IMPROVEMENT OF SOLAR SALT WORKS PERFORMANCE

by

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ABSTRACT

Coal, asphalt, black oil paint, naphthol green b and alkali blue 6b were tested for improvement of solar energy utilisation in solar salt manufacture. It was found that the use of alkali blue 6b dye dissolved in raw seawater improves efficiency by 3.6 percent. Both modifications could increase solar salt works with a coal coated surface than one employing raw seawater dyed with alkali blue 6b.

INTRODUCTION

Solar salt manufacture depends largely on availability of solar energy on the earth's surface which is limited in terms of intensity and duration depending on location on the globe and period of the year. Solar salt manufacture can hardly escape the effects of natural weather variations. The process almost ceases during heavy rain seasons of the year though some evaporation may still be taking place. Efficient use of available solar energy during dry and favourable periods is necessary and highly recommended as a means of achieving higher productivity. The objective of this study was to look into the possibility of improving solar energy utilisation. This paper discusses different options that were used. The study was conducted at Changwahela salt works located latitude 6° 31'S, longitude 39° 4'E in Bagamoyo district, Coast region, Tanzania.

THEORY

Solar Energy Efficiency in Solar Salt Works

Solar energy efficiency in solar salt manufacture may be defined as the ratio of energy utilised for evaporation of water to the incident solar radiation received.

That is

$$\eta = \frac{Q_e}{Q_s} x100\% \tag{1}$$

Where

$$Q_e = E_b \lambda_b \tag{2}$$

Where λ_b is obtained from steam table [1] at brine temperature.
For pure water and air in mutual contact Dalton's evaporation law holds:

$$E_f = k(p_f - p_a) \tag{3}$$

The variation of k with brine concentration can be neglected so that for the brine,

Equation 3 becomes

$$E_b = k(p_b - p_a) \tag{4}$$

P_b is given by the following empirical equation

$$\ln p_b = 17{,}9 - (\frac{5337.84}{T_b}) + 6.64 p_b - 3.49 p_b^2 \tag{5}$$

Division of equation 4 by equation 3 and rearranging gives;

$$E_b = (\frac{p_b - p_a}{p_f - p_a}) E_f \tag{6}$$

Substituting E_b and Q_e in equation 1 gives:

$$\eta = (\frac{p_b - p_a}{p_f - p_a})(\frac{\lambda_b E_f}{Q_s}) x100\% \tag{7}$$

Where [2]

$$p_a = \Phi p_T \tag{8}$$

The equation for calculating global radiation is given by the instrument manufacturers as follows:

$$Q_R = [(1 + 0.0033t_a)19.4A]K \tag{9}$$

Increased solar energy absorption raises the temperature of brine. In this way the driving force (P_b - P_a) in equation 7 is increased by increased aqueous vapour pressure P_b above the brine surface. Consequently efficient utilisation of solar energy is enhanced.

EXPERIMENTAL SET-UP

Mild steel pans (0.5 m x 0.5 m x 0.4 m) were fabricated to act as solar ponds. Mild steel was easy to fabricate into leak proof pans. All pans were painted with read lead oxide to protect them from corrosion.

The following set of controlled experiments were installed.

An initial 10 cm thick layer of mother salt works soil was laid into each of the pans; this was done to reduce the heating effect of mild steel. Feed to each pan was 25 litres of raw sea water.

Pan 1. Blank or control pan.

Pan 2. A layer of a 1 : 2 v / v mixture of black oil paint with mother salt worlds soil, 5 cm. thick was coated on top of the initial 10 cm thick soil.

Pan 3. A layer of asphalt, 5 cm. thick was coated onto the initial salt worlds soil. Feed sea waster was dyed with 5 grams of Naphthol Green B.

Pan 4. A layer of ground coal, 3 cm. thick was coated onto the saltworks soil.

Pan 5. No coating. Feed sea water was dyed with 2.5 grams of Alkali Blue 6B which was first dissolved in 10 cc of ethyl alcohol.

