

**Sudan University of Science and Technology  
Collage of Graduate Studies**

**Treatment of produced water  
from some wells in Mareb oil fields  
in Yemen**

**معالجة المياه المنتجة من بعض الآبار في حقول  
نفط مأرب في اليمن**

**A Thesis Submitted for fulfillment of the requirements  
for the degree of Ph. D in water and environment science**

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

( ظهر الفساد في البر والبحر بما كسبت أيدي الناس ليذيقهم بعض  
الذي عملوا لعلهم يرجعون )  
صدق الله العظيم

الروم ( ٤١ )

## **Dedication**

To Dr. Gurashi Abdalla Gasmelseed, who lead my first steps  
on the road of Knowledge

Dear father, mother

Beloved wife and daughters

Beloved brothers and sisters

Friends

All those who work hard so that others can benefit.

## *Acknowledgment*

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## *Abstract*

The aim of this study is to analyse and desalinize contaminated water produced from block 18 of Safer Company in Mareb- Yemen. To produce one barrel of crude oil, one barrel and half of water was obtained. This amount tended to increase with depletion of oil and gas, bearing in mind that the increase in water was an indication of depletion of oil. Hence the contaminated produced water needs to be treated with advance and cost effective technology. The waste-water produced in the Central Production Unit of Safer Company was estimated at 80,000 BPD. In this study the water-shut off technique was reviewed and guessed to be ineffective due the factor that the wells in these areas are deep with a high temperature that the viscosity of the shutting off materials would decline effectively.

Therefore a novel technique was developed and investigated and found to be much effective and practical. This technique used adsorption of oil on a packed bed of bagasse. Bagasse was found to be a good adsorbent of emulsified oil at low pH (2.0). At conditions of ambient temperature, pH of 2.0, 0.70 m packed bed height and particle size of 1.5 mm, the percentage of oil adsorbed on bagasse was 98 %. The spent bagasse in addition to oil adsorbed could be used as a fuel with a calorific value of 38 kj/kg.

The technique practiced in this work was first to settle the salt for 5 days and separate the salt crystals, then emulsifying the oil with a surface active agent. The mixture of brine water and oil was then eluted through a packed

bed of bagasse of particle size of diameter 1.5 mm and 0.70 m height. The flow rate was adjusted so that the resident time was 320 minutes, this was the equilibrium time determined for adsorption. The eluted brine was almost oil-free with about 2 % traces of crude oil emulsion.

The brine solution was then processed through single-stage Reverse Osmosis unit (RO) at pump pressure of 13 atmospheres. The unit was able to separate 98 % from the salt feed water at TDS level of 2500 to 3000 mg/L using pressure of 13.6 to 17 atmospheres and 24 L/m<sup>2</sup>.day. Today the state of the art technology uses thin film composite membranes in place of cellulose acetate and polyamide membranes. The composite membranes work over wide range of pH, at higher temperatures, and within broader chemical limits, enabling them to withstand more operational abuse and conditions more commonly found in most industrial applications. In general, the recovery efficiency of RO desalination plants increases with time as long as there is no fouling of the membrane.

## ملخص الدراسة

إن الهدف من هذه الدراسة هو تنقية وإزالة ملوحة المياه المصاحبة لإنتاج النفط في قطاع ١٨ (شركة صافر – مأرب اليمن)

إن إنتاج برميل واحد من النفط يصاحبه إنتاج برميل ونصف من المياه، وهذه الكمية من المياه تميل إلى الارتفاع مع استمرار عملية استهلاك النفط والغاز. ويجب الأخذ في الاعتبار بأن الزيادة في إنتاج المياه المصاحبة للنفط هي مؤشر لاستنزاف ونضوب النفط.

ولذا فإن المياه الملوثة المصاحبة للنفط تحتاج إلى معالجة بطرق متقدمة ذات تكنولوجيا فعالة.

إن المياه الملوثة المصاحبة للنفط في وحدة الإنتاج المركزية لشركة صافر يقدر بـ ٨٠,٠٠٠ ثمانية آلاف برميل يوميا، وفي هذه الدراسة فإن تقنية قطع أو إغلاق المياه تم عرضها وتحليلها بأنها طريقة غير فعالة حيث تكون الآبار عميقة مع درجة حرارة عالية بحيث أن لزوجة مواد القطع أو الإغلاق تكون قليلة الفعالية. ولهذا السبب فقد تم تطوير تقنية مستحدثة وتم التحقق منها ووجدت أنها أكثر فعالية وعملية.

هذه التقنية استخدمت عملية امتزاز النفط من خلال حزم من البقاس. وقد وجد البقاس بأنه مادة جيدة الامتصاص لمستحلب النفط عند درجة حامضية منخفضة (٢.٠).

عند ظروف درجة الحرارة المحيطة ودرجة حامضية (٢.٠) وارتفاع عمود عبوة البقاس يساوي (٠.٧٠) م والحجم الجزيئي يساوي (١.٥) مم وجد إن نسبة امتصاص النفط من قبل البقاس تساوي ٩٨ %.

إن مادة البقاس المستهلكة بالإضافة إلى النفط الممتص يمكن استخدامها كوقود بقيمة حرارية تساوي 38 kJ/kg

إن التقنية المطبقة في هذا العمل بدأت بعملية ترسيب للملح حوالي ٥ أيام ومن ثم فإن خليط المياه المشبع بالملح مع النفط تمرر عبر عبوات من مسحوق قصب السكر ذو حجم جزيئي يساوي (١.٥) مم وارتفاعا يساوي (٠.٧٠) م.

تم تعديل الجريان حتى يكون زمن البقاء يساوي (٣٢٠) دقيقة، وهذا كان زمن التوازن المحدد للامتصاص.

المحلول المشبع بالملح المزال يكون تقريبا خالي من النفط، حيث توجد آثار فقط من مستحلب النفط الخام لا تتجاوز ٢ %.

المحلول المالح يعالج بعد ذلك عبر مرحلة وحيدة في وحدة التناضح العكسي ويكون ضغط المضخة يساوي ١٣ جوي.

إن وحدة التناضح العكسي قادرة على فصل ٩٨ % من ملوحة مياه التغذية التي يكون مجموع الأملاح الذائبة فيها من ٢٥٠٠ إلى ٣٠٠٠ ملجم / لتر باستخدام ضغط من ١٣.٦ إلى ١٧ جوي وجريان يساوي ٢٤ لتر/م<sup>٢</sup>. يوم.

اليوم تستخدم تكنولوجيا ذات أغشية مكونة من طبقات رقيقة بدلا من الأغشية القديمة التي تستخدم ملح حامض ألكليك السليلوزي.

إن مركبة هذه الأغشية تعمل على مدى واسع للرقم الهيدروجيني وبدرجة حرارة عالية وضمن حدود كيميائية واسعة.

وهذه الظروف تمكن هذه الأغشية من مقاومة كثير من عمليات سوء الاستخدام والظروف الأخرى عموما الموجودة في معظم الاستعمالات الصناعية.

بشكل عام، فإن تحسن كفاءة وحدة التناضح العكسي تزداد مع الزمن بشرط عدم فساد أو تلوث الأغشية



## Nomenclature

A	mass velocity of adsorbed solute, $\text{kg/ m}^2 \cdot \text{s}$
B	mass velocity of adsorbate-free adsorbent, $\text{kg/ m}^2 \cdot \text{s}$
c	solute concentration in solution, $\text{M/ L}^3$ or $\text{mole/ L}^3$ ; for ion exchange, $\text{equivalent/ L}^3$
C	distance, impeller to bottom of tank, m heat capacity, FL/MT mass velocity of more strongly adsorbed solute, $\text{kg/ m}^2 \cdot \text{s}$
d	Diameter
D	diffusivity, $\text{L}^2/ \text{s}$
E	mass velocity of adsorbent-free adsorbate, $\text{kg/ m}^2 \cdot \text{s}$
Fl	Liquid-phase mass-transfer coefficient, $\text{mole/ L}^2 \cdot \text{s}$
G <sub>s</sub>	mass velocity of unadsorbed gas based on container cross section, $\text{kg/ m}^2 \cdot \text{s}$
h	Packed bed height
k	a constant
L <sub>s</sub>	solvent liquid: mass in a batch process, kg; mass velocity in a continuous process, $\text{kg/ m}^2 \cdot \text{s}$
m	Constant
n	Constant
N	rotational speed, $\text{s}^{-1}$
p	equilibrium vapor pressure, $\text{F/ L}^2$
P	agitator power transmitted to fluid or slurry, FL/ s
S <sub>s</sub>	adsorbate-free solid: mass in a batch process, kg ; mass velocity in a continuous process, $\text{kg/ m}^2 \cdot \text{s}$
V	Volume of packed bed $\text{m}^3$
V <sup>-</sup>	Inlet volumetric flow rate $\text{m}^3/\text{min}$
X	adsorbate concentration, mass solute/mass adsorbent, $\text{kg/kg}$ ; for ion exchange , $\text{equivalent/M}$ or $\text{equivalent/ L}^3$
Y	concentration of solute in fluid, mass solute/mass solvent, $\text{kg/kg}$

### **Greek letters**

$\tau$	Residence time min.
v	volume of solute/mass adsorbed, $\text{L}^3/\text{kg}$
$\rho$	fluid density, $\text{kg/ m}^3$
$\Delta\rho$	absolute value of density difference, solid and liquid, $\text{kg/ m}^3$
$\pi$ (Pi)	Constant =3.14
$\varepsilon$	Void volume $\text{m}^3$

## **Subscripts**

p	Particle
0	Initial
1	stage 1; bottom of a continuous-contact adsorber
2	stage 2; top of a continuous-contact adsorber

## **Superscript**

*	at equilibrium
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## **Abbreviations**

BBL/D	Barrels per day
CPU	Center production unit(part of oil company located in Yemen)
CTA	Cellulose tri-acetate membrane
KPU	Kaamil production unit(part of oil company located in Yemen)
JHOC	Janah hunt oil company(oil company located in Yemen)
MPa	Mega Pascal
NF	Nanofiltration
NOM	Naturally occurring organic matter
PVDF	Polyvinylidene fluoride
RO	Reverse osmosis
SWRO	Sea water reverse osmosis
SDI	Silt density index
TFC	Thin film composite membrane
TFM	Thin film membrane
UV	Ultra violet
UF	Ultrafiltration
WOR	Water oil ratio