouting reeds die vernaamste bron van drinkbare water in droë kusstreke soos die Arabiese golfgebied.

Konvensionele multi-effek distillasie (MED) en multi-stadium flits (MSF) distilleerders gebruik kupro-nikkel en titaan hitte-oordrag-oppervlakke. Poli-olefiene soos hoë-digtheid polietileen (HDPE) en polipropileen (PP) is meer bestand teen korrosie as hierdie materiale, en maak dit moontlik om veel dunner wande te gebruik. Vir redelike aannames oor die interne en eksterne konveksie-koëffisiënte, sal 20-50μ HDPE en PP film hitte-oordrag-elemente 60-105% van die U-waarde hê van 1mm wand kupro-nikkel buise. Die ervaring wys dat hulle netso goed soos – en in sommige skaalvormende hergebruik toepassings beter as – titaan elemente hou. Maar per m^2 kos hulle slegs 1% soveel.

In hoofstuk 2 toon ons hoe die lae koste die installering van veel meer hitte-oordrag oppervlak toelaat as wat ekonomies is met metaal oppervlakke. Dit lei tot 'n kleiner temperatuurverskil ΔT_l tussen die kondenseer- en verdampingskante, en tot 'n laer energie-verbruik per m^3 distillaat.

Die proefskrif beskryf ook die ontwerp, bou en evaluering van 'n eenvoudige vallende

soutwater film meganiese dampsaampersings-distilleerder – met parallele buis poli-olefien film hitte-oordrag elemente (HOE) in 'n lugmatras-tipe konfigurasie. Ontwerp vir bedryf (onder vakuum) by temperature tussen 50 en 65°C, met 'n klein temperatuurverskil ΔT_l tussen die kondensasie- en verdampingskante van die HOE.

In hoofstuk 3 bepaal ons die drukval van die damp vir laminêre vloei binne 'n filmbuis – om die verband te bepaal tussen filmbuis deursnee, lengte, U-waarde, temperatuur en die verhouding $R_T = \Delta T_l / \Delta T_f$ van ΔT_l tot die vloeiweerstand-geïnduseerde temperatuurval ΔT_f.

Ons bepaal ook, vir $\Delta T_l = 1K$ en $R_T = 8$, die verband tussen trekspanning en temperatuur vir die HDPE en PP films wat ons gebruik het om HOE te fabriseer. Vir 39µ HDPE film-elemente tot 60-65°C, en vir 50µ PP film tot 90-95°C, is die spanning minder as 0.4 MPa – en in die meeste gevalle minder as die kruip-sterkte van die materiale vir 'n 10 jaar ontwerpleeftyd.

In hoofstuk 4 bespreek ons die sweis van dun HDPE en PP films met spesiaal ontwikkelde apparate om lugmatras-vormige hitte-oordrag elemente (HOE) te vervaardig. Sommige hiervan is met druklug getoets (tot verskeie bar by kamertemperatuur) om die sterkte van die lyn-sweislasse te bepaal.

Hoofstuk 5 bespreek die suksesvolle ontwerp en konstruksie van die damp-inlate tot die HOE, en die saamvoeg van HOE tot hitte-oordrag eenhede. Ook die ontwerp, konstruksie en toets van 'n vakuum-houer, en van 'n turbo dampsaamperser. Ook van die ander toebehore (toevoerwater verwarmer, vakuumpomp met beskermende kondenseerder, waterpompe, instrumentasie . .).

Dit bespreek ook probleme met die bestaande apparaat en bedryfsmetode, en die meriete van verskillende potensiële oplossings.

Hoofstuk 6 bespreek geskikte oppervlak-behandelings om die oppervlak-spanning en benatbaarheid van die HOE te verhoog. Aangesien hulle van 'n nie-polêre hidrofobiese materiaal is, is sodanige behandeling – daarop gemik om polêre of polariseerbare plekke op die polimeer-oppervlakte te skep – essensieel vir film-verdamping. Aangesien ons eerste proses – oksifluorinering – slegs gedeeltelik geslaagd was na jare se werk, het ons begin met 'n tweede proses – sulfonering – wat tans in 'n vroeë stadium van evaluering is.

To my family:

"My mother would have been proud of me!!"

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