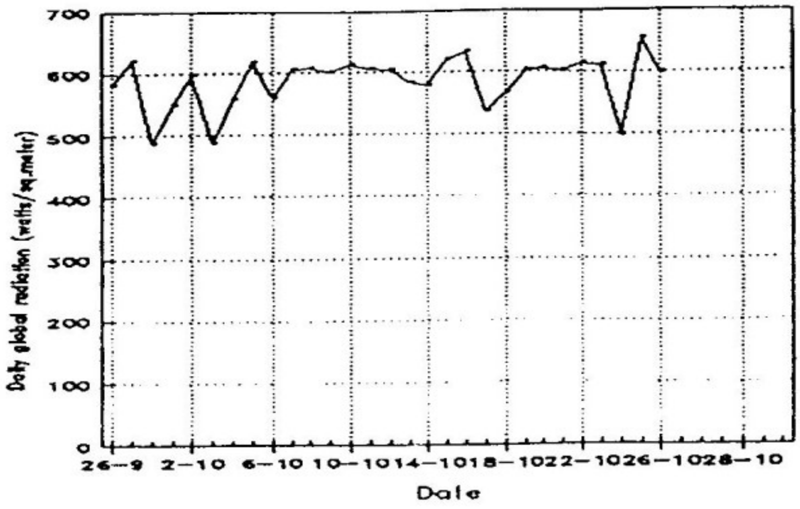

Fig. 1 Daily Global Radiation

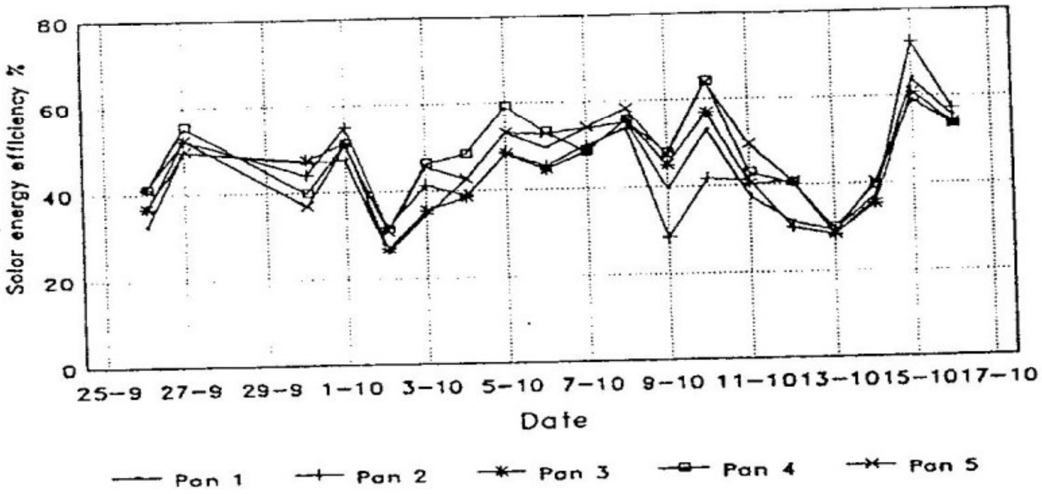

Fig. 2 Solar Energy Efficiency

All pans were exposed to the same atmospheric conditions. The following data were collected using respective instruments:

(i) Incident solar radiation by bimetallic detector model Siap 290947.

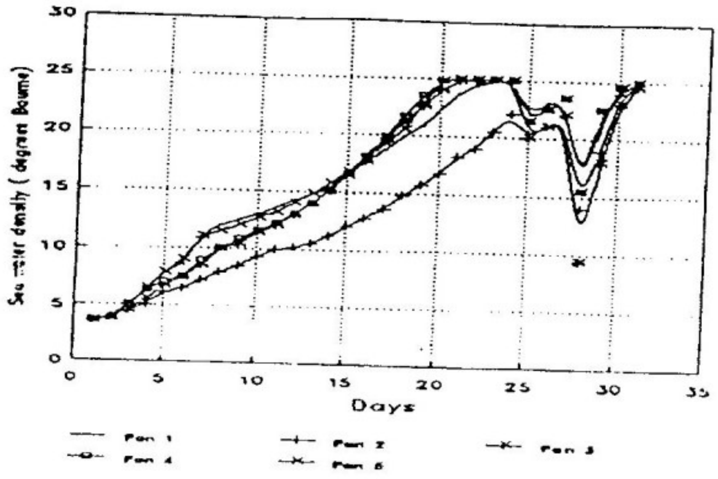

Fig. 3 Sea water evaporation

(ii) Atmospheric temperature was recorded once daily at 9.00 hrs from thermometers in a Stephenson screen.

(iii) Wind speed by cup counter anemometer.

(iv) Fresh water evaporation by a micrometer gauge in a standard pan evaporimeter. Readings were taken at 6.00 hrs and 18.00 hrs.

(v) Fresh water temperature by a dry bulb thermometer at 12.00 noon daily.

(vi) Brine concentration by hydrometers graduated in degrees Baume. Readings were taken at 6.00 hrs.

(vii) Brine surface temperature by dry bulb thermometer at 12.00 noon daily.

(viii) Rainfall by a Casella London rain gauge of diameter 127 mm. Readings were taken at 6.00 hrs.

EXPERIMENTAL RESULTS

Daily global horizontal insolation for Changwahela salt works for the period 26th September to 26th October 1992 was calculated according to equation number 9 which gives values in calories per centimetre. Daily global insolation is plotted in Figure 1 in watts per square metre. Solar energy efficiency calculated by equation 7 is presented graphically in Figure 2. The solar energy efficiency (%) averages for pans 1 to 5 were 44.05, 44.02, 44.35, 47.66 and 47.15 respectively. Sea water evaporation is plotted in Figure 3.

DISCUSSION

It can be seen from Fig. 1 that during the period of study, global radiation averaged to 585.58 watts per square meter, a value less than half the solar constant. Fig. 2 shows that pans 4 and 5 had higher efficiencies compared with pans 1, 2 and 3. This is in accordance with evaporation rate. According to observations, pans 4 and 5 reached sodium chloride saturation point after 20 days of evaporation, compared to pan 3 (21 days), pan 1 (23 days); pan 2 was interrupted by rainfall.

ECONOMIC ANALYSIS

The differential cost analysis method, a technique that identifies the most profitable alternative based on cost differences between the alternatives and ignoring uniform costs [3] was used to calculate economic performance of the modified solar salt works. This analysis refers to the year 1992. The following designations were used to represent respective projects under analysis:

A: Normal, represented by pan 1.
B: With seawater dyed with Alkali Blue 6B; by pan 5.
C: With coal coated surface, represented by pan 4.
D: With asphalt coated surface and raw sea water dyed with Naphthol Green B, represented by pan 3.

Project Production Capacities

Project A.

One hectare of solar salt works has an average annual production capacity of 100 tonnes of salt [4]. Assuming an evaporation area to crystallization area ratio of

10:1 [5] which is based on volume reduction during evaporation, a project to produce 60,000 tonnes requires 545.5 hectares evaporation area and a crystallization area of 54.5 hectares. Annual raw material for such a project would be around 4.1 million cubic meters of sea water. It was experimentally found that fresh water daytime evaporation was 81 percent daily evaporation values. Assuming this holds for salt solutions, average daily evaporation for pan 1 is 5.7 kg m^{-2}.

Calculations:

Basis:- 100 tonnes salt product per hectare per year.

Weight (wt.) if raw material = 4.1×10^9 kg/year.
Weight of water (96% of raw material) = 3.462×10^9 kg/year.
Water to be evaporated in evaporation ponds (90% of water in raw material) = 3.69×10^9 kg/year.

Total evaporation per batch E_T, is given by:

$$E_T = E_r A d \tag{10}$$

Where:

E_r = evaporation rate
A = evaporation area
d = number of days taken to attain salting point.

Based on 23 days of evaporation
total evaporation = 5.7 x 545.5 x 23 = 7.151 E8 kg of water.
number of batches needed per year = 3.69 E9 / 7.151 E8kg = 5.
equivalent to 12,000 tonnes/batch (for annual production of 60,000 tonnes)
number of effective evaporation days/year = 23 x 5 = 115.

When the evaporation period to salting point is reduced to 20 days (for projects B and C), number of batches/year increases to 6 with a production rate of 72000 tonnes/year.

Project Profitability

Based on year 1992, dye costs according to Sigma Chemical Company (1992), projects' profitability was calculated as follows:

$$\text{Profit before tax (PBT)} = R - (MC + G) \qquad (11)$$

Where: R is annual revenue from salt sales.
MC is annual manufacturing cost including cost of buying dye.
G is annual general expenses including administrative and sales costs.

Project Profitability are summarised in Table 1.

Table 1. Project Profitability.

Project	A	B	C	D
Sales USD/ton	63	63	63	63
Prod. (ton/yr)	60,000	72,000	72,000	60,000
R, USD	3,780,000	4,536,000	4,536,000	3,780,000
Prod.cost $/ton.yr	14.6	325.7	14.6	267.9
MC, USD	876,000	23,450,400	1,051,200	16,074,000
Expences $/ton	43.9	43.9	43.9	43.9
G, US $	2,634,000	3,160,800	3,160,800	2,634,000
PBT R - (MC + G) US $	270,000	-22,075,200	324,000	-14,928,000

CONCLUSION

The solar energy utilisation was improved by 3.6% by coating the bottom surface with coal. Almost the same improvement (3.1%) was obtained by using alkali Blue 6B dye. This improvement correspond to an increase in production rate of 12,000 tonnes per year (or 20%). The cost of purchasing Alkali Blue 6B dye, however, makes the use of coal coated surfaces the only feasible alternative.

Some of the tested materials showed very low or no improvement on efficiency of solar utilisation.

NOMENCLATURE

A	area, m^2
d	days taken to reach salt point, day
E	evaporation rate, $kg.m^{-2}.S^{-1}$
G	general expenses, US$
K	instrument compensation factor, (= 1.18)
k	mass transfer coefficient, $kg.m^{-2}.S^{-1}.bar^{-1}$
MC	manufacturing cost, US$
P	vapour pressure, bar
Q	energy, W/m^2,
R	revenue, US$
T	absolute temperature, °K
t_a	daily average air temperature, °C
t	thickness, mm.

Greek

λ	latent heat of vaporisation, $J.kg^{-1}$
ρ	density, $kg.m^{-3}$
ϕ	percent relative humidity
η	solar energy efficiency

Subscripts

a	air
b	brine
c	evaporation
f	fresh (pure) water
R	radiation
r	rate
s	solar
T	total

